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CHAPTER ONE

PROPERTIES of RADIO WAVES

Contents

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 seafarers 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.

ELECTRO-MAGNETIC (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 ie 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.

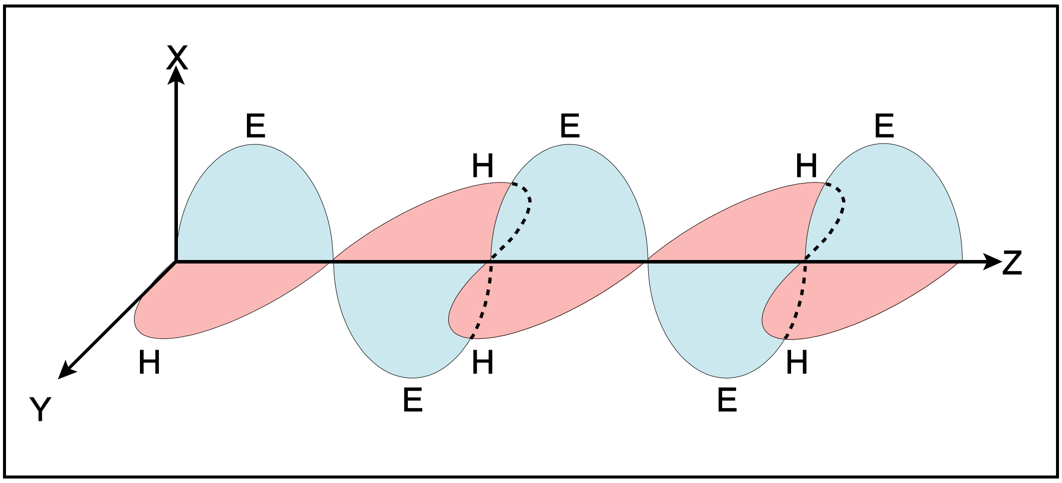

Figure 1.1 Vertical Polarisation

POLARISATION

The polarisation 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 polarised wave, and a horizontal aerial will produce a horizontally polarised wave.

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

Circular polarisation can be produced in a variety of ways, one of which is using a helical antenna, (see Chapter 22). In circular polarisation 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 polarised 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 polarisation 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 polarisation, 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 micro-seconds (μs). ($1\mu s = 10^{-6}$ second).

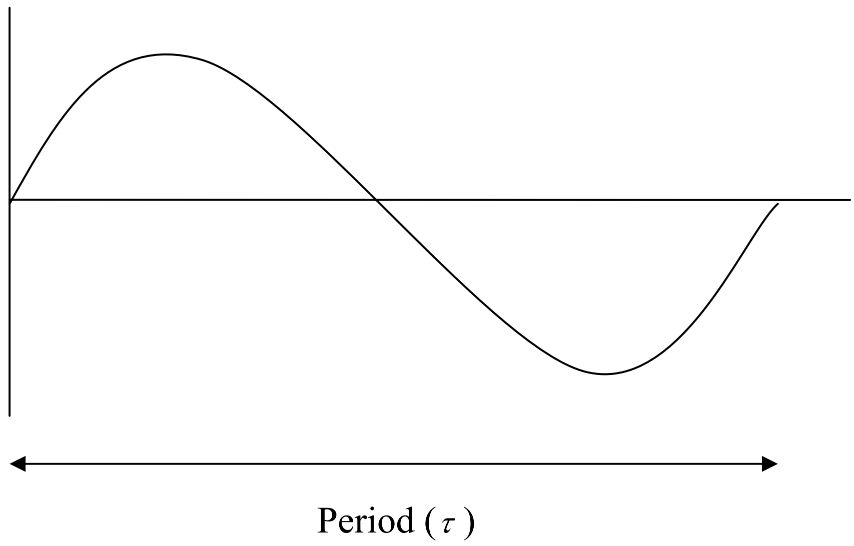

Figure 1.2 Sinusoidal Wave - Period

If, for example, the period of one cycle of a radio wave is 0.125μs 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:

Kilo-Hertz (kHz)	=	10^3 Hz	=	1 000 Hz
Mega-Hertz (MHz)	=	10^6 Hz	=	1 000 000 Hz
Giga-Hertz (GHz)	=	10^9 Hz	=	1 000 000 000 Hz

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

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 x 10^6 ms^{-1}), or 162 000 nautical miles per second

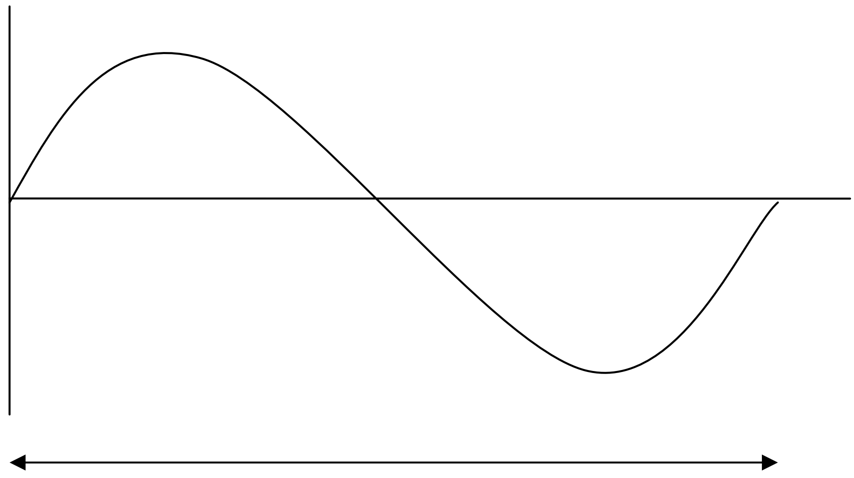

Figure 1.3 Sinusoidal Wave - Wavelength

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

λ = c.τ **(2)**

300 x 10^6 x 0.125 x 10^{-6} = 37.5 m

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

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

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:

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

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?

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

For ease of calculation we can simplify the formulae:

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

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

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

Example:

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

Noting that 3.2 cm = 0.032 m the calculation becomes:

$$f = \frac{300}{0.032} = 9375 \quad \textbf{Mhz (or 9.375 Ghz)}$$

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

Noting that 375 kHz = 0.375 MHz the calculation is:

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

FREQUENCY BANDS

The radio part of the electro-magnetic spectrum extends from 3 kHz to 300 GHz. For convenience it is divided into 8 frequency bands. These are shown at table 1 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, LORAN C
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 localiser, marker beacons
Ultra High Frequency (UHF)	300 – 3000 MHz	100 – 10 cm	ILS glidepath, 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

Table 1

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.

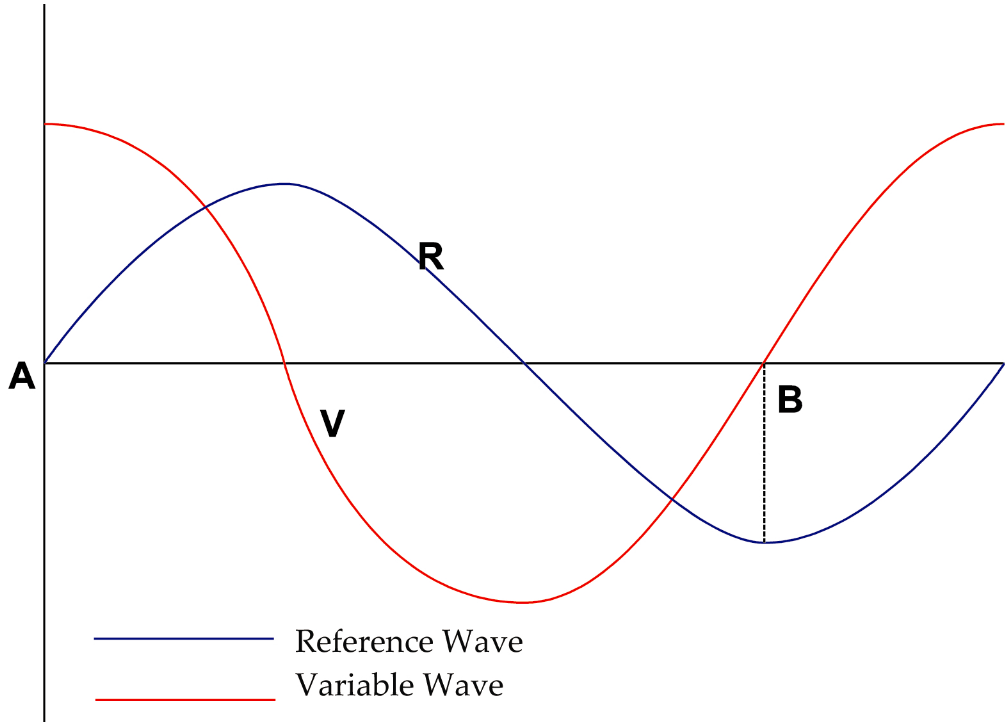

Figure 1.4 Sinusoidal Wave - Phase Comparison

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.

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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 *f* - 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***	***MF***
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 polarisation 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

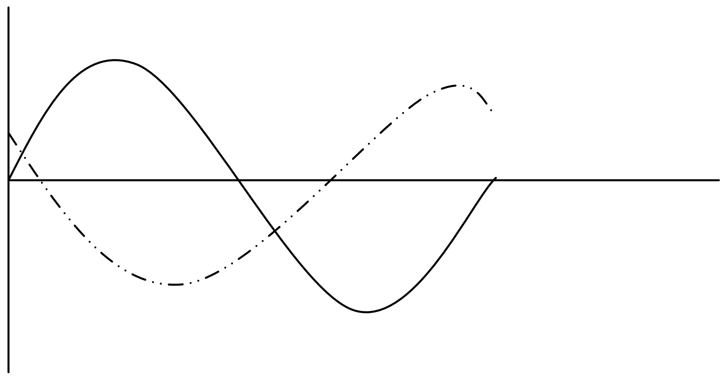
8. To carry out a phase comparison between two electromagnetic waves:

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	C
2	B
3	B
4	C
5	A
6	B
7	D
8	B
9	C
10	C
11	C
12	B

CHAPTER TWO

RADIO PROPAGATION THEORY

Contents

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.

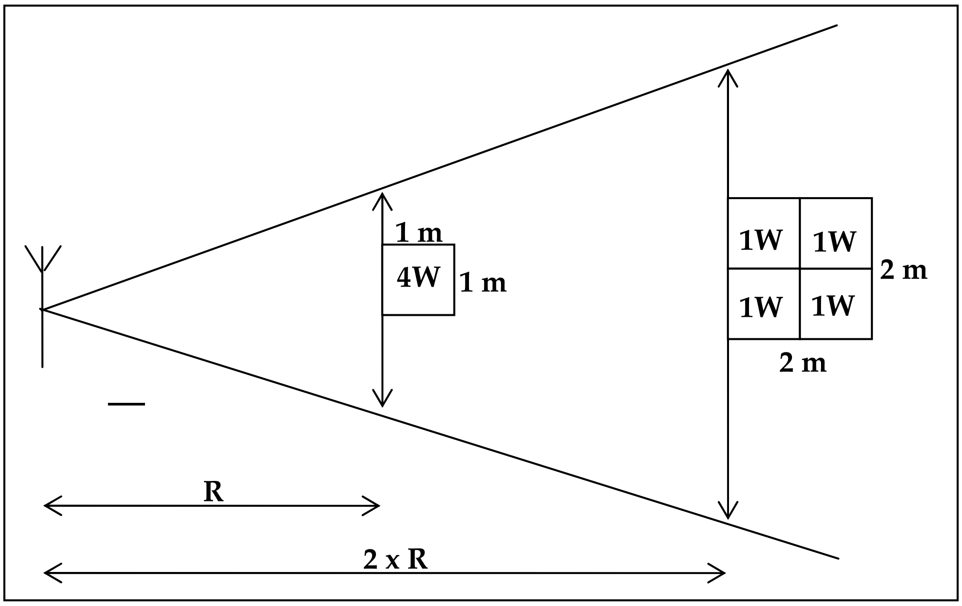


Figure 2.1 Inverse Square Law

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

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 and 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.

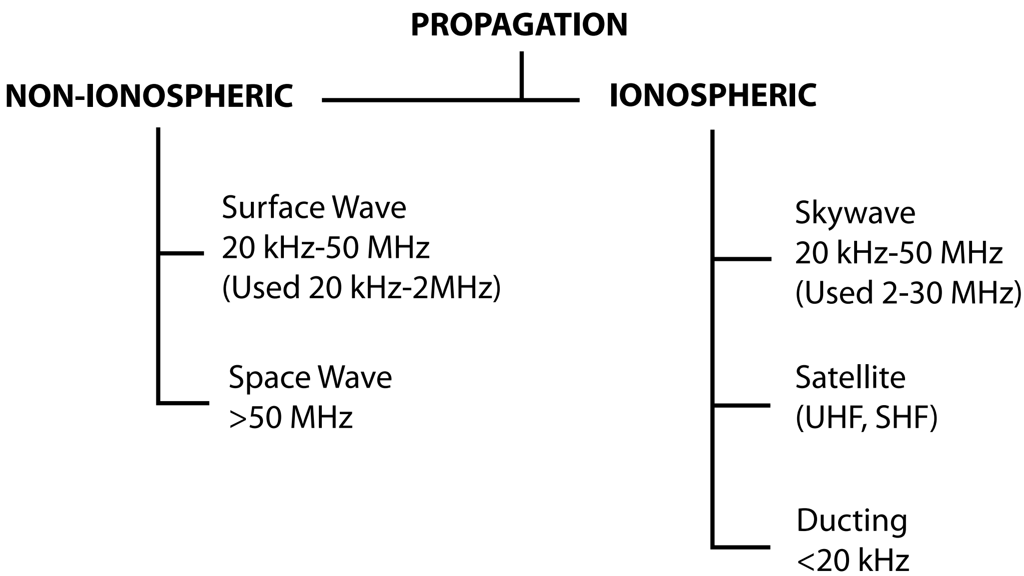
Power. An increase in the power output of a transmitter will increase the range, within the limits of the inverse square law. As noted above, to double the range of a radio transmitter would require the power to be increased by a factor of 4.

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



Ionospheric propagation is propagation affected by the properties of the ionosphere. At this stage it is only necessary to discuss skywave, satellite propagation will be considered in conjunction with global navigation satellite systems (GNSS) in chapter 19. Knowledge of propagation below 30 kHz is not required.

Non-Ionospheric propagation covers the other propagation paths.

The knowledge of propagation of radio waves in the VLF band is not required for the JAA examinations as there are no civil aeronautical communication or navigation systems in this band.

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**.

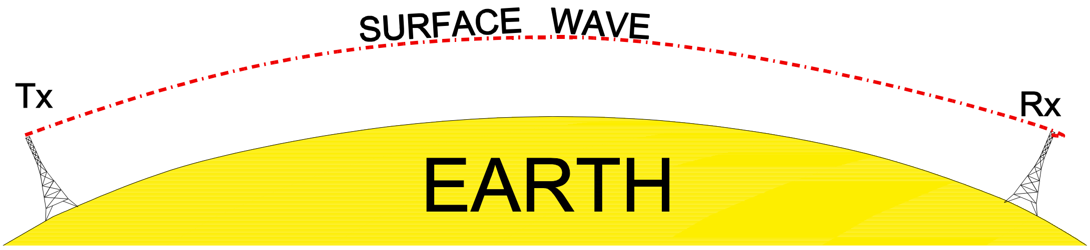


Figure 2.2 Surface Wave

The range achievable is dependent on several factors: the frequency, the surface over which the wave is travelling and the polarisation 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 polarised wave will be attenuated very quickly and give very short ranges; therefore, vertical polarisation is generally used at these lower frequencies.

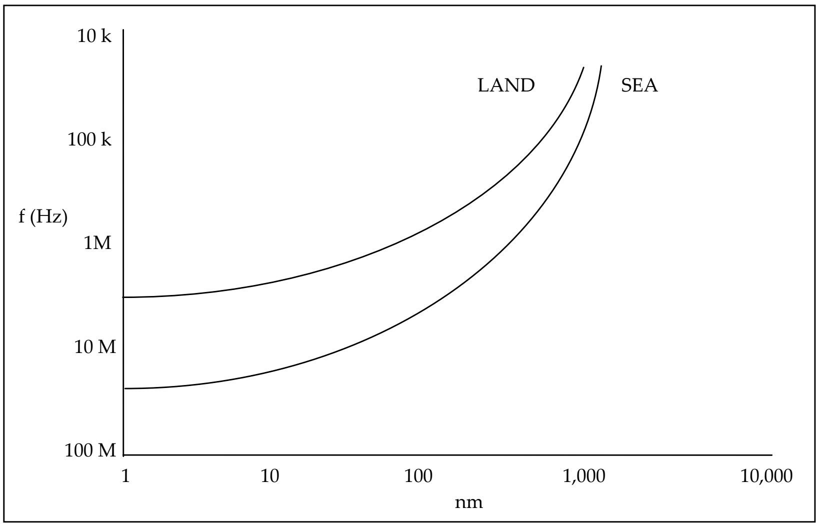


Figure 2.3

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

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

Sea: **range** $\approx$ **3 x** $\sqrt{Power}$
Land: **range** $\approx$ **2 x** $\sqrt{Power}$

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.

Because the surface wave is retarded more over land than over sea there is a change in the direction the wave takes as it passes from land to sea. The portion of the wave which first passes over the sea accelerates and the wave bends away from the normal, that is towards the coast. This is known as **coastal refraction** and will be looked at in greater detail in ADF.

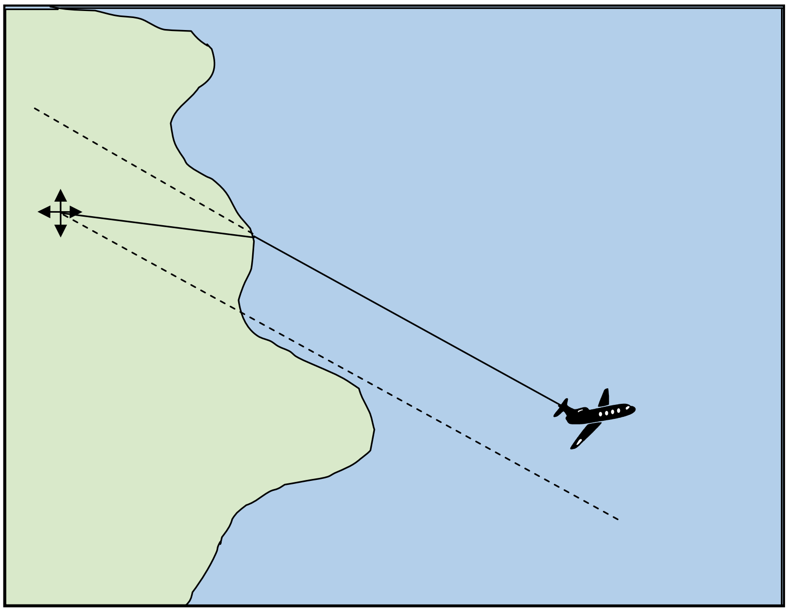


Figure 2.4 Coastal Refraction

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

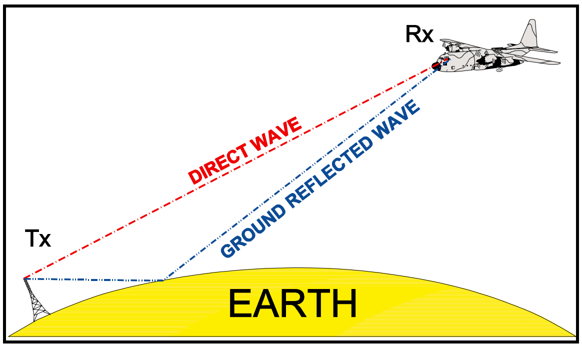


Figure 2.5 Space Wave

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 JAA syllabus the **line of sight range** can be calculated using the formula:

Range (nm) = 1.23 x $(\sqrt{H_{TX}} + \sqrt{H_{RX}})$

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.

Note 2: At the time of writing, the JAA Question Bank uses a constant of 1.25 in line of sight range calculations, but this will be amended to 1.23 in the new syllabus (NPA25); these notes reflect the new syllabus and consequently answers to Examples are worked out using 1.23.

IONOSPHERIC PROPAGATION

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

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 ionisation will be found shortly after midday (about 1400) local time, when there is a balance between the ionisation and the decay of the ionisation with the electrons rejoining the ions and the lowest just before sunrise (at the surface). In summer the ionisation levels will be higher than in winter, and ionisation 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 ionisation, 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 ionise the atoms at lower levels reduces and hence the levels of ionisation 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 ionisation is not linear but the ionised particles form into discrete layers.

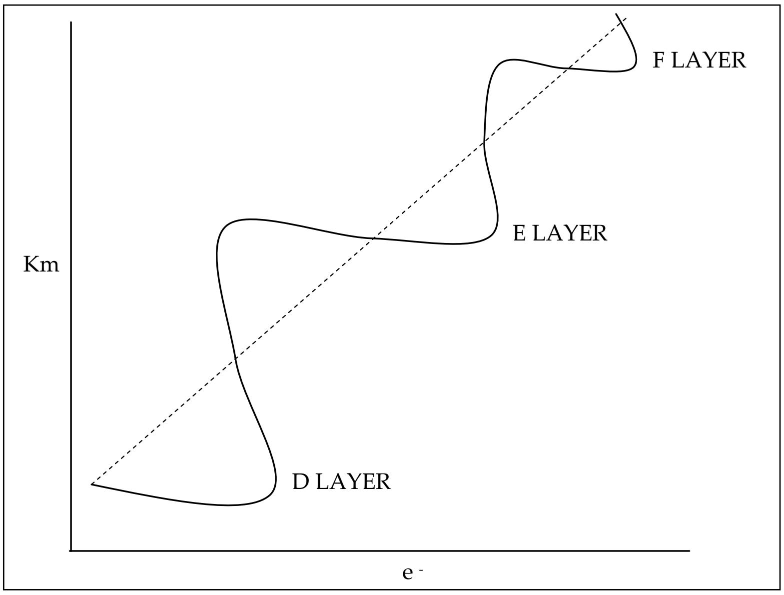


Figure 2.7 Effect of Ionisation with Height

The ionisation 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 ionisation. 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.

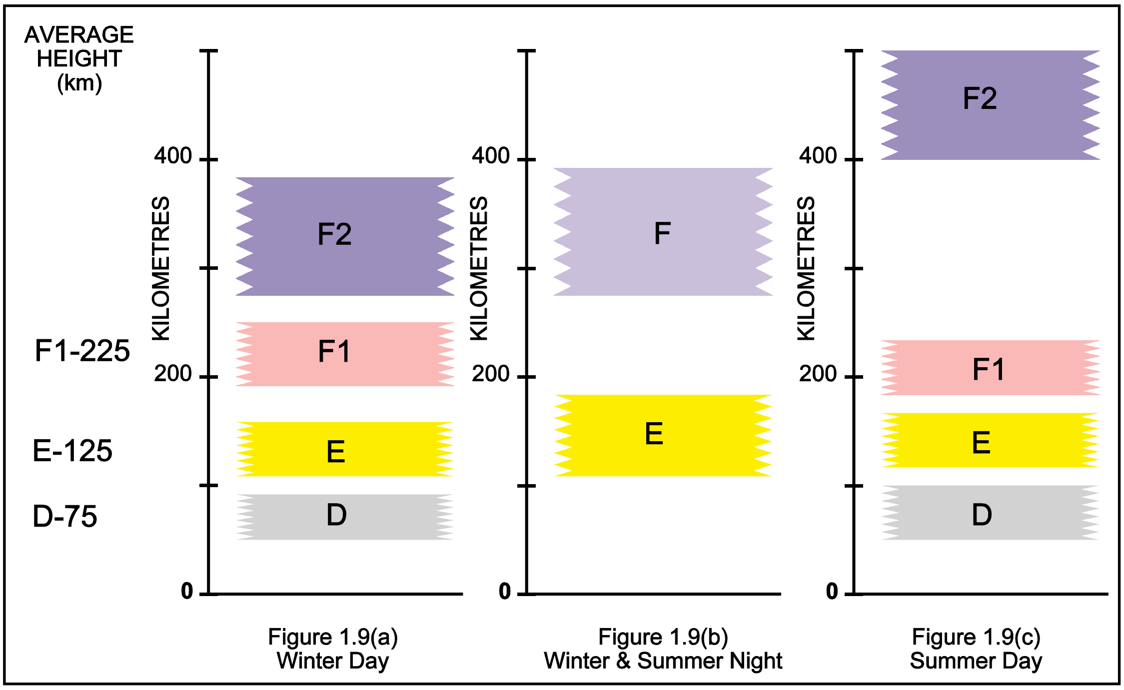


Figure 2.8 Layers of the Ionosphere

Although, overall the levels of ionisation 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 ionisation 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.

SKYWAVE

The ionisation 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.

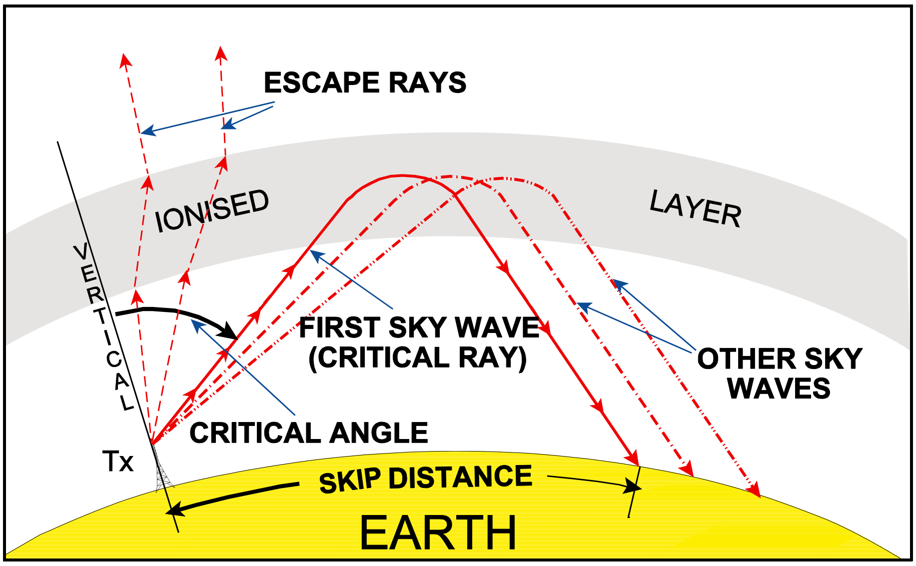


Figure 2.9 Skywave Propagation - Critical Angle

The amount of refraction experienced by the radio waves is dependent on both the frequency and the levels of ionisation. 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 skywave; 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 skywave** 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 skywave appears at the surface is known as the **skip distance**. As skywaves 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 skywave appears there will be no detectable signal, this area is known as **dead space**.

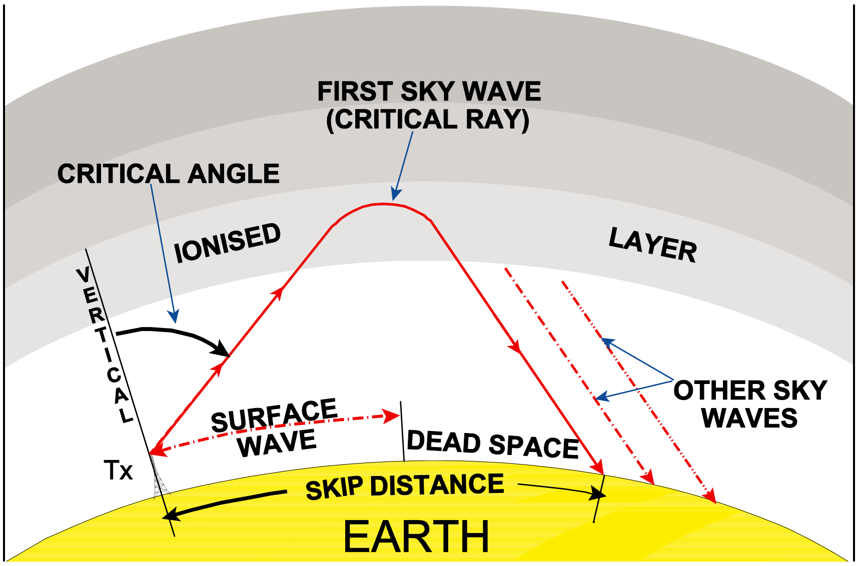


Figure 2.10 Skywave Propagation - Dead Space

The height at which full internal refraction occurs is dependent on frequency, but, as a generalisation frequencies up to 2 MHz will be refracted at the E-layer and from 2 – 50 MHz at the F-layers. Skywave 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 skywaves.

Effect of change in ionisation intensity. Since the reason for the refraction is the ionisation of the upper atmosphere it follows that if ionisation intensity changes, then the amount of refraction of radio waves will also change. At a given frequency, as ionisation **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 ionisation will result in an increase in critical angle, skip distance and dead space.

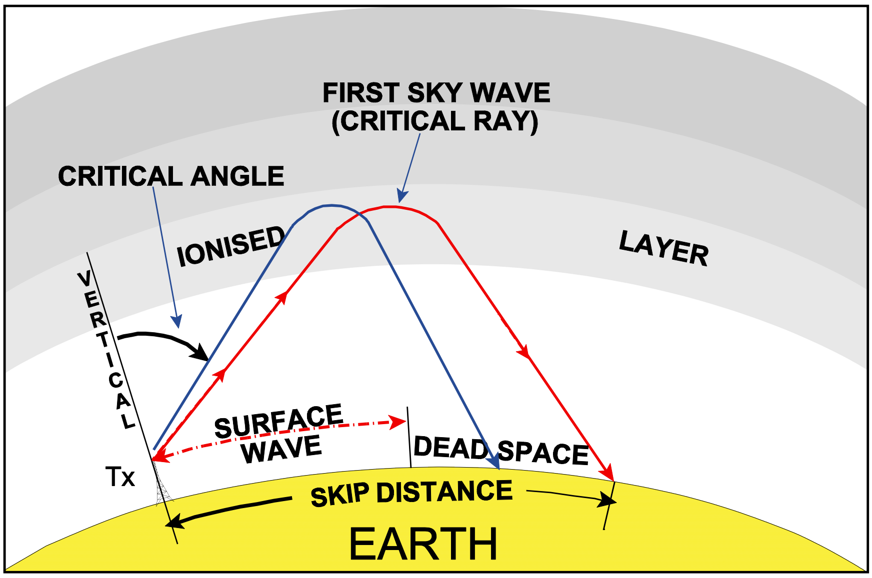


Figure 2.11 Skywave Propagation - Effect of Increased Ionisation

Effect of change of frequency. For a given ionisation 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 skywave propagation. During the day the D-region absorbs radio energy at frequencies below about 2 MHz (LF and MF bands). At night the D-region is effectively non-existent so, at these frequencies, sky waves, refracted at the E-layer are present. This means the skywaves at LF and MF are not reliable for continuous long-range use and the presence of skywaves 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.

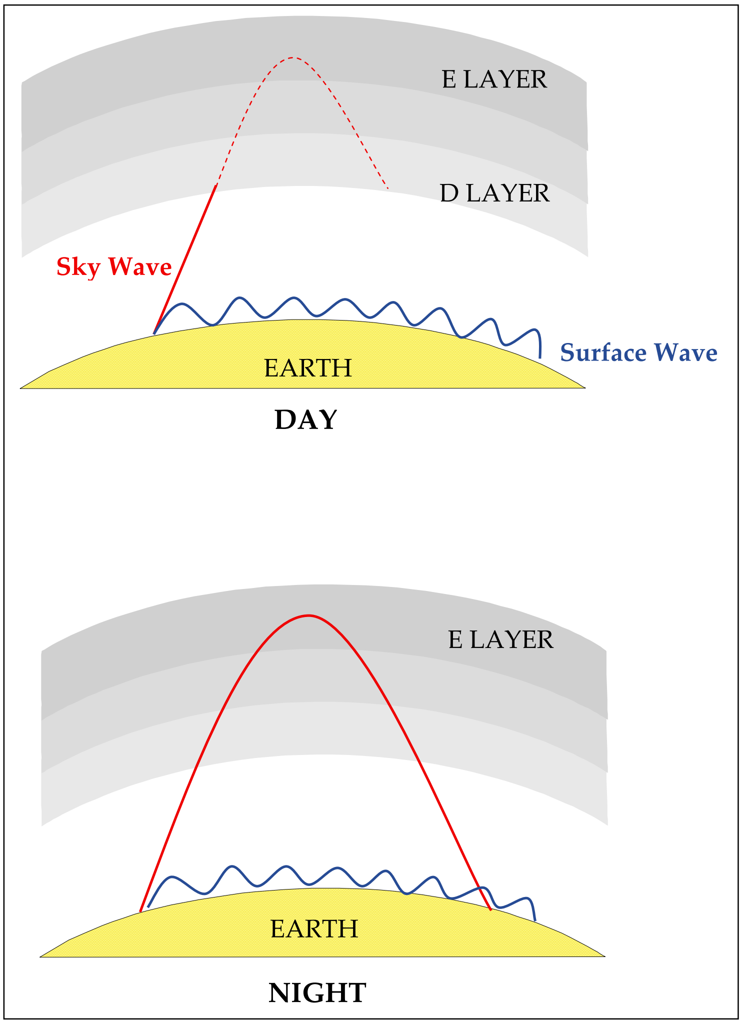


Figure 2.12 LF/MF Skywave Propagation

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 ionised layers changes.

Multi-hop skywave 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 skywave can achieve ranges of half the diameter of the earth.

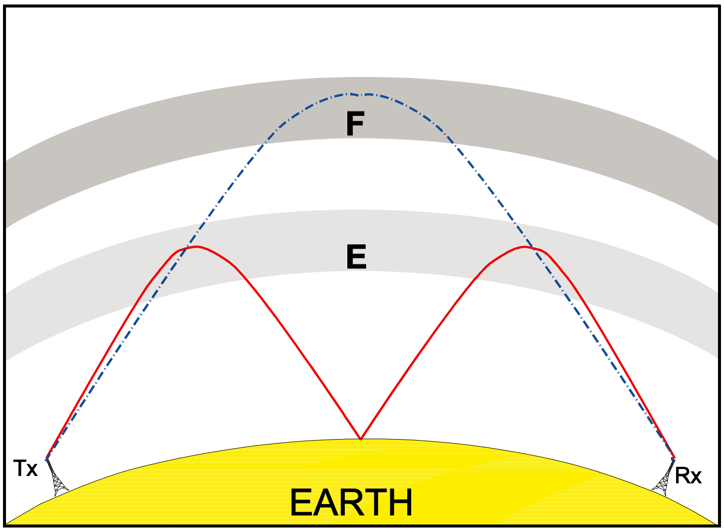
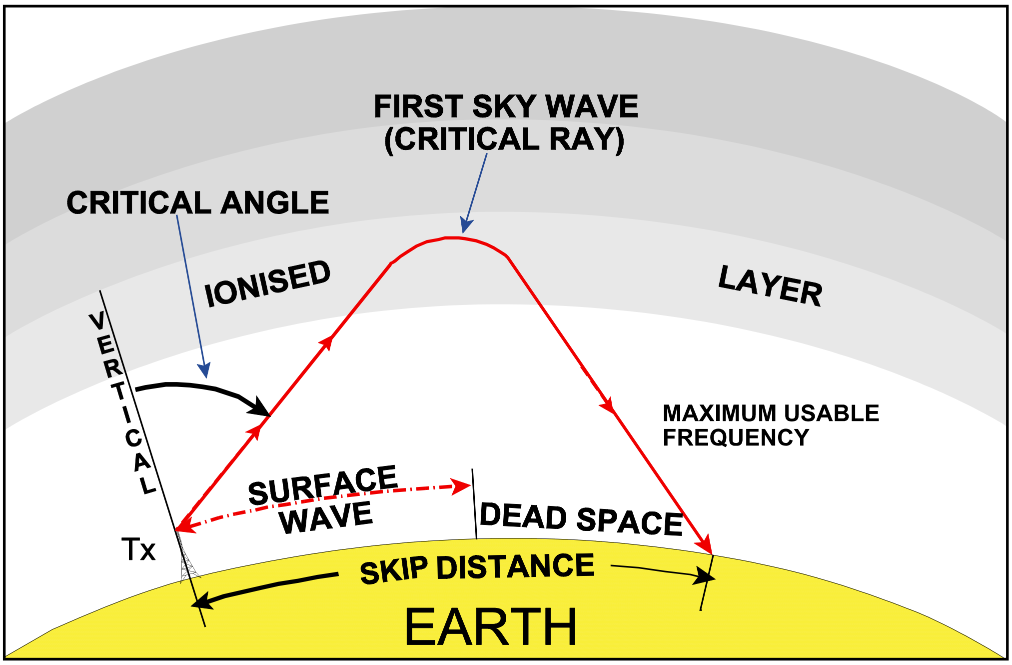


Figure 2.13 Multi-Hop Skywave Propagation

VLF Propagation. At VLF frequencies, up to about 20 kHz, the wavelength (15 – 100 km) is of the same order of magnitude as the altitude of the D-region and E-layer. At these frequencies the surface of the earth and the lower edge of the ionosphere act as a wave guide, effectively channelling the radio waves around the earth with very little loss of power, this is known as duct propagation. Theoretically, at relatively modest power levels a VLF transmission could circumnavigate the planet. As there are no civilian equipments in the VLF band detailed knowledge is not required.

HF COMMUNICATIONS

Over inhabited land areas VHF communications are ideal for all communications between aircraft and ground. However, until satellite communications are fully implemented, the only means of communication between aircraft and ground when over the oceans, or other uninhabited areas, is either surface wave or skywave. To achieve ranges of 2000 nm to 3000 nm using surface wave would require frequencies at the lower end of LF or the upper end of VLF. The use of these frequencies for aeronautical communications would require relatively complex equipment with the associated weight penalty, and they would be more susceptible to static interference than higher frequencies making them somewhat tedious to use and they would also have very low data rates. Thus, the only practical means of communication over long ranges is skywave (until satellite communications are fully implemented).



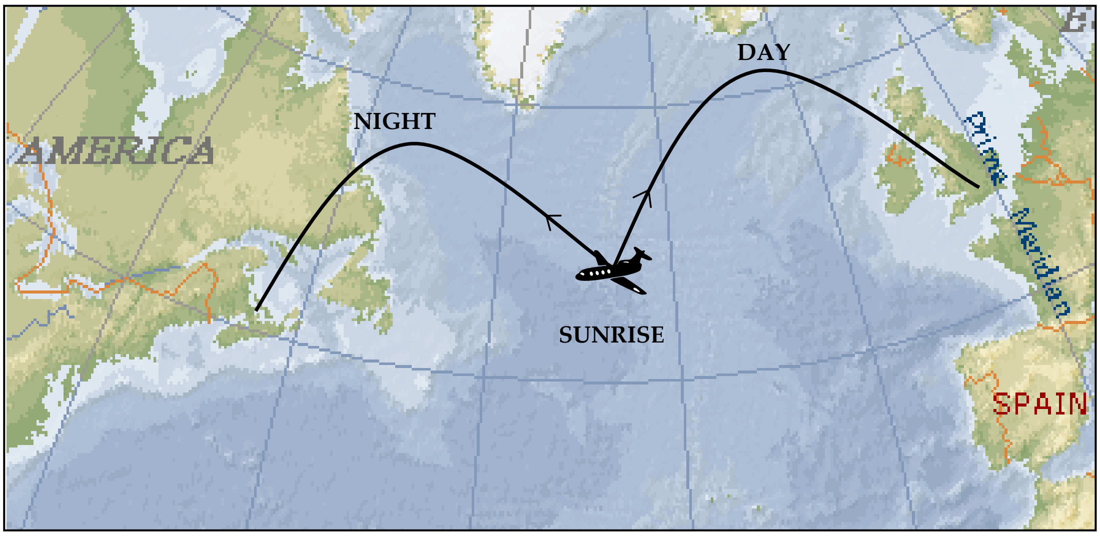
The maximum usable frequency (MUF) for a given range will be that of the first returning skywave and this is the ideal frequency for that range because it will have had the shortest path through the ionosphere, and therefore, will have experienced less attenuation and contain less static interference. However, since the ionisation intensity fluctuates, a decrease in ionisation 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 ionisation 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?



Answer: 6 MHz.

The wave will be refracted half way between the aircraft and the UK, and half way between the aircraft and the USA. Mid way 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.

SELCAL

Because the frequencies have transited the ionosphere they will have accumulated a considerable amount of static interference and, because of the long ranges, signals may be received from more than one ground station. Pilots are required to maintain a continuous listening watch when receiving an ATC service, however, these factors combine to make HF frequencies very difficult and stressful to listen to. To reduce the stress experienced by pilots using HF a **sel**ective **cal**ling system (SELCAL) is installed in HF equipment to alert pilots when ATC wish to communicate.

Each radio fitted with SELCAL has a unique code comprising 4 letters (eg ABCD). When the aircraft is to be flown in an area where HF communications are used, the pilot notifies ATC of the aircraft's SELCAL code. Then, having made initial contact with ATC and checked that the SELCAL is serviceable, the pilot can rely on ATC using the SELCAL facility to alert him when communication is required by ATC, if the pilot wishes to communicate with ATC then he will just make a call. SELCAL is also available on VHF in some remote areas.

PROPAGATION SUMMARY

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

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

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 surfaces

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, eg 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 most 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. A 300 kHz transmitter has an output of 1600 watts, the effective range over the sea will be:

   a. 52 nm
   b. 80 nm
   c. 35 nm
   d. 120 nm

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

   a. 80 nm
   b. 64 nm
   c. 52 nm
   d. 65 nm

6. What is the minimum height for an aircraft at a range of 200 nm to be detected by a radar at 1600 ft amsl?

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

7. Determine which of the following statements concerning atmospheric ionisation are correct.

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

8. The average height of the E-layer is …… and the maximum range for skywave will be ……

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

9. 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	C
2	B
3	D
4	D
5	A
6	B
7	D
8	D
9	D

CHAPTER THREE

MODULATION

Contents

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.

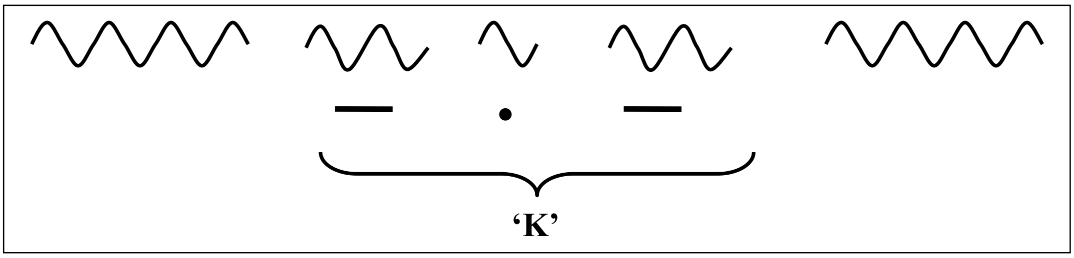


Figure 3.1 Morse 'K' in Keyed Modulation

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)

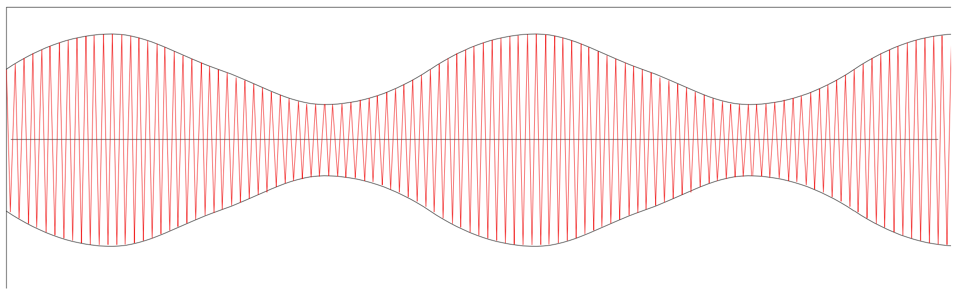


Figure 3.2 Amplitude Modulation

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, ie double the audio frequency used.

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

Table 1 AM Side Band 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	
				~~*(25W)*~~ ***(150W)***	⇧	**Upper Side Band (USB)**
(100 W)	**RF**	**2182 kHz**			**2182.001 kHz**	
			⇨	~~*(100 W)*~~	~~**2182 kHz**~~	
(50 W)	**AF**	**3 kHz**			~~**2181.999 kHz**~~	
				~~*(25 W)*~~	⇩	~~**Lower Side Band (LSB)**~~
					~~**2179 kHz**~~	

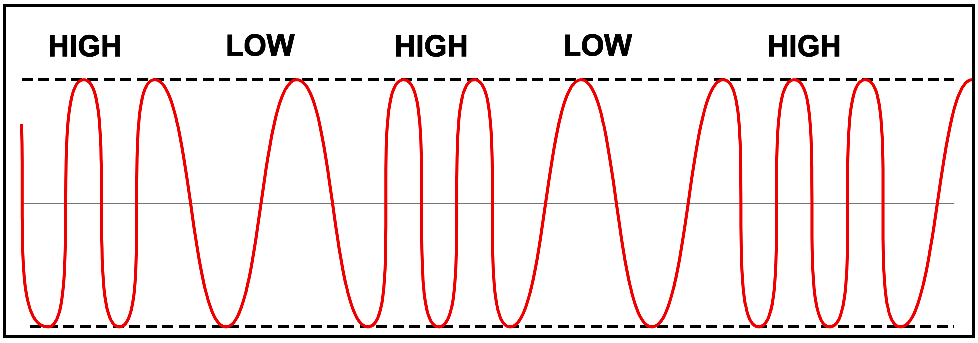
Table 2 Single Side Band

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 side band
Better signal/noise ratio (less interference)
Less power required hence lighter equipment

FREQUENCY MODULATION (FM)

In FM the ***amplitude*** of the AF modifies the ***frequency*** of the RF.



The frequency deviation is primarily dependent on the amplitude of the AF; the greater the amplitude the greater the frequency deviation. The frequency of the AF determines the rate of change of frequency within the modulated RF. When used for sound broadcasting the bandwidth permitted by international agreements is 150 kHz, compared to a maximum bandwidth permitted in AM broadcasting of 9 kHz. Hence FM is generally unsuitable for use below VHF because of the bandwidth requirement.

For 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 still greater than the 6 kHz permitted for aeronautical communications and the 3 kHz used in HF communications. NBFM is not, at present, used in aviation communications.

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; econdly, with a digital signal it is known as phase shift keying, the phase change reflects a 0 or 1; eg 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.

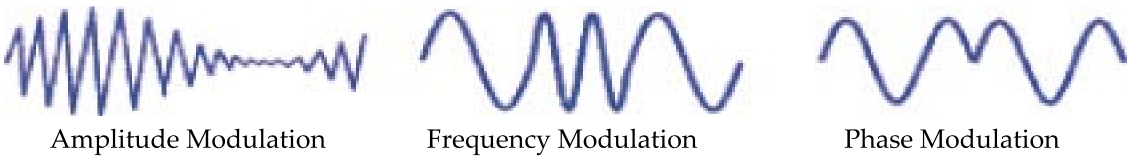


Figure 3.4 Comparison of Methods of Modulation

PULSE MODULATION

Pulse modulation is used extensively in radar systems and for data exchange in communications systems.

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 quantised 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 quantised 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 quantised 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 quantised 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	C
2	B
3	D
4	D

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CHAPTER FOUR

ANTENNAE

Contents

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.

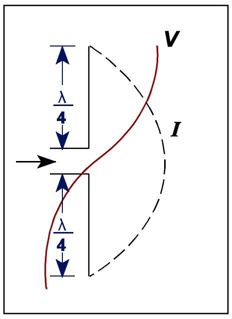


Figure 4.1 Half-Wave Diplole

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.

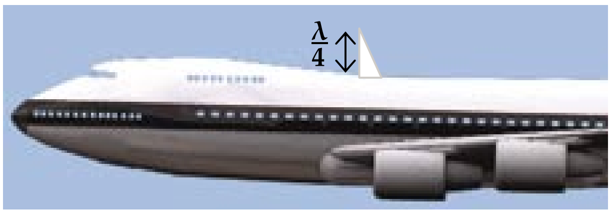


Figure 4.2 Marconi Aerial

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.

The speed of electromagnetic energy in metal is approximately 95% of the free space speed, so our aerial needs to be 95% of half or quarter the wavelength.

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

The wavelength is 2.4 m, so $0.95 \times \frac{\lambda}{4} = 57$ **cm**

LOADED ANTENNAE

The wavelengths of aeronautical VHF radio telephony are 2.19 m to 2.54 m which means that for maximum efficiency the aircraft (and ATC) aerial must be adjustable between approximately 52 cm and 60 cm. To achieve maximum efficiency aerials would have to be adjustable in length, which would pose significant technical problems. Furthermore, aircraft aerials are about 20 - 30 cm long, so would operate very inefficiently.

To overcome these problems an aerial loading unit (ALU) is fitted in the circuit between the radio equipment and the aerial. The ALU samples the signal, then through a series of capacitors and resistors balances the signal travelling to/from the aerial to effect maximum aerial efficiency.

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:

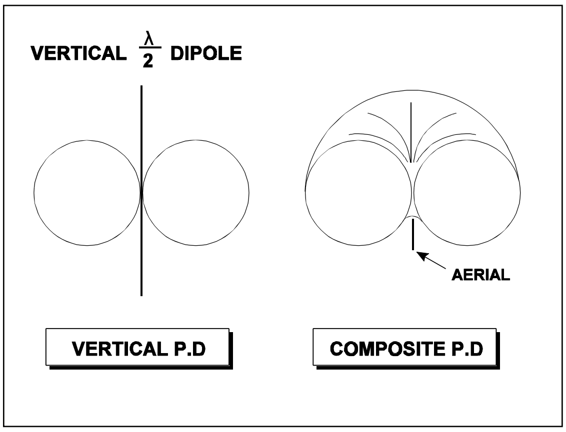


Figure 4.3 3-D Polar Diagram

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

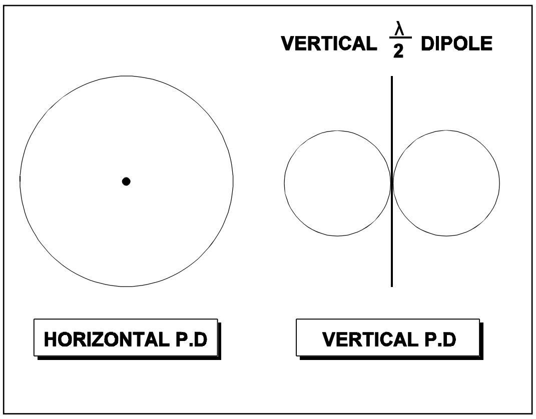


Figure 4.4 Plan View Polar Diagram

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.

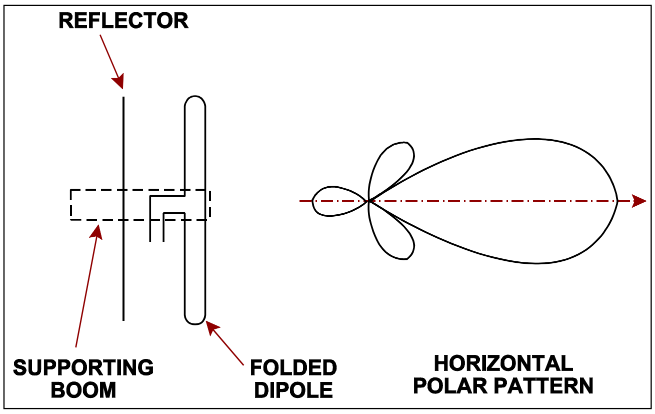


Figure 4.5 Directivity Using Reflector

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.

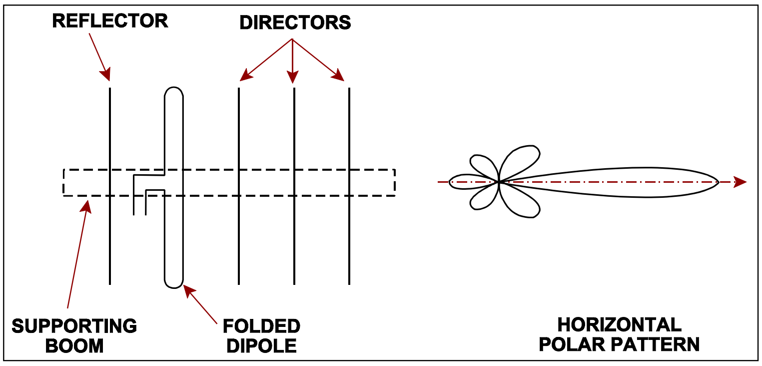


Figure 4.6 Improved Directivity Using Reflector and Directors

All will recognise 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 sidelobes which would receive (and transmit) unwanted signals. Signals received in these sidelobes produce characteristic ghosting on television pictures, usually caused by reflections from buildings etc. These sidelobes give major problems which have to be addressed in SSR and ILS, and also produce problems in primary radars.

OTHER SYSTEMS

The instrument landing system (ILS) uses an extension of this idea to produce the narrow beams of energy required to guide aircraft along the runway centreline. The localiser aerial array 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 centreline of the runway:

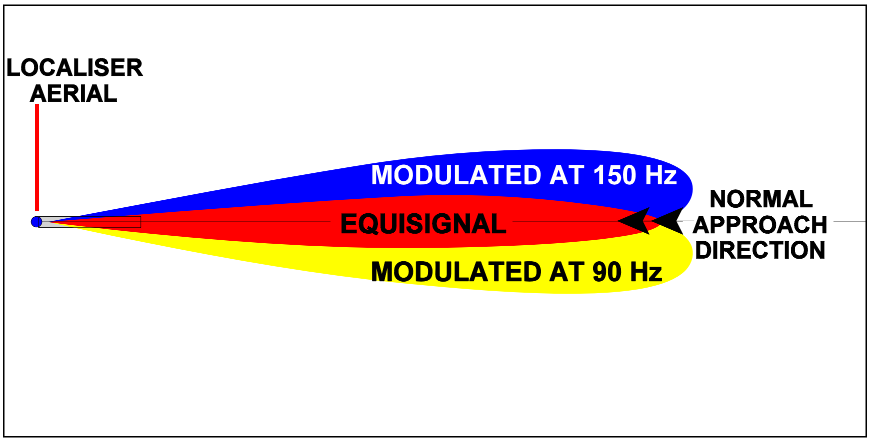


Figure 4.7 ILS Localiser Polar Diagram

In the automatic direction finder (ADF) a loop aerial is used.

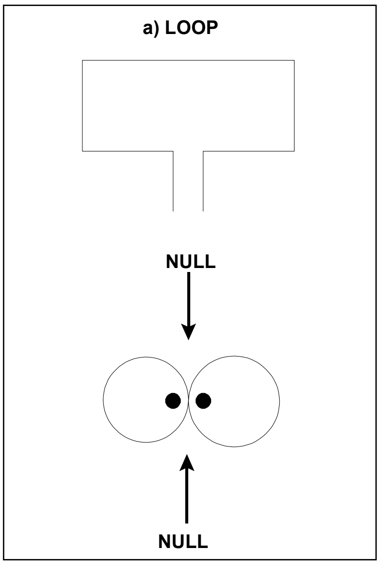


Figure 4.8 Loop Aerial 'Figure-of-Eight' Polar Diagram

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 utilised will be discussed in detail in Chapter 7.

RADAR AERIALS

Radar systems operate in the UHF and SHF bands where waveguides are used to carry the radio energy, and the end of the waveguide is the aerial. Since radar systems are required to be directional the aerial is placed at the focal point of a parabolic reflector and the energy is then focussed into a narrow beam.

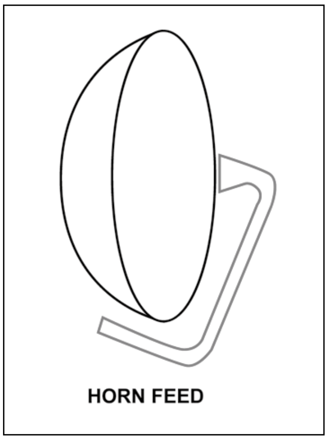


Figure 4.9 Horn Feed to Parabolic Reflector

In principle a very narrow pencil beam should be produced as shown above. However, this does not happen because the focal point is infinitesimally small compared to the opening of the waveguide, so the energy actually diverges slightly.

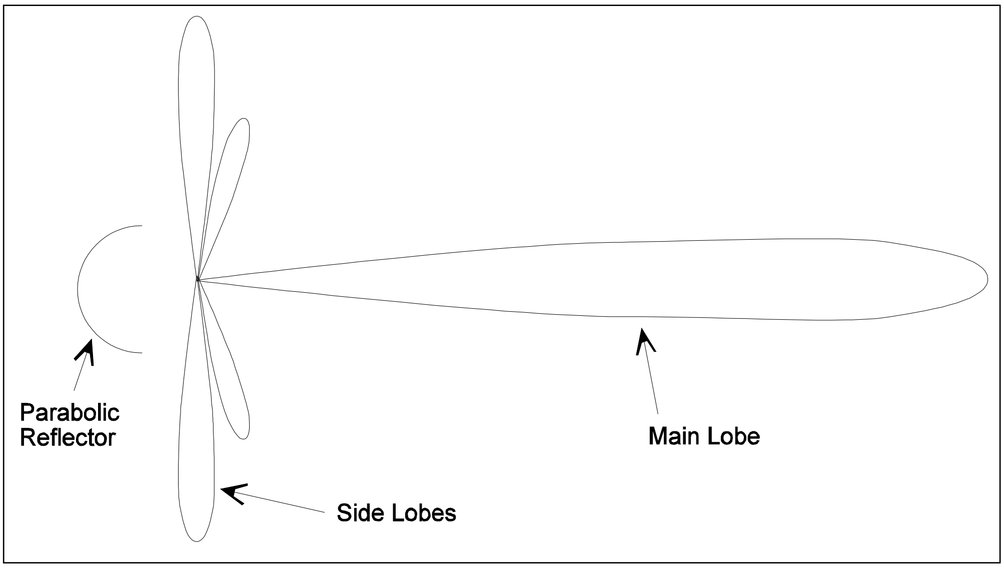


Figure 4.10 Polar Diagram of Parabolic Reflector

Additionally, this uneven reflection produces sidelobes which contain sufficient energy to give valid returns outside the main beam.

The width of the lobe is dependent on the cross-section of the waveguide and the diameter of the reflector. For a parabolic reflector, this relationship is:

Beamwidth $= \dfrac{70 \times \lambda}{D}$ where D is the diameter of the reflector.

It follows from this formula that to achieve a narrow beam requires either a very large reflector or a very short wavelength, or both. These problems will be discussed further in Chapter 11. Another type of radar aerial is the phased array or slotted antenna.

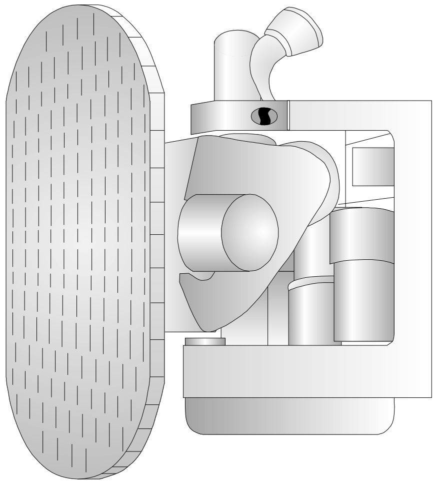


Figure 4.11 Phased Array or Slotted Antenna

This is a flat plate with numerous waveguide size slots cut into it. These slots are fed with the radio energy which forms a narrow beam similar to a parabolic reflector.

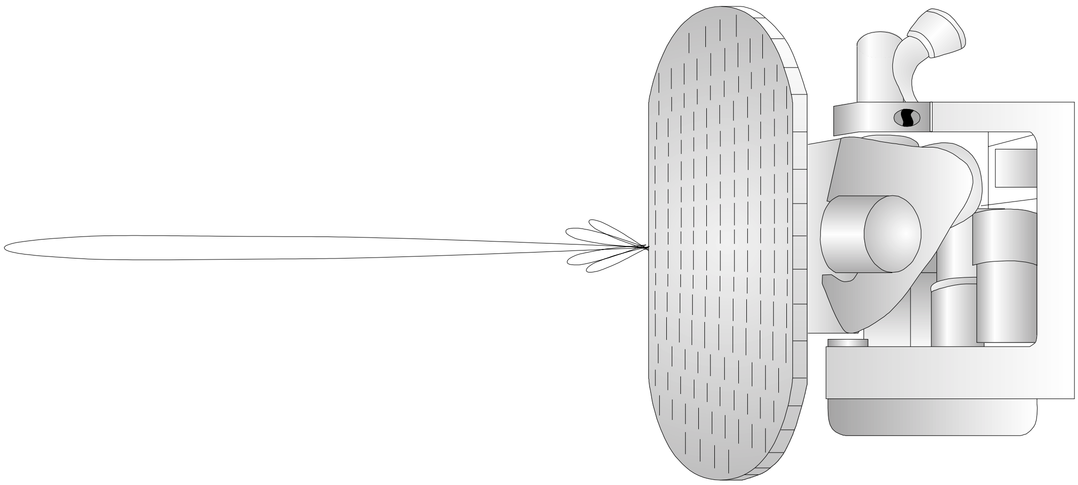


Figure 4.12 Polar Diagram of Phased Array/Slotted Antenna

As can be seen from the diagram the beam is much narrower than that from a parabolic reflector, and with much smaller sidelobes. This means the power requirements for phased arrays is less than that required for parabolic reflectors. Hence the advantages of a slotted antenna over the parabolic reflector are:

- Narrow beam
- Reduced sidelobes
- 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. sidelobes
   c. phase distortion
   d. ambiguity

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

   a. reduced sidelobes
   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	C
2	B
3	D
4	A

CHAPTER FIVE

DOPPLER RADAR

Contents

INTRODUCTION

A Doppler Navigation System uses the Doppler principle to measure an aircraft's ground speed and drift. The Doppler radar functions by continuous measurement of Doppler shift and converting the measured values to groundspeed and drift angle. In early systems the aircraft's departure point was loaded into a navigation computer, which then converted the aircraft's heading and Doppler ground speed/drift inputs into a continuous display of aircraft position; this was then displayed as latitude and longitude, and/ or as distance to go along track and position left or right of track, in nautical miles.

A Doppler navigation system:

- is completely self-contained and requires no ground based navigation aids.
- is usable worldwide.
- is most accurate overland.
- is less accurate during flight over the sea because the surface winds, tides and currents move the surface in random directions.
- sometimes fails to measure a ground speed and drift during flight over a smooth, glassy sea.

The latest improved Doppler Navigation Systems combine the inherent accuracy of Doppler ground speed and drift measurement with information from Decca, Inertial Reference Units, Loran C, Global Positioning Systems and VOR/DME, in various combinations to suit customer requirements. These navigational inputs also help to eradicate the errors of the original Doppler Navigation Systems, caused by inaccurate heading reference and degradation, or loss, of Doppler ground speed and drift when flying over large expanses of water.

The Doppler principle is also utilized in other navigation systems, such as VOR and VDF, and some radar equipments.

DOPPLER PRINCIPLE

Whenever there is relative motion between a transmitter and receiver a frequency shift (change) occurs which is proportional to the rate of relative motion. This change in frequency, $\mathbf{f_D}$, is known as the Doppler shift, Doppler effect, or Doppler frequency.

In an airborne Doppler system (Figure 5.1.) the transmitter and receiver are screened from each other, but share the same aerial. An array of beams are transmitted towards the earth's surface at a depression angle of between **60° and 70°** and the receiver measures the frequency shift in the reflected signal, which is caused by the aircraft's speed along track, ground speed, and speed across track, (drift).

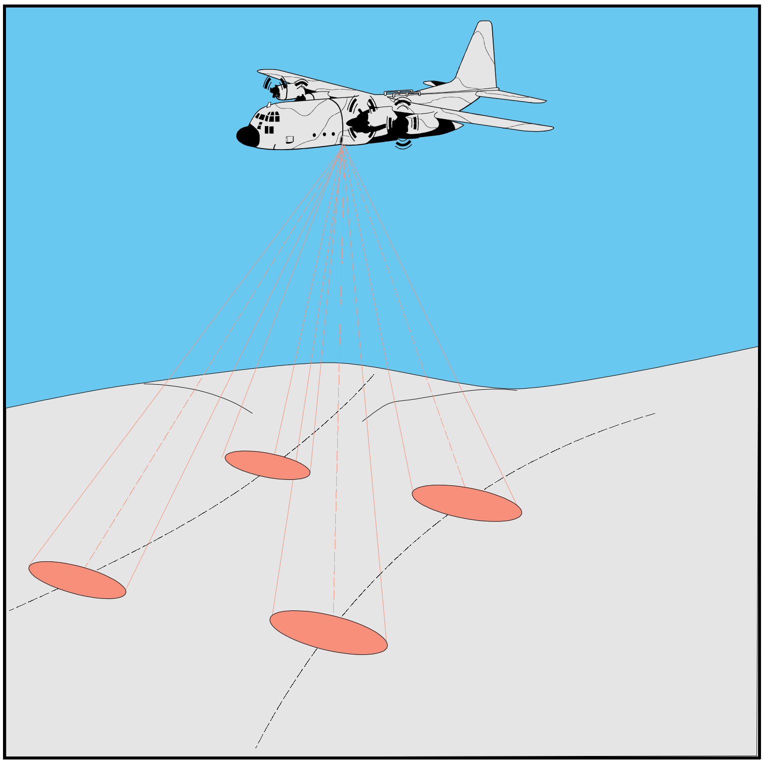


Figure 5.1

To explain the Doppler principle a separate ground-based transmitter T and receiver R are considered. (Figure 5.2)

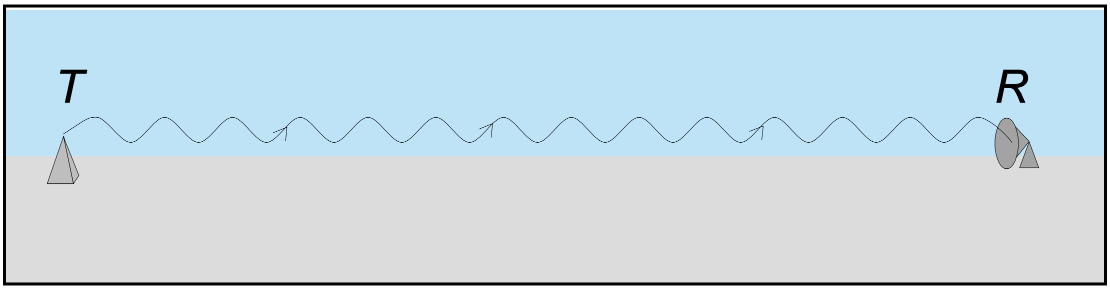


Figure 5.2

The stationary transmitter T broadcasts at a carrier frequency of **f** Hz. The stationary receiver R receives **f** waveforms each second at the constant speed of electro-magnetic waves, c m/s. Thus the received frequency = c/λ, which is the transmitted frequency; hence no frequency shift occurs.

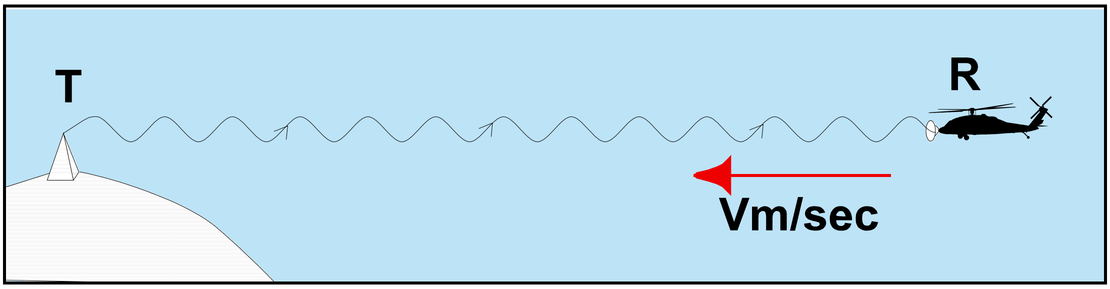


Figure 5.3

Figure 5.3 depicts R moving towards stationary T at V ms^{-1}. The speed of the transmission remains constant at c ms^{-1}; but each transmitted wavelength arrives at moving R at a shorter time interval. This is perceived as a wavelength reduction.

As $\mathbf{c} = f\lambda$

then as λ appears to decrease f must increase.

This apparent increase in frequency is due solely to the relative motion between T and R.

The difference in transmitted frequency f and received frequency f_R is known as the Doppler Shift f_D.

Therefore $f_D = f_R - f$

Because there is an apparent change in wave length the relationship can be expressed as:

$$f_D = \frac{V}{\lambda}$$

Since $\lambda = \frac{c}{f}$, then $f_D = \frac{V \times f}{c}$

When R is moving away from T then the wavelengths take longer to reach T and they appear to lengthen; this results in a perceived reduction in received frequency and hence a negative f_D. Figure 5.4 summarises the various transmitter and receiver combinations.

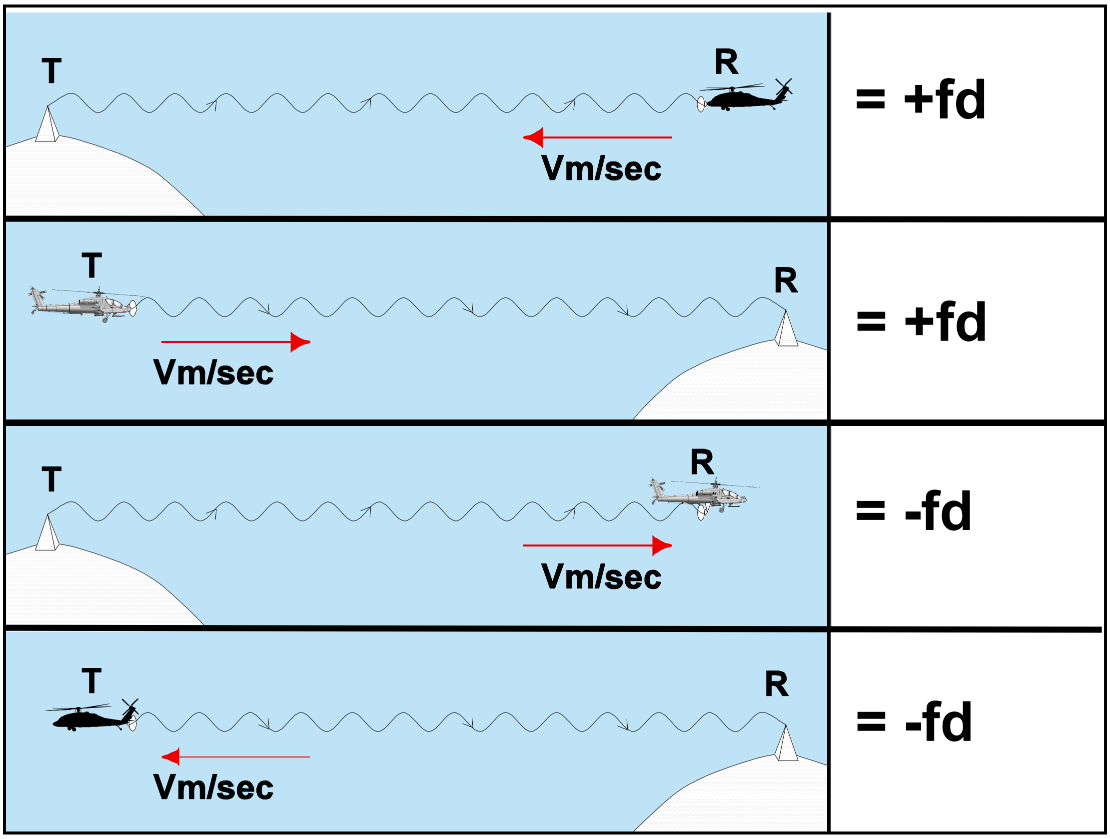


Figure 5.4

AIRBORNE DOPPLER

A typical slotted waveguide antenna consists of separate transmitting and receiving arrays designed to produce one of the common aerial beam configurations (Figure 5.5). This technique of using opposing beams is called a JANUS array after the Roman god of doorways; he was able to face both ways simultaneously. A commonly adopted system is the four beam X array.

Each aerial of a particular array transmits at a **depression angle, θ, of between 60° and 70°.** (Figure 5.6) This is a compromise. If **θ** is too close to 90° the Doppler shift approaches zero; if **θ** is too small the transmissions would strike the surface at a shallow angle, causing the signals to reflect away from the aircraft, resulting in weak un-measurable Doppler shift returns at the aircraft's receiver.

Using the four beam Janus array, zero drift and an aircraft traveling forwards: the received frequency from the two front beams is shifted upwards and that from the two rear beams is shifted downwards, equally, in proportion to the aircraft's ground speed.

If the aircraft is drifting then there will be a difference in the frequencies received from the port and starboard beams; this information is electronically converted in modern fixed aerial equipments to a continuous indication of drift. In earlier mechanical systems, with pitch stabilized, rotating aerials, the difference in shifts was converted to an electrical signal which actuated a motor. The motor then rotated the aerial until it was aligned with the aircraft's track; at this instant the port and starboard shifts were equalized and the drift equaled the difference between the aircraft's heading and the aerial's track alignment.

The higher the Doppler system frequency the more sensitive and efficient it becomes at assessing the frequency shifts to be converted to ground speed and drift, and the narrower the beam widths (1° to 5°) for a given aerial dimension. An excessive increase in the transmitted frequency causes absorption and reflections from precipitation. Therefore, the compromise frequencies allocated are **8,800MHz (8.8 GHz) or 13,300MHz (13.3. GHz), the SHF band.**

Janus arrays also reduce errors caused by minor variations in the transmitted frequency; pitch, roll and vertical speed changes and unlocking during flight over an uneven surface. When a Doppler system unlocks it reverts to "memory" and ceases to compute ground speed and drift.

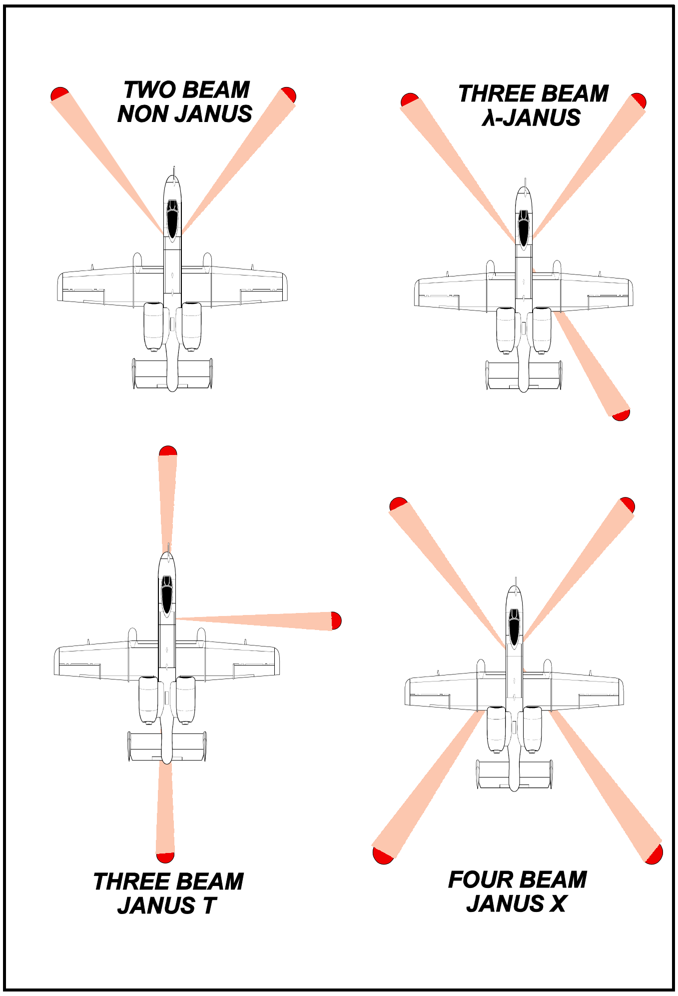

TWO BEAM
NON JANUS
THREE BEAM
λ-JANUS
THREE BEAM
JANUS T
FOUR BEAM
JANUS X

Figure 5.5

JANUS ARRAY SYSTEM

Figure 5.1 illustrates a typical aerial array for a modern 4- Beam Janus system transmitting at a frequency of 13.325GHz. The depression angle to the center of each **beam is 67°; the depth and width of each beam is 5.6° and 11°.** The quoted accuracy for this system is **0.3% of ground** speed and drift on 95% of occasions.

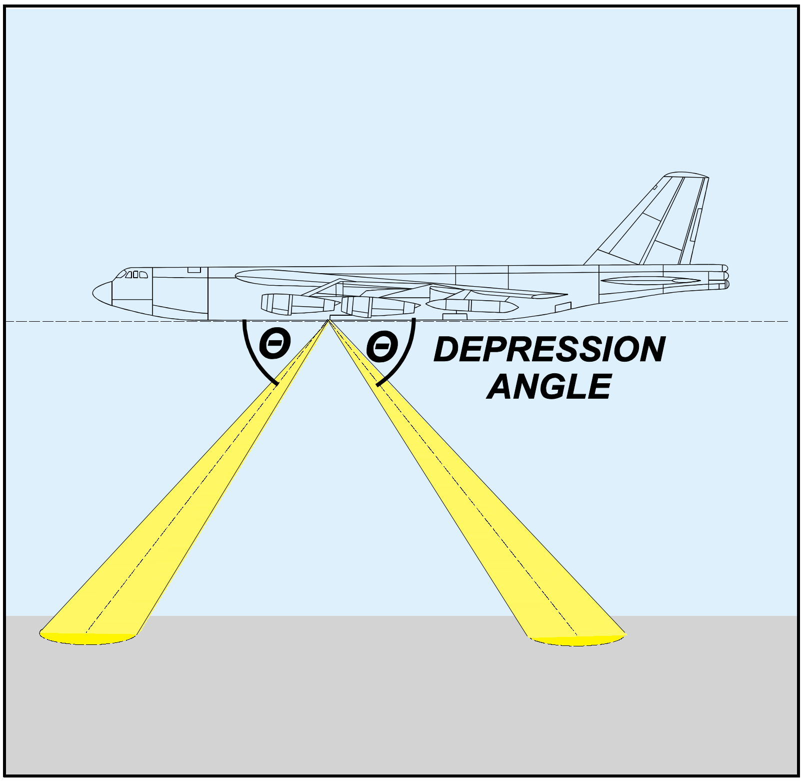


Figure 5.6

Figure 5.7 is the Control Display Unit (CDU) for the above aerial system. The STBY (Standby) function is selected when the aircraft is close to structures and people. This safeguards the equipment, prevents damaging the health of people in the radiation path and allows the equipment to be energized for immediate use when the aircraft is clear.

The SEA indicator illuminates when the aircraft is flying over the sea or large expanses of water. As stated previously the reflected returns from water are less than those from land due to "spillage" of reflected energy from the front of the forward beams and the rear of the rearward beams. This results in a smaller measured fd spectrum from the four beams, evidenced by a reduction in the actual ground speed readout. Circuitry within the computer will compensate for this ground speed reduction and increase the readout for the assessed ground speed loss.

Figure 5.7 Racal RNS 252 Navigation Computer Unit

QUESTIONS

The following questions illustrate the Doppler principle:

1 . A transmitter is moving directly towards a receiver at 250m/sec. The wavelength of the transmission is 5cm. Calculate the frequency shift in kHz at the receiver.

2. A receiver is moving directly towards a transmitter at 900kph. The transmission frequency is 6 GHz. Calculate the frequency shift in kHz caused by the relative motion between the transmitter and receiver.

3. A stationary transmitter is operating on a wavelength of 3cm. A receiver moving directly away from the transmitter measures a Doppler shift of 6kHz. Calculate the speed of the receiver away from the transmitter in m/sec and knots.

4. An 8800MHz transmitter is moving directly away from a receiver at 291 kt. Calculate:

   a. the speed of relative motion in m/sec
   b. the frequency shift at the receiver in kHz
   c. the frequency received in MHz

5. Complete the following Doppler shift table which relates to the relative motion between a transmitter and a receiver:

TRANSMITTED WAVELENGTH (CM)	FREQUENCY SHIFT (KHZ)	RELATIVE SPEED (MS^{-1})	RELATIVE SPEED (KT)
2		300	
3.41			450
2.26			314
23	2.3		
3.41	7.0		

ANSWERS

1 5 kHz

2 5 kHz

3 180 ms^{-1}, 350 kt

4 a. 150 ms^{-1}

b. 4.4 kHz

c. 8799.9956 MHz

5

TRANSMITTED WAVELENGTH (CM)	FREQUENCY SHIFT (KHZ)	RELATIVE SPEED (MS^{-1})	RELATIVE SPEED (KT)
2	***15***	300	***583***
3.41	***6.79***	***231.4***	450
2.26	***7.15***	***161.7***	314
23	2.3	***529***	***1028***
3.41	7.0	***238.7***	***464***

QUESTION PAPER

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. An aeroplane is flying at 486 kt directly towards a beacon transmitting on a frequency of 12 GHz. The change in frequency observed will be:

   a. 10 MHz
   b. 6.25 Hz
   c. 10 kHz
   d. 6.25 kHz

3. 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

4. When an aircraft is flying directly away from a transmitter, transmitting on a frequency of 15 GHz, a frequency shift of 6.0 kHz is measured. The speed of the aircraft is:

   a. 120 kt
   b. 222 ms^{-1}
   c. 300 kt
   d. 222 kt

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

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

ANSWERS

1	B
2	C
3	**B**
4	D
5	A

CHAPTER SIX

VHF DIRECTION FINDER (VDF)

Contents

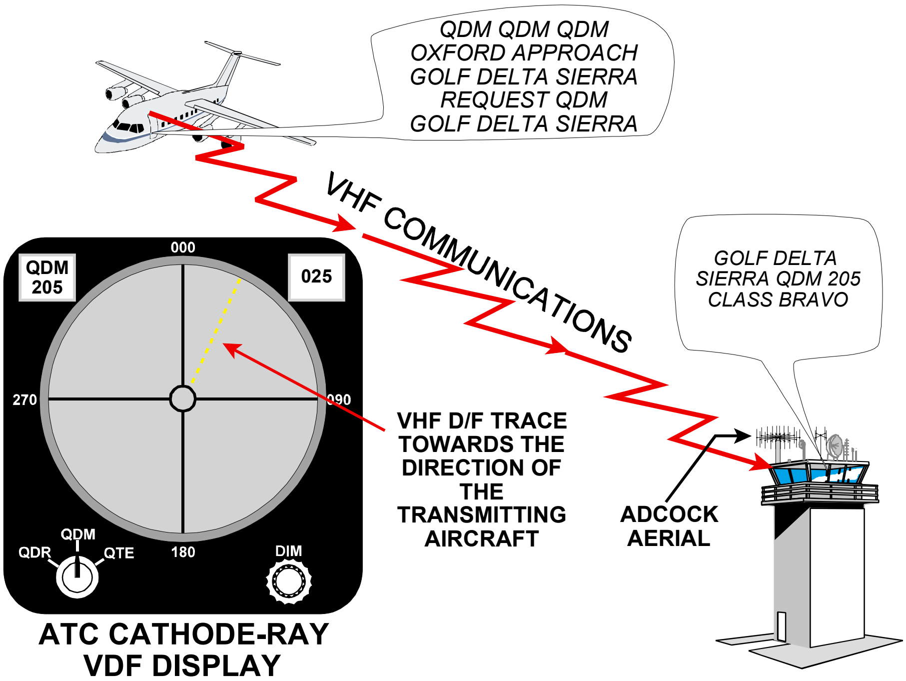


Figure 6.1 Ground Equipment for VHF Direction Finder

INTRODUCTION

Most ground stations in the aeronautical mobile service are equipped to take automatic bearings of an aircraft's VHF transmissions (118 - 137 Mhz, emission code A3E). The ground installation comprises a suitable aerial and a CRT display as shown in Figure 3.1. The UHF band is used for direction finding by the military only at present. Information on stations providing VHF DF is found in Aerad and UK air pilot.

PRINCIPLE OF OPERATION

The aerial is vertically polarised and has an array of vertical elements arranged in a circle. This is known as an Adcock aerial (see figure 3.1). The equipment resolves the bearing from the transmissions received at each aerial in the array. The bearing is then displayed on a cathode ray tube (CRT). Hence the system is sometimes known as Cathode Ray DF (CRDF). The latest high resolution equipments use Doppler principles to determine the bearing and the bearings may be displayed as digital readouts with an accuracy of +/- 0.5 deg. (UHF or VHF).

SERVICE PROVIDED

- **QDM** - Aircraft's Magnetic Heading to steer in zero wind to reach the station; used mainly for station homing and letdowns.
- **QDR** - Aircraft's Magnetic Bearing from the station; used for en-route navigation.
- **QTE** - Aircraft's True Bearing from the station; used for en-route navigation.
- **QUJ** - Aircraft's True Track to the station; not generally used.

When a pilot wishes to obtain bearing information he calls up on the appropriate VHF RT channel:

"QDM QDM QDM OXFORD APPROACH GBDOF Request QDM GBDOF"

USE OF SERVICE

QTE or QDR:

- To check true or magnetic tracking from a VDF station.
- For en route position lines. Two stations will be required for a position fix.

QDM

- To home to a VDF station.
- For let down in cloud using published procedures.

ATC can use VDF as means of identifying aircraft in a radar environment.

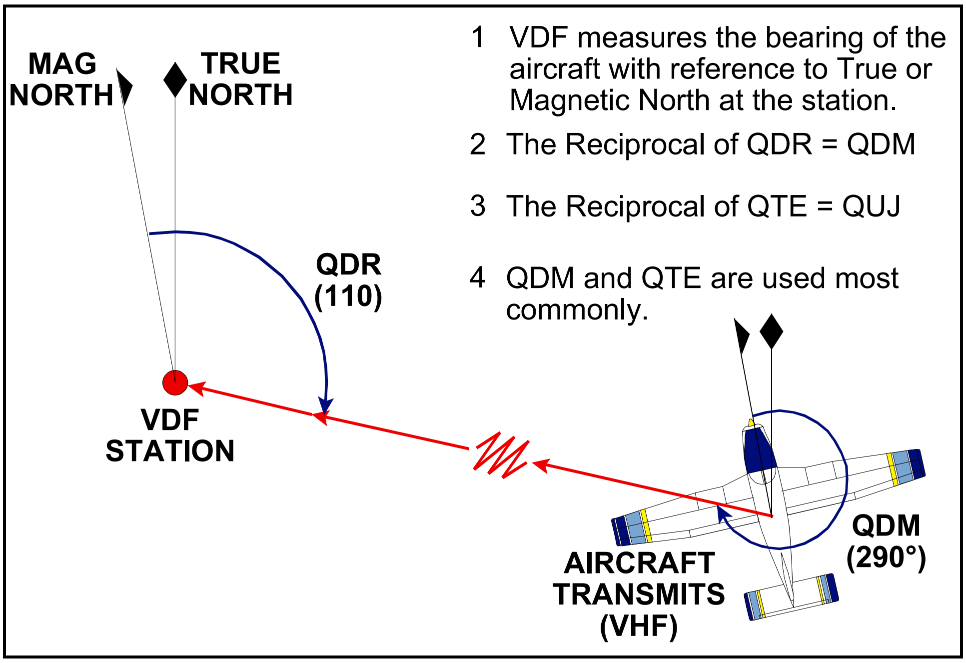


Figure 6.2

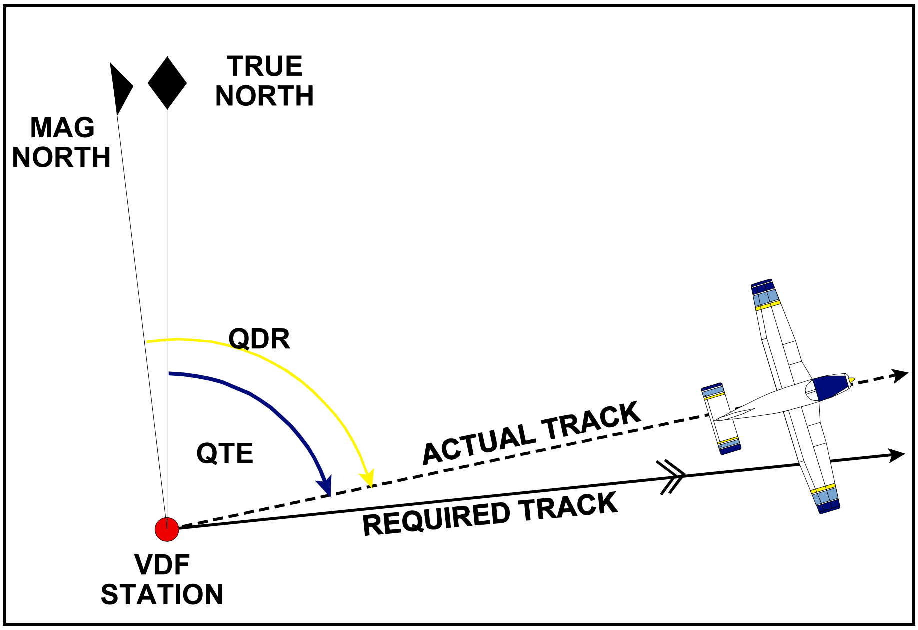


Figure 6.3 The use of QTE/QDR for Checking Track

CLASSIFICATION OF BEARINGS

The operator assesses the accuracy of the bearings and passes a classification to the pilot. e.g. "Your true bearing is 060 , class bravo".

VDF bearings are classified as follows:

Class A: accurate to within + 2°
Class B: accurate to within + 5°
Class C: accurate to within + 10°
Class D: accurate to > 10°

VDF bearing information will only be given when conditions are satisfactory. Normally no better than class B bearing will be available.

RANGE OF VDF

- As VDF utilises the VHF band (or UHF as required) the range will obey the line of sight formula. Therefore the higher the transmitters the better the reception range.
- 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 ranges.
- Synchronous transmissions by two or more aircraft will cause momentary errors in the bearings.

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's attitude. The VDF system and VHF communications are vertically polarised. Therefore, best reception and results will be obtained if the aircraft is flown straight and level.
- Poor accuracy 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; this phenomenon is usually short lived. Together with other multi-path signals this give rise to bearing errors.

VHF EMERGENCY SERVICE

In the UK 16 outstations provide auto-triangulation position-fixing service on the VHF emergency frequency (121.5 Mhz) and on the UHF emergency frequency (243.0 MHz) to pilots who are:

- in distress
- in urgent need of assistance
- experiencing difficulties (ie lost)

On VHF this service is available at 3,000 ft and above in the London FIR (2,000 ft and above in the London area). Elsewhere the auto-triangulation service is not available, however the D & D cell at SCATCC can manually plot bearings from outstations to fix an aircraft's position. The UHF service is available on 243.0 MHz throughout the UK for the military.

VHF LET DOWN SERVICE

There are two types of VDF procedure, QDM and QGH. In the QDM the pilot calls for a series of QDM and uses them to follow the published approach pattern, making his own adjustment to heading and height.

In the QGH procedure the controller obtains bearings from the aircraft's transmissions, interprets this information and passes to the pilot headings and heights to fly designed to keep the aircraft in the published pattern. Normally at civil aerodromes only QDM procedure is available; however, in some cases, for specific operational reasons, there will be provision for a QGH procedure.

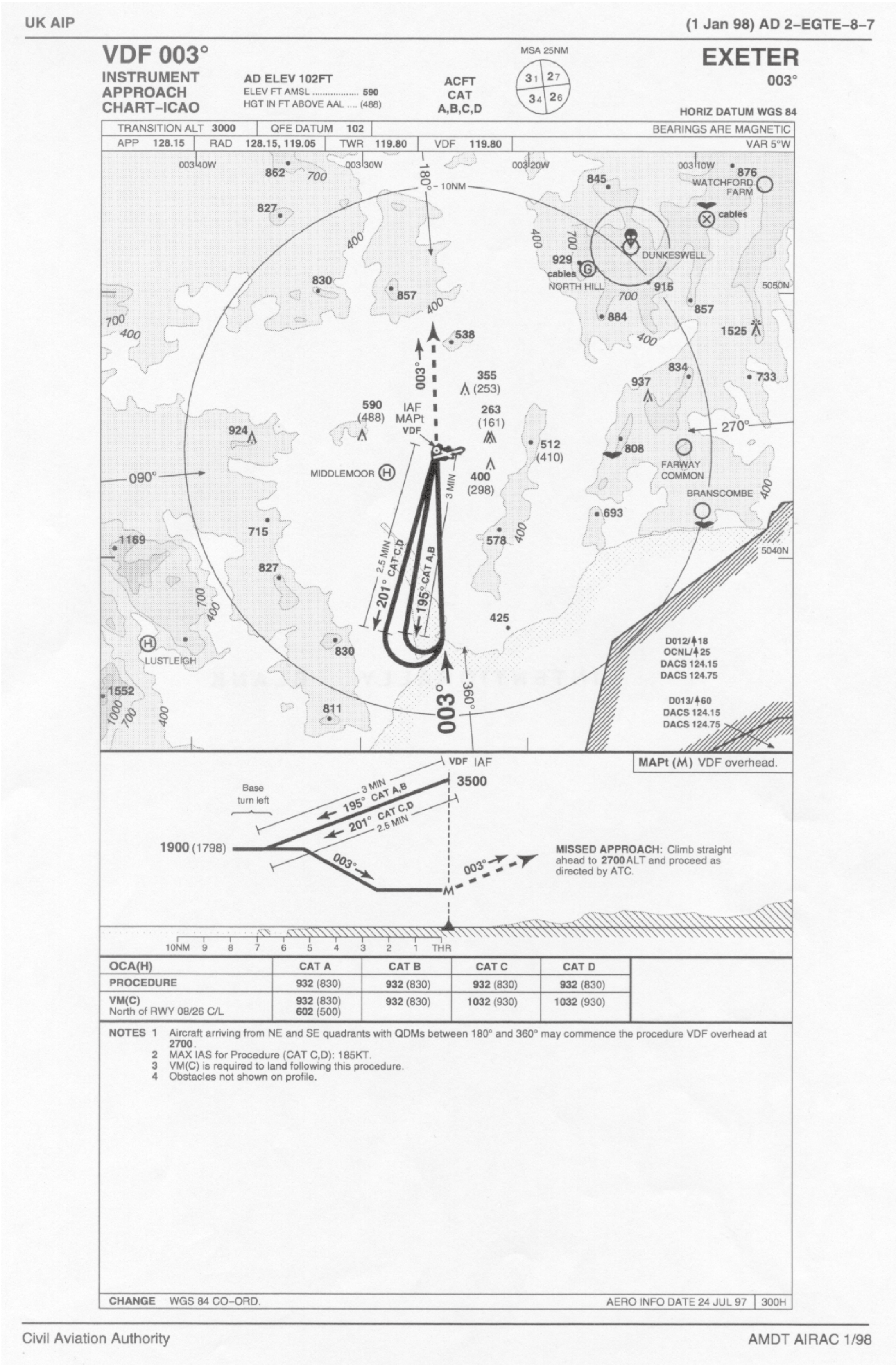


Figure 6.4. VDF Let-Down Procedure

VDF SUMMARY

Bearings:	QDM - Mag TO station QDR - Mag FROM station QTE - True FROM station
Uses:	Check track, Position line, Homing, Let-downs
Class:	A = + 2 B = + 5 C = + 10 D = >10
Principle:	Ground equipment - Adcock aerial, CRT
Range:	Line of sight, Power of transmitters, Intervening high ground, Atmospheric conditions (ducting)
Accuracy:	Propagation error, site error, Aircraft attitude, Overhead station, Fading due to multi-path signals
Emergency service:	Position fixing by auto-triangulation
Let-down service:	QDM procedure - pilot interpreted QGH procedure - controller interpreted

QUESTIONS

1. An aircraft has to communicate with a VHF station at a range of 300 nm, if the ground station is situated 2,500′ amsl which of the following is the lowest altitude at which contact is likely to be made?

   a. 190′
   b. 1,378′
   c. 36,100′
   d. 84,100′

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 9,000 feet wishes to communicate with a VHF/DF station that is situated at 400 feet amsl. What is the maximum range at which contact is likely to be made ?

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

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 19,000ft wishes to communicate with a VDF station at 1,400ft amsl.
   What is the maximum range at which contact is likely ?

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

ANSWERS

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

CHAPTER SEVEN

AUTOMATIC DIRECTION FINDER (ADF)

Contents

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 the 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 polarised 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 callsign 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 a 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.

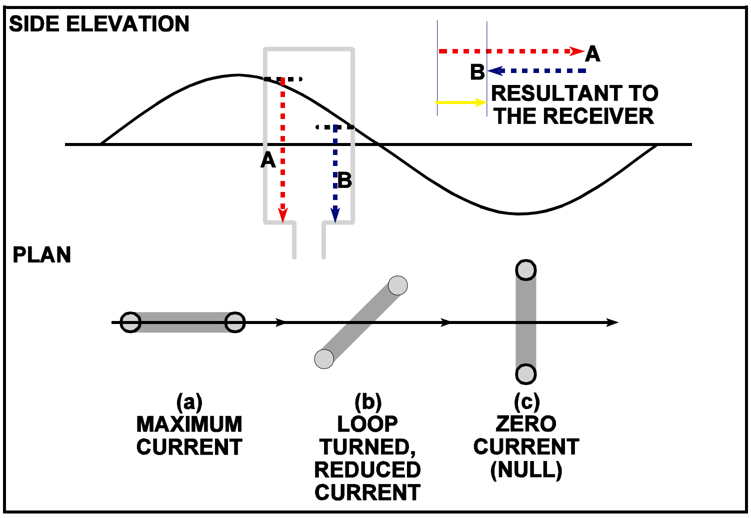


Figure 7.1 A Loop Aerial

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.

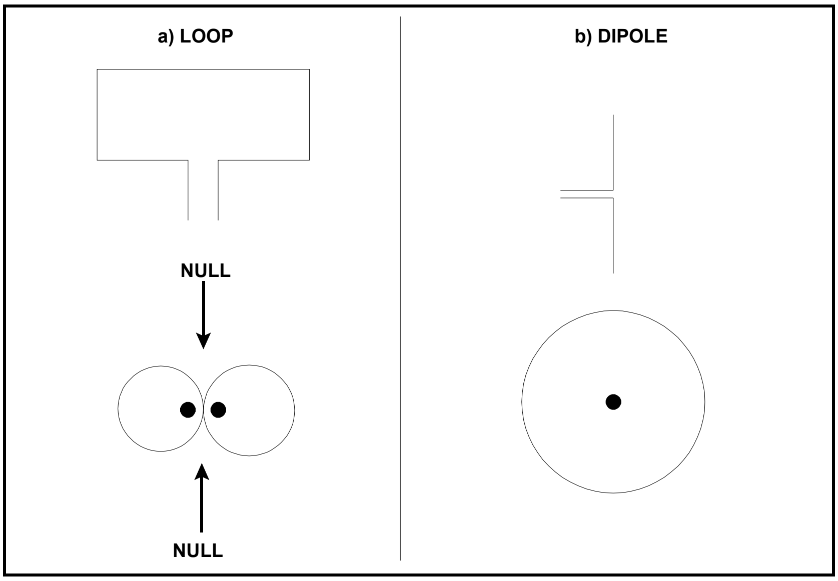


Figure 7.2 Polar Diagrams of Loop and Dipole Aerials

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.

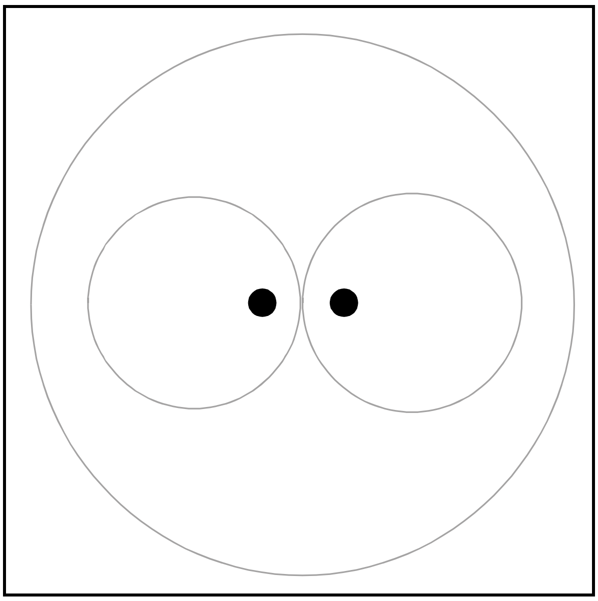


Figure 7.3

It is arranged for the field from the sense aerial to be in phase with the one element (left hand 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.

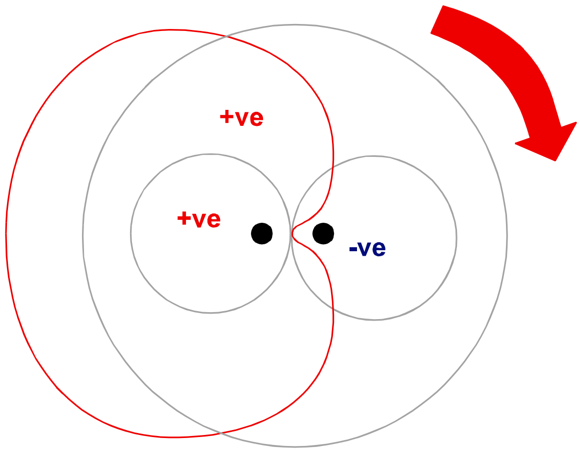


Figure 7.4

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.

CORRECT NULL

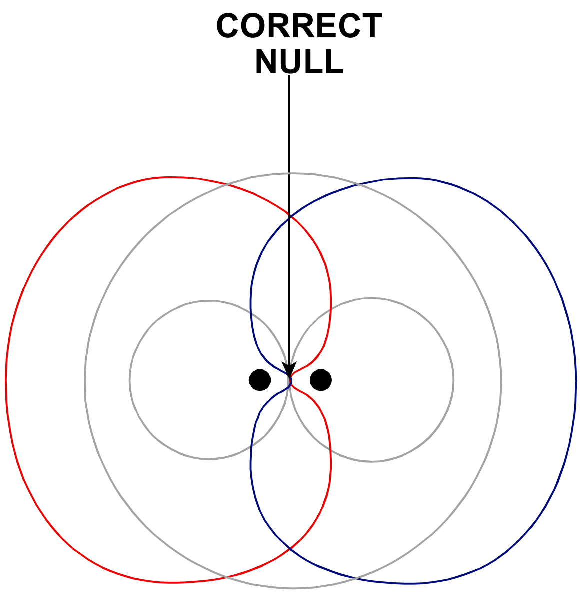


Figure 7.5

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.

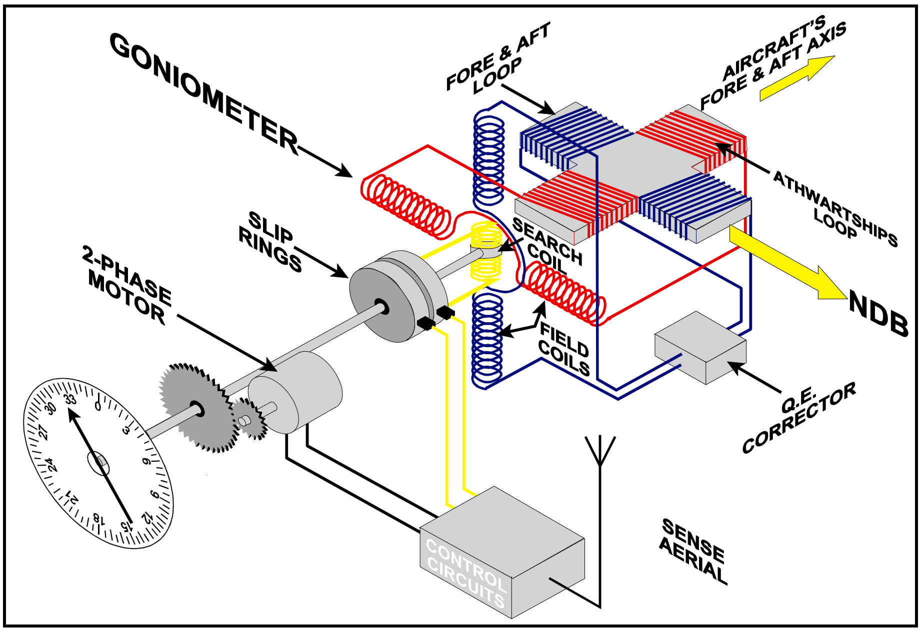


Figure 7.6 A Fixed Loop ADF

FREQUENCIES AND TYPES OF NDB

The allocated frequencies for NDB,s are 190 - 1,750 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 25nm and may only be available during an aerodromes published hours of operation.

En route NDBs. These have a range of 50nm 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

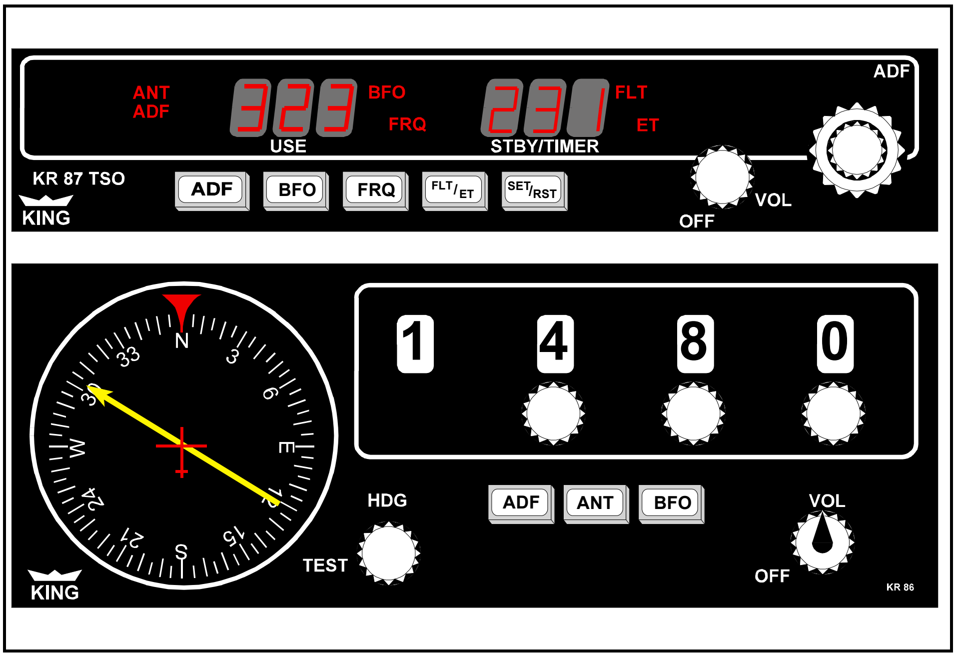


Figure 7.7 Two ADF Receivers.

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 1,020 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.

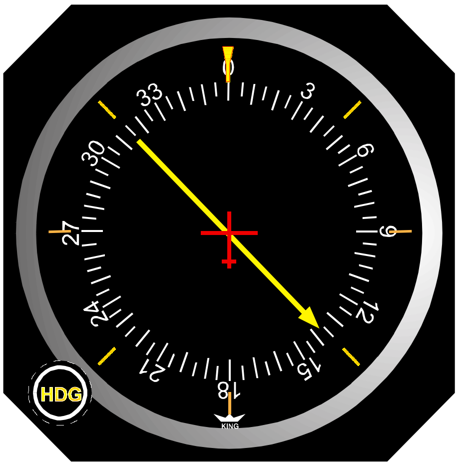


Figure 7.8 RBI

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.

INBOUND TRACKING

Figure 7.10 shows an aircraft maintaining a track of 077° in zero wind (zero drift). The aircraft is heading 077° and has a relative bearing of 360°.

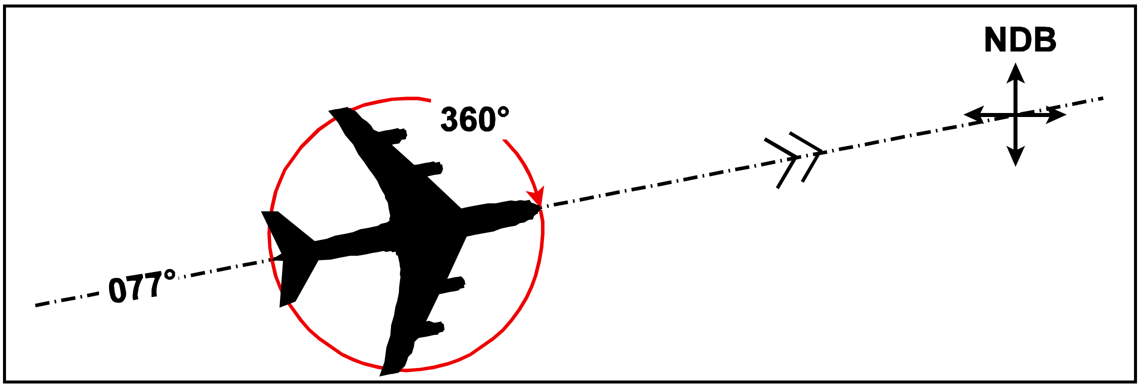


Figure 7.10 Homing in Zero Drift.

Figure 7.11 shows an aircraft attempting to maintain an inbound track in a crosswind using the incorrect technique. By not allowing for drift and persisting in maintaining a relative bearing of 360° a curved track is flown.

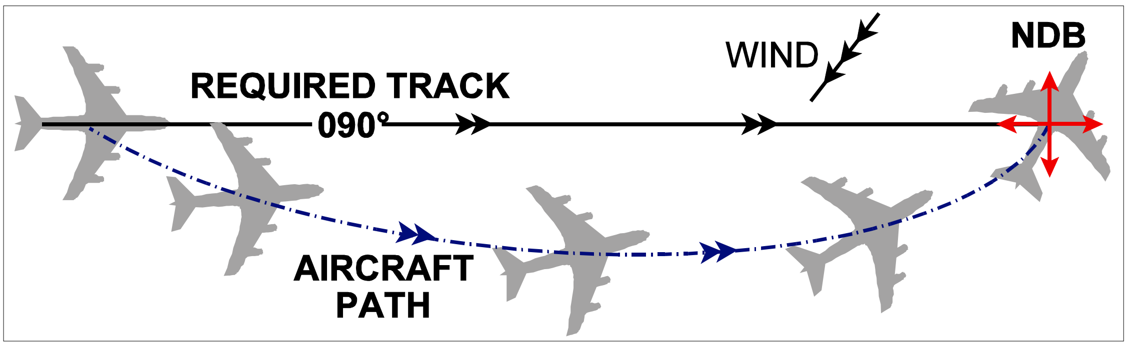


Figure 7.11 Homing Making No Allowance for Drift.

MAINTAINING AN INBOUND TRACK IN A CROSSWIND

To maintain the required track to an NDB in crosswind conditions using the correct method it is necessary to allow for the anticipated drift. 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°.

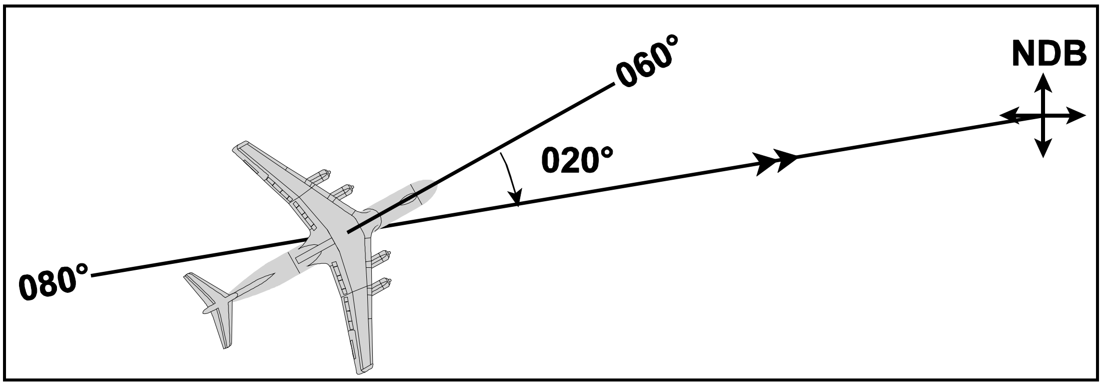


Figure 7.12

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°.

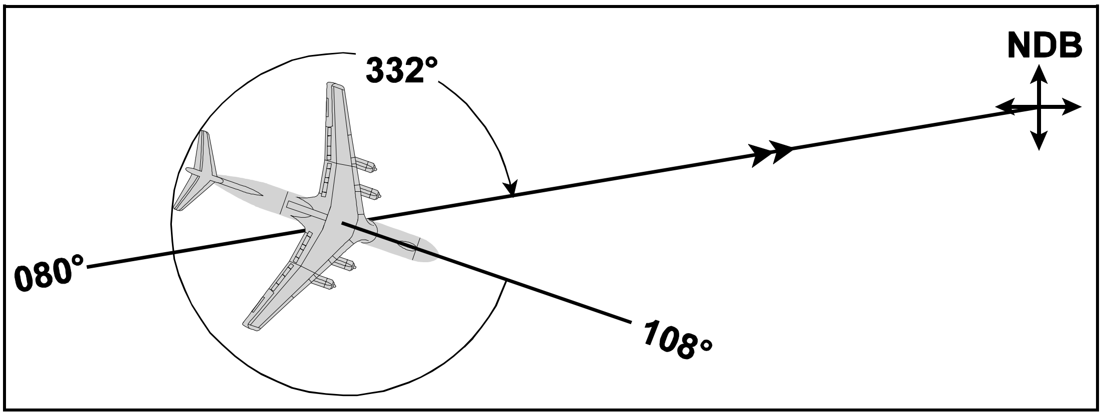


Figure 7.13

OUTBOUND TRACKING

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°.

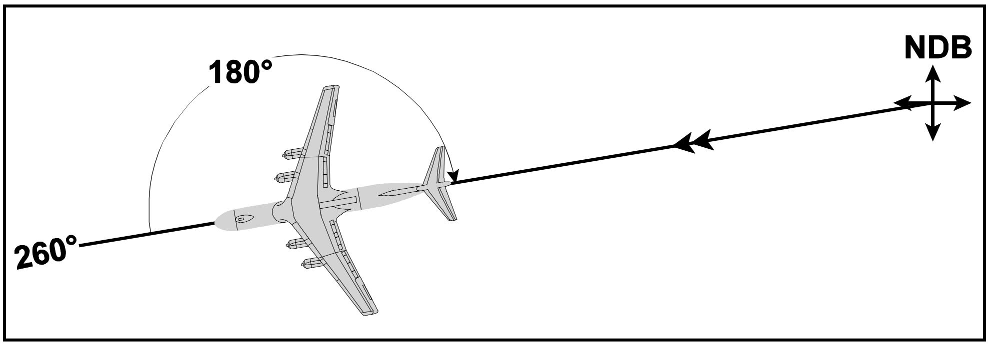


Figure 7.14

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.

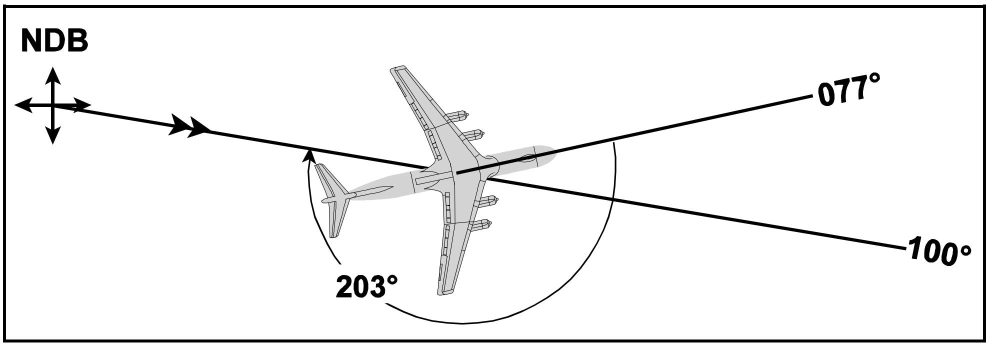


Figure 7.15

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°.

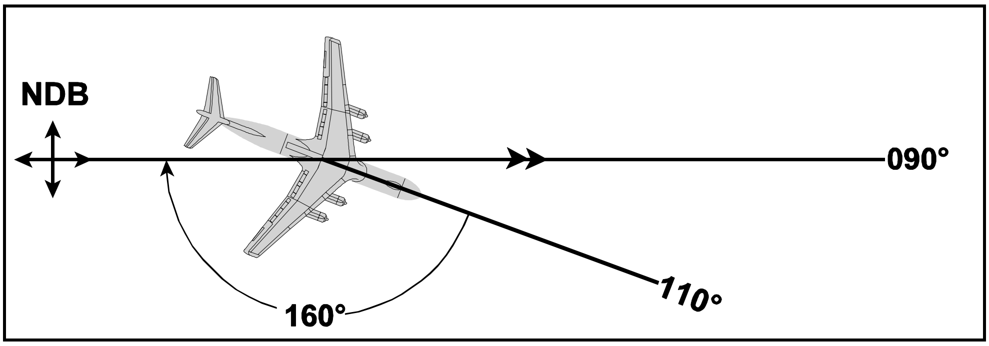


Figure 7.16

DRIFT ASSESSMENT AND REGAINING INBOUND TRACK

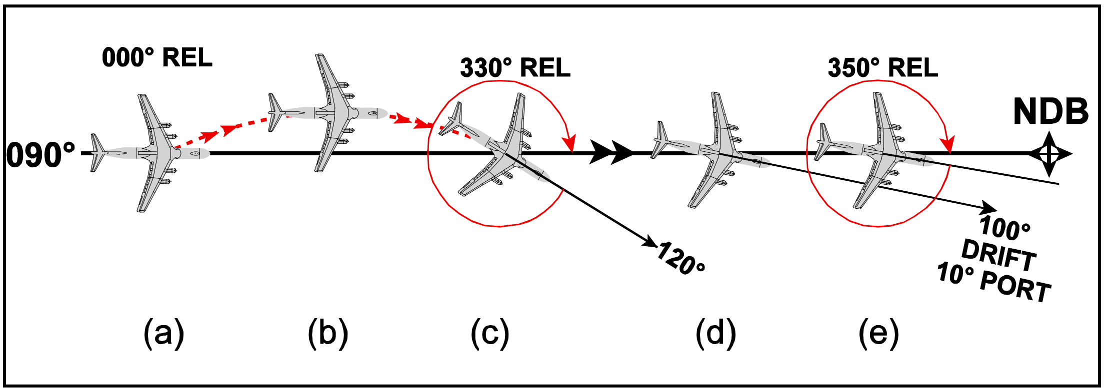


Figure 7.17 Assessing Drift Inbound

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 (say10° 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

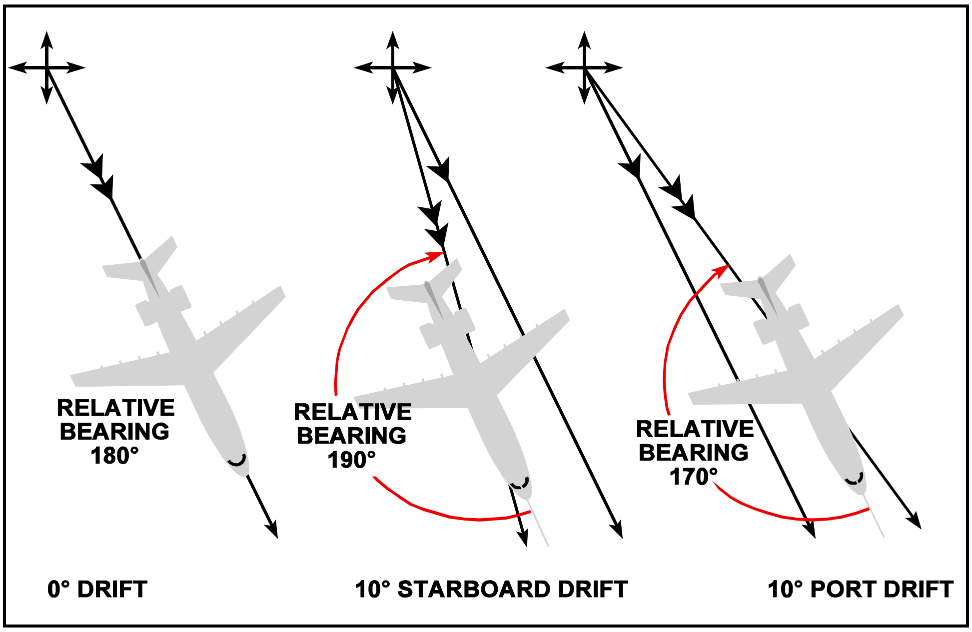


Figure 7.18 Drift Assessment Outbound

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.

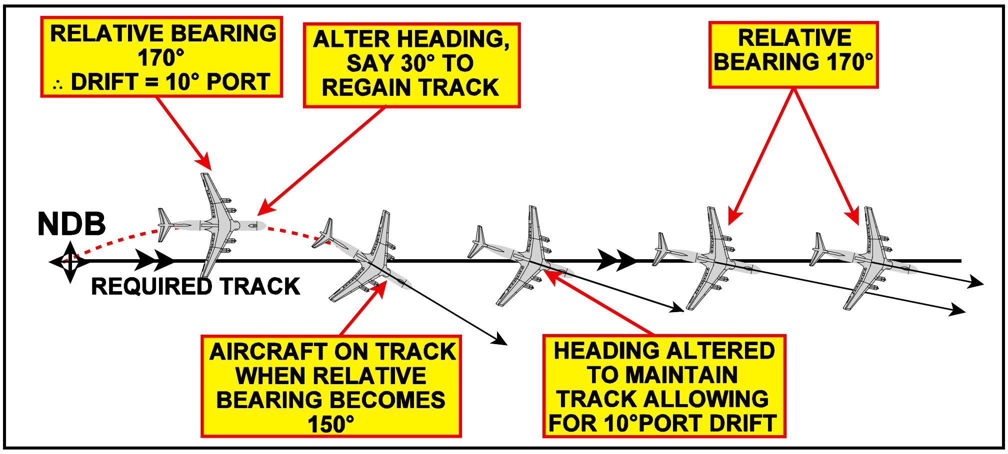


Figure 7.19 Determining Drift and Maintaining Track away from an NDB

HOLDING

THE HOLDING SYSTEM 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 'stack', is organised over a 'radio' beacon where each waiting aircraft flies a special circuit separated vertically from other aircraft by a minimum of 1,000ft. 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.

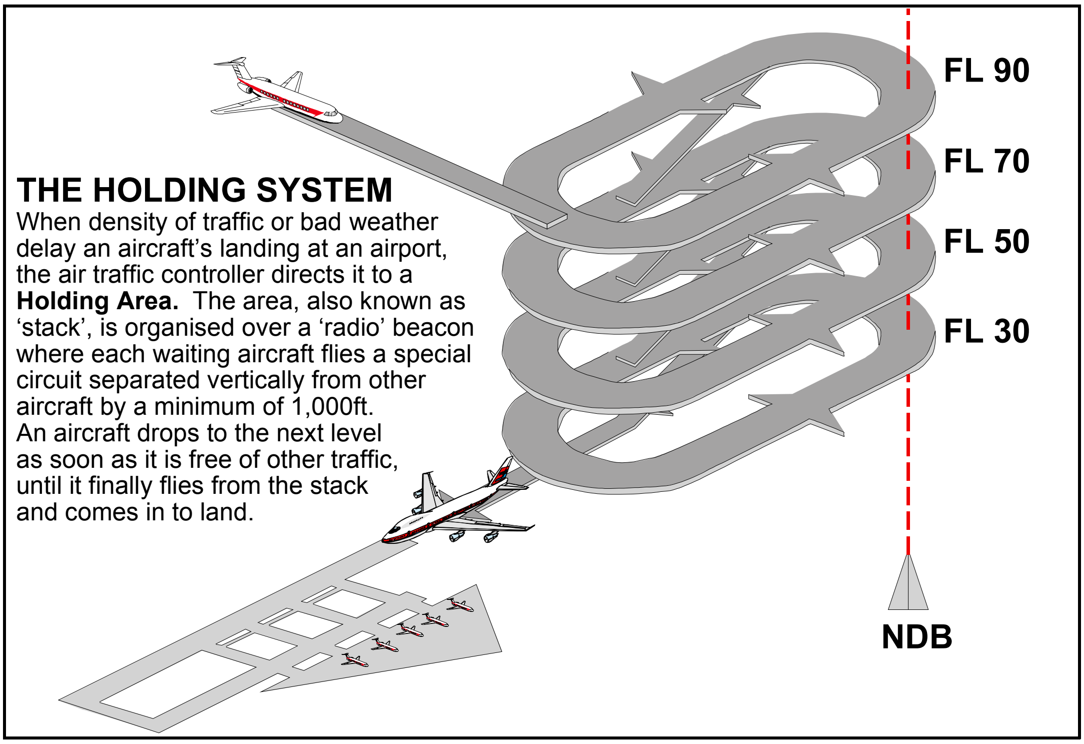


Figure 7.20 The Holding System

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.

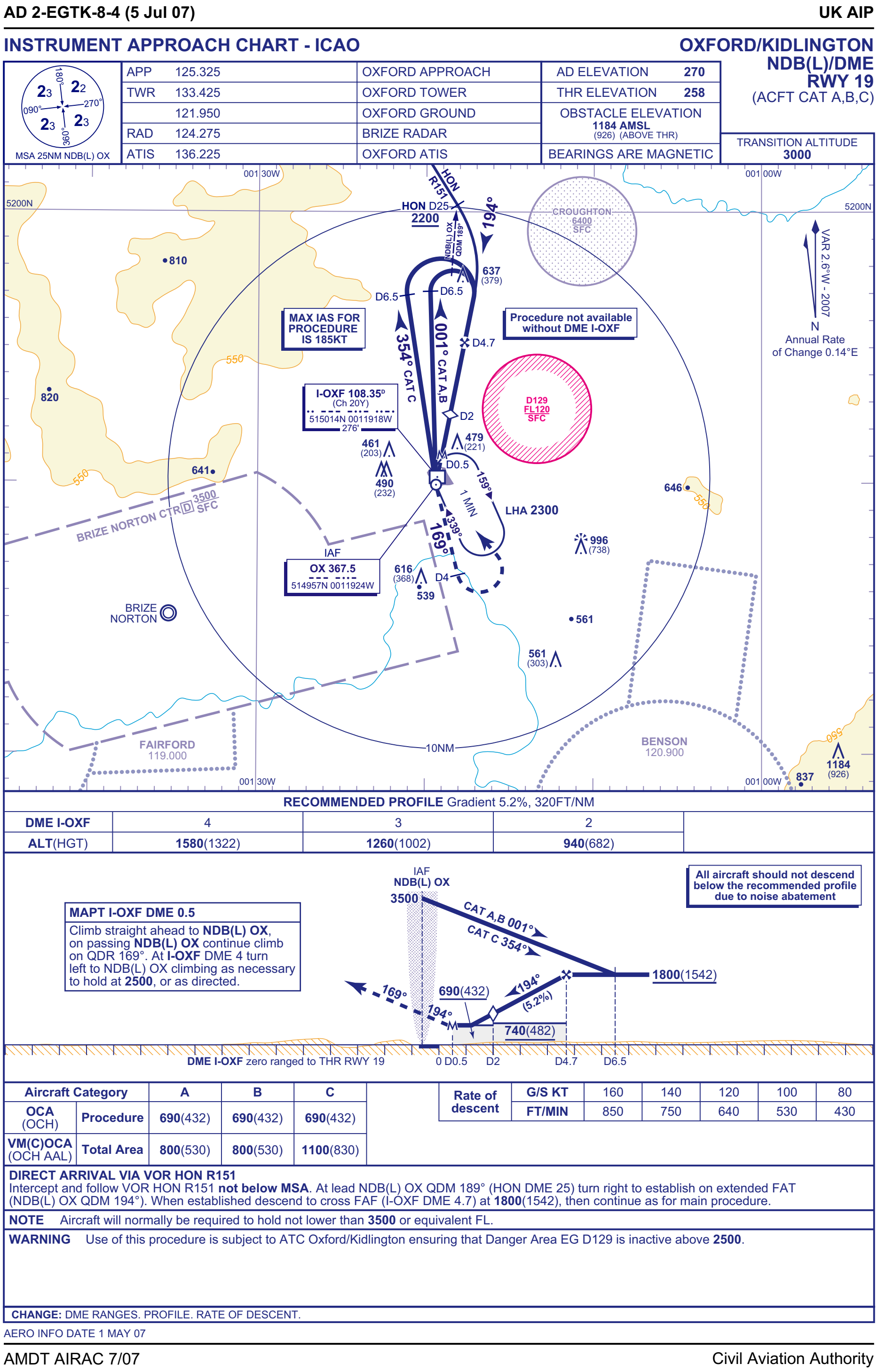


Figure 7.21 Example of an NDB Instrument Approach

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. 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. 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 skywave contamination of the surface wave being used. This arises for two reasons: phase interference of the skywave 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 - 100nm 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.

- To minimise the above effects:
- Positively identify the NDB callsign.
- 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 skywave 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 minimised 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.

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 (ie 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 polarised waves for direction finding. If the incoming wave has any horizontal component of polarisation 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 emfs 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 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.

Non A1A NDBs have greater ranges than non A2A. 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	Ground transmitter in LF or MF band (190 - 1750 kHz)		
	Types of NDB:	Locator (L) En Route	- airfield let-down (10 - 25 nm) - Nav-aid (50 nm or more)
	Range (nm)	$3 \times \sqrt{P\ (W)}$	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	

QUESTIONS

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

   a. is most marked at night.
   b. can be minimised by using beacons situated well inland.
   c. can be minimised 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°

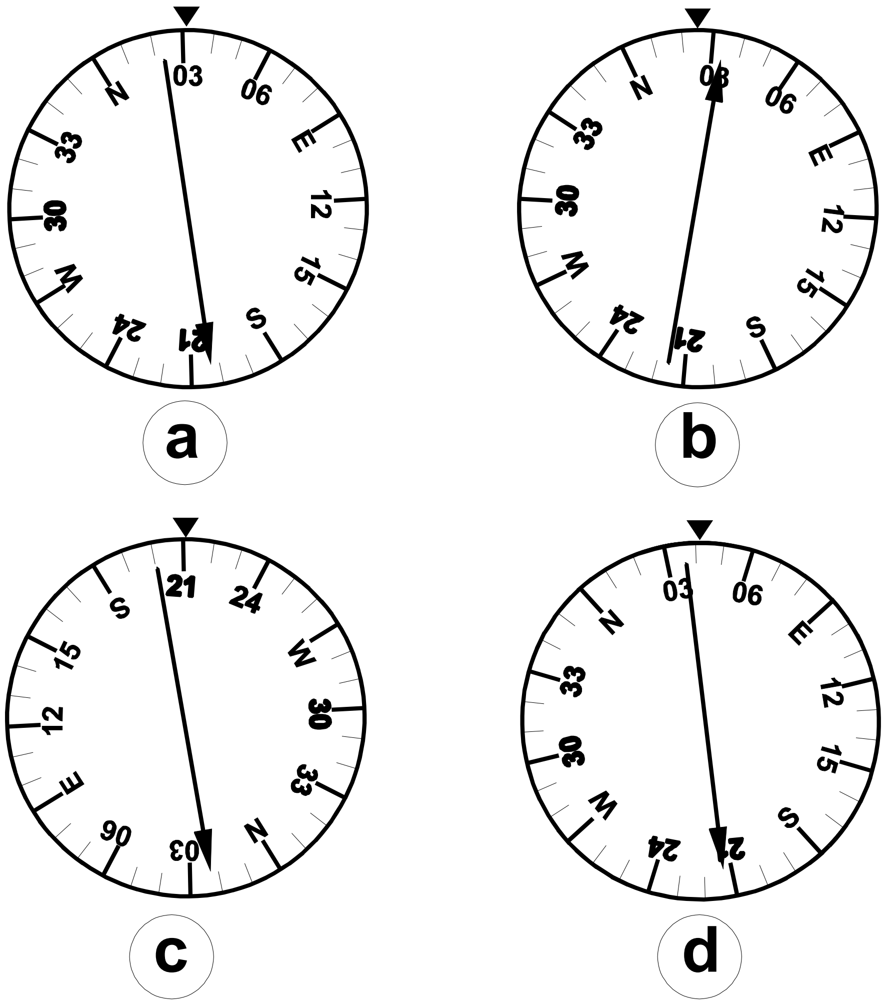
5. In order to Tune, Identify and Monitor NON A1A NDB emissions the BFO should be used as follows:

	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 NON A2A 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 NON A1A 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.

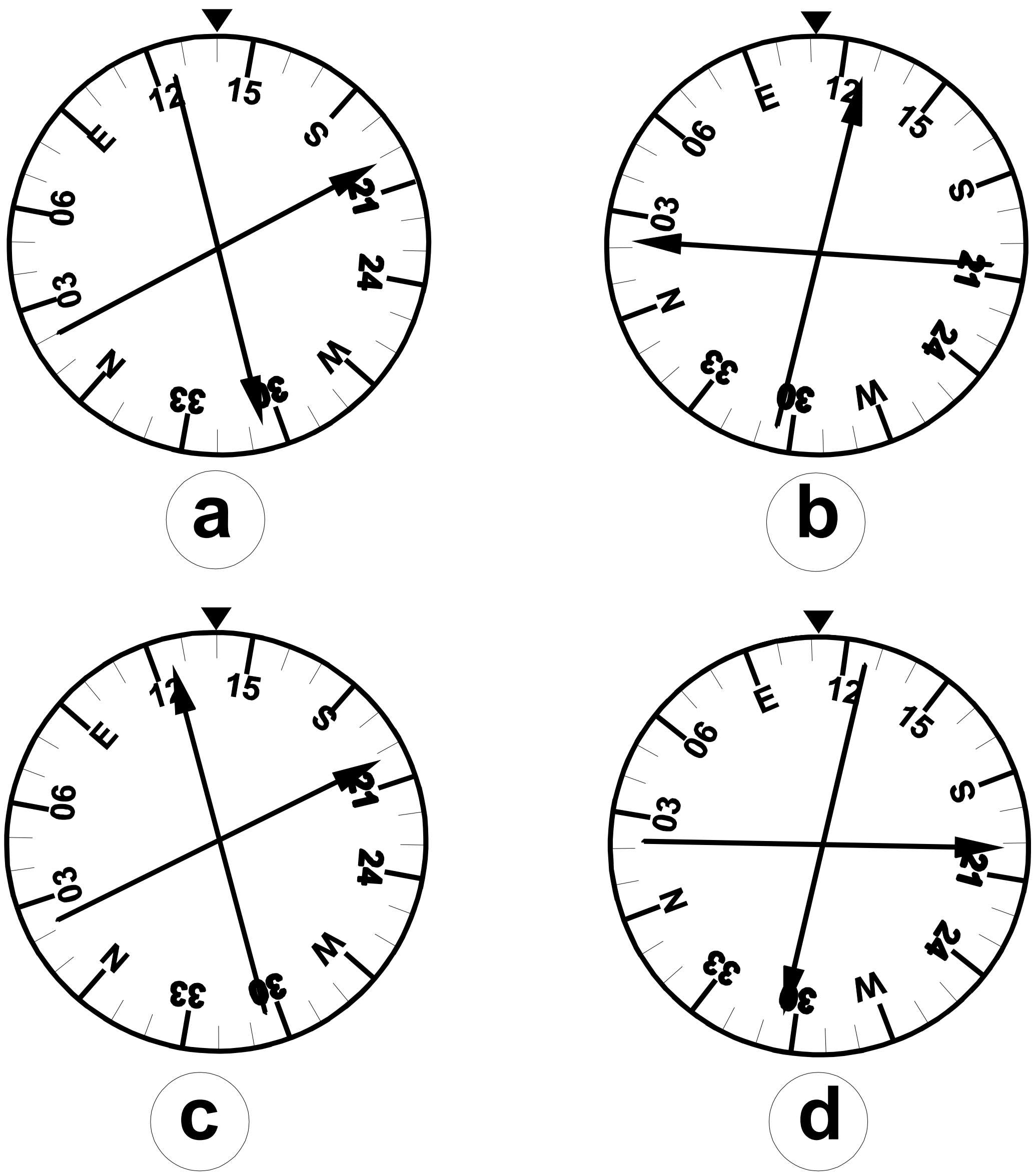
9. The Protection Ratio of 3:1 that is provided within the Promulgated range/Designated Operational Coverage of an NDB by day cannot be guaranteed at night because of:

   a. Long range skywave interference from other transmitters.
   b. Skywave 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 140° 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 Air Pilot. 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 Air Pilot 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 skywave 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. skywave
    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	C
2	D
3	B
4	B
5	B
6	D
7	D
8	D
9	A
10	A
11	A
12	C
13	D
14	A
15	C
16	D
17	B
18	B
19	A
20	B
21	A

CHAPTER EIGHT

VHF OMNI-DIRECTIONAL RANGE (VOR)

Contents

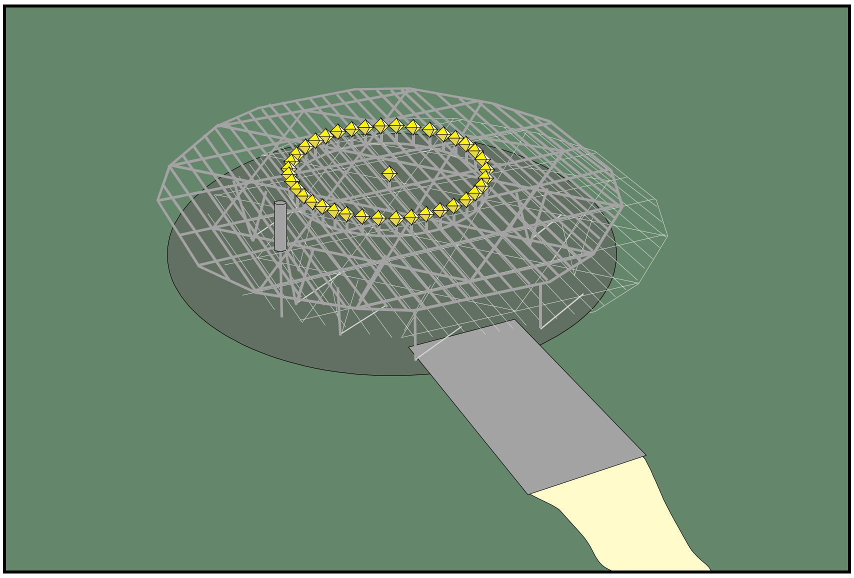


Figure 8.1 A Combined VOR / DME

INTRODUCTION

The VHF Omni-directional Range (VOR) was adopted as the standard short range navigation aid in 1960 by ICAO. It produces 360 radials/tracks at 1° spacing which are aligned in relation to 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 - 117.95MHz.

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.

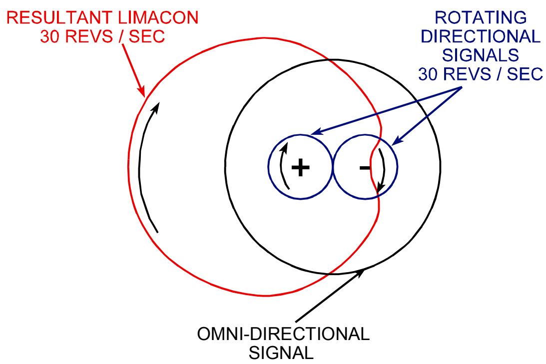


Figure 8.2 A VOR Polar Diagram

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 30Hz frequency modulated omni-directional, reference signal which produces constant phase regardless of a receiver's bearing from the VOR, and
    - a 30Hz amplitude modulated variable phase (directional) signal created by the rotating transmission pattern (limaçon).
- The 30Hz FM reference signal is synchronised with the 30 revs/sec rotating directional AM signal (limaçon) such that:
    - the two 30Hz 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 inter-action 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.

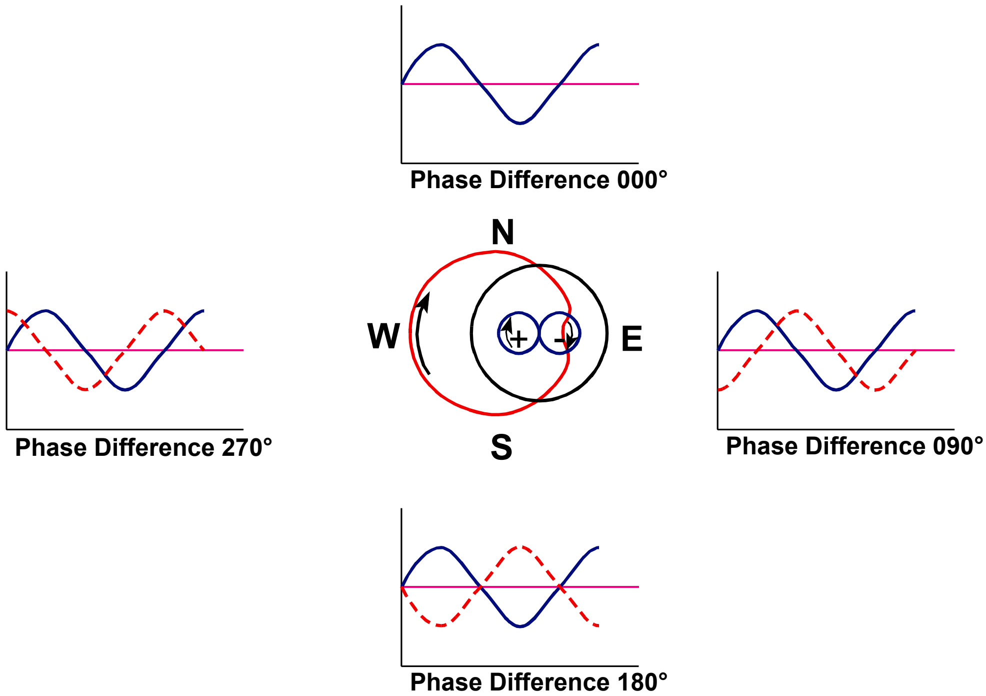


Figure 8.3 Phase Differences Corresponding to the Cardinal Points

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 360 radials continuously. The bearing information is supplied even during the identification period.

TERMINOLOGY

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

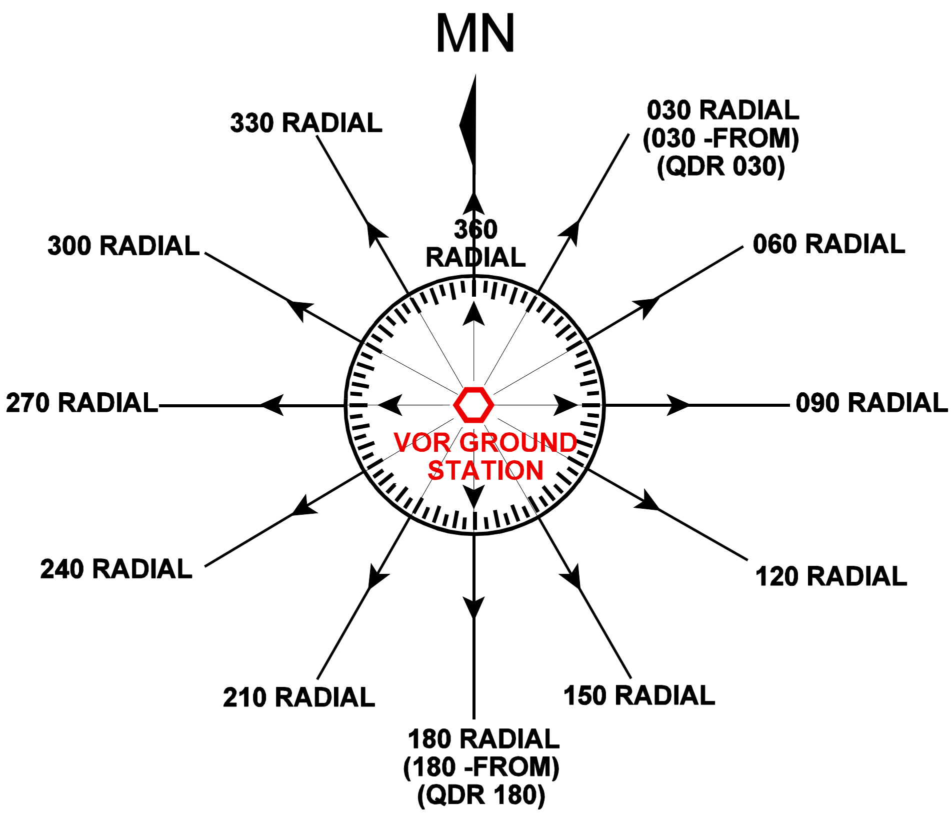


Figure 8.4 A Radial is a Magnetic Bearing FROM the VOR (i.e. QDR)

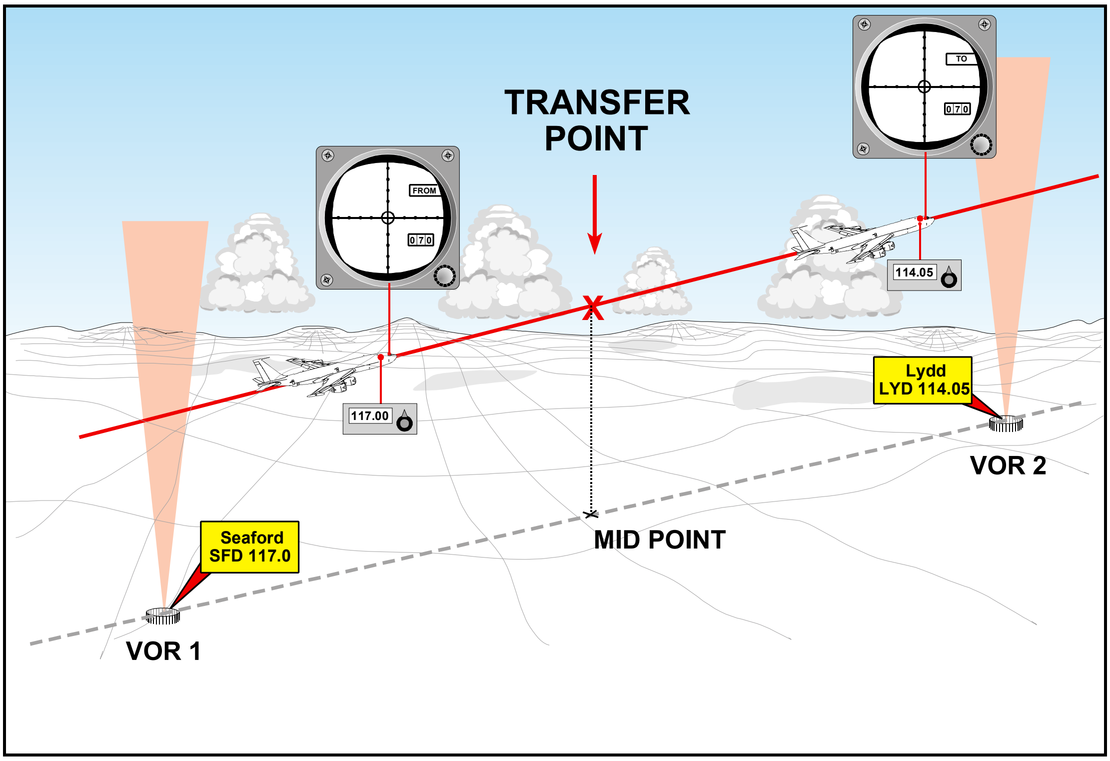


Figure 8.5 Tracking Between Two VORs

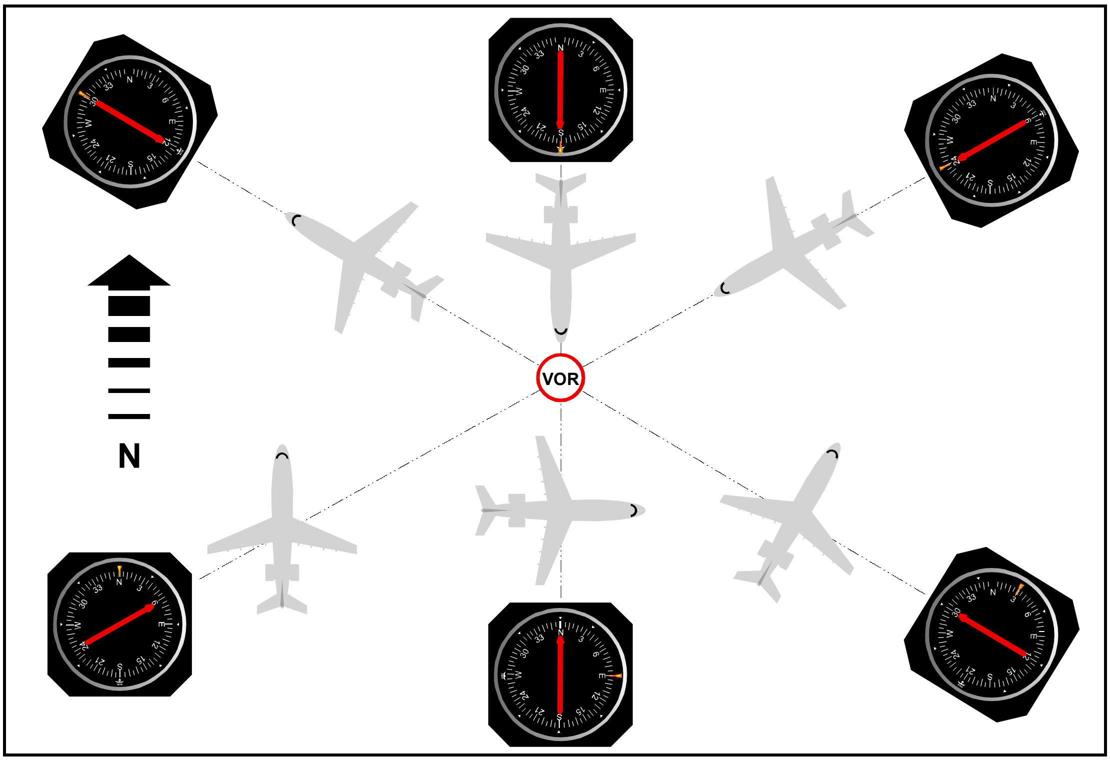


Figure 8.6 RMI Usage

TRANSMISSION DETAILS

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

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

  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 (VOR frequencies are given even decimal digits)

- **120 channels, 112 - 117.95:**

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 30Hz 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

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 200nm 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) = 1.25 x ($\sqrt{H_1}$ + $\sqrt{H_2}$)

where: H_1 =Receiver height in feet amsl, and
H_2 = Transmitter height in feet amsl.

Nature of terrain. 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 5½° 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′ and the VOR situated at MSL.

Reception range (nm) = 1.25 x $\sqrt{25,000}$
= 198 nm
Separation = 396 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 100nm to about 500nm. 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 50nms of a VOR beacon, up to a height of 25,000'. 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.

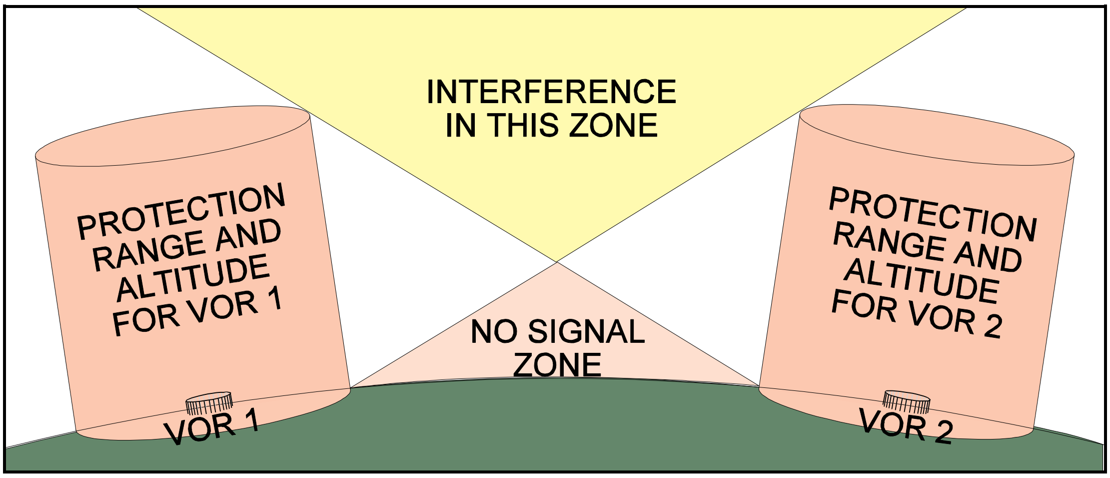


Figure 8.7 Designated Operational Coverage

VOR 1: DOC 50/25 = No interference within 50 NMS range up to 25,000'.

VOR 2: DOC 100/50 = No interference within 100 NMS range up to 50,000'.

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 radials to deviate from their standard track and is the 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 aggregate errors 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 stabilise.

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.

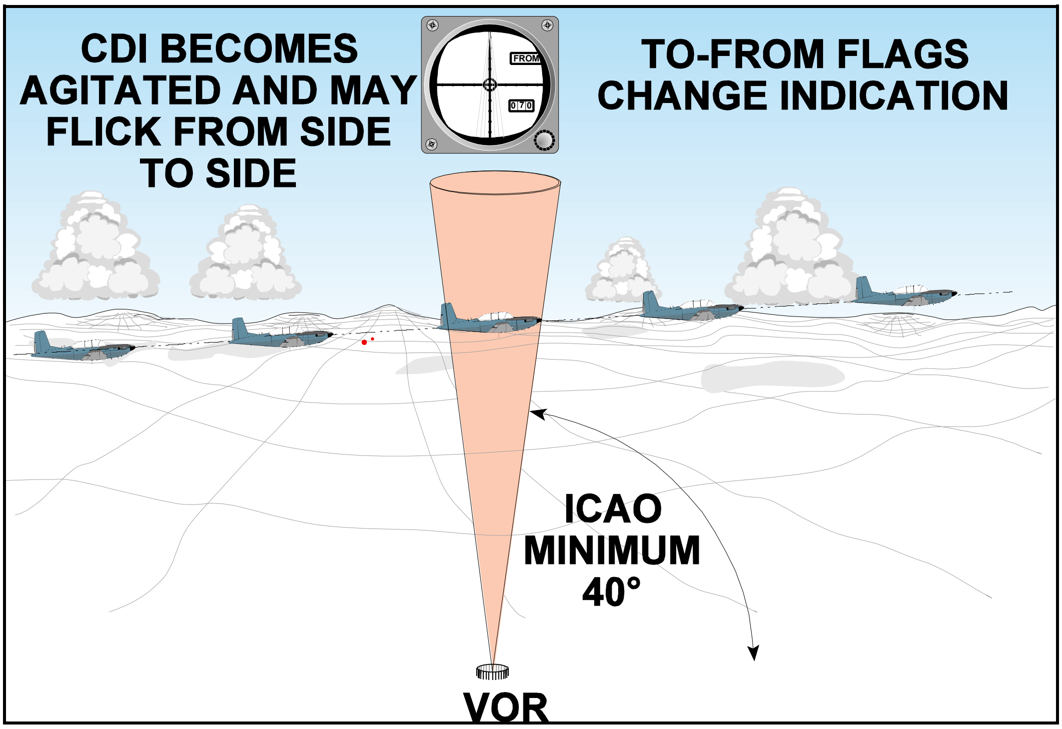


Figure 8.8 The Cone of Confusion

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:

- The 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.
- The receiver. This is a box fitted in the avionics bay.
- The 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 / ILS DEVIATION INDICATOR

As the name implies, this instrument displays VOR or ILS information, and is widely used in light aircraft. It may be known as a VOR/LOC indicator, particularly if it is a simplified version having a localiser needle but no glide path needle for use with ILS. The display is also known as the omni bearing indicator (OBI). In the VOR role, the instrument indicates the displacement of the aircraft with respect to a bearing (to or from the VOR station) which the pilot has selected on his Omni Bearing Selector (OBS). See Figure 8.9.

This displacement (or deviation) is presented by a Left / Right needle of the dual role (VOR/ ILS) indicator. Figure 8.10 shows that the displacement of the needle 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.

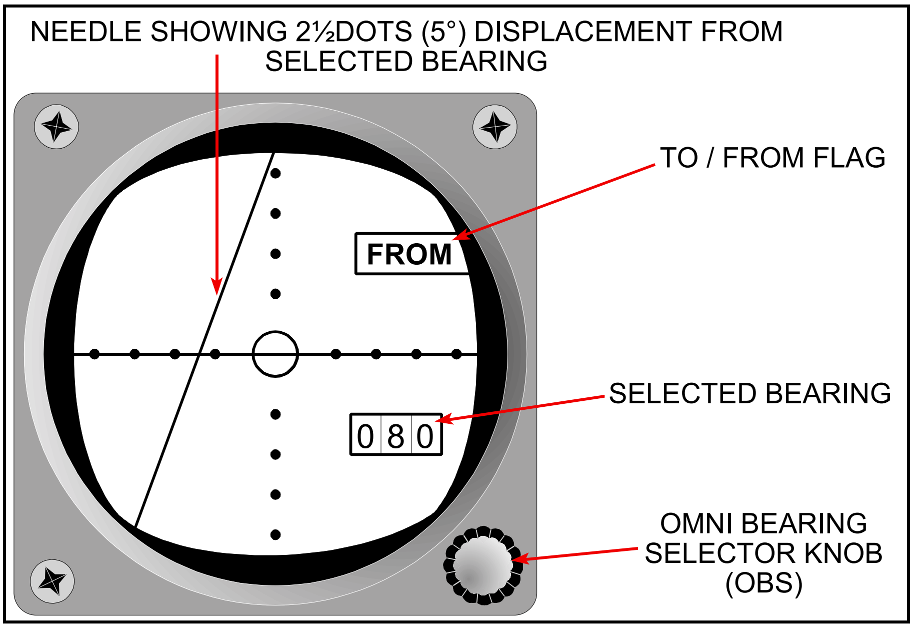


Figure 8.9 VOR / ILS Deviation Indicator

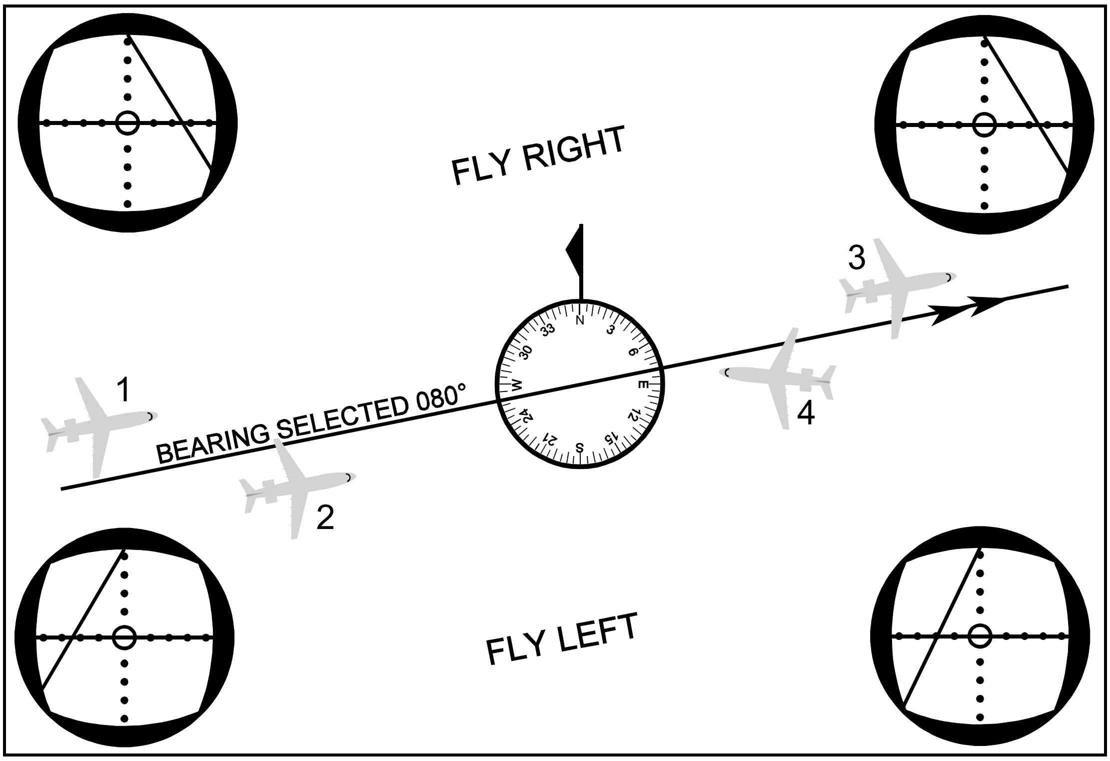


Figure 8.10 Left / Right Indications

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 needle would be central.

Aircraft at positions 2 and 4 both receive a Fly Left indication (needle 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 needle 'sense' is wrong for the aircraft at position 4, and this is generally undesirable. To keep the needle 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 (see Figure 8.9) the rule to be followed to keep the needle 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 Figure 8.9, the bearing of 080°, which the pilot has selected by turning the OBS knob, is showing in the OBS window and the To / From flag has automatically flicked to 'From'. These indications would be obtained by an aircraft in the region of position 4 in Figure 8.10, meaning that the aircraft (regardless of its heading) is displaced to the right of a magnetic track of 080° from the VOR station. However, for this aircraft the needle sense is wrong because its heading is near enough the reciprocal of the selected track of 080°. To put it another way, the aircraft is inbound but an outbound track has been selected on the OBS.

The indicator drawn in Figure 8.9 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°.

(It should be noted that when the instrument is being used in the ILS role, each dot represents only ½° displacement from the ILS localiser centre line i.e. full-scale deflection represents 2½°.)

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.

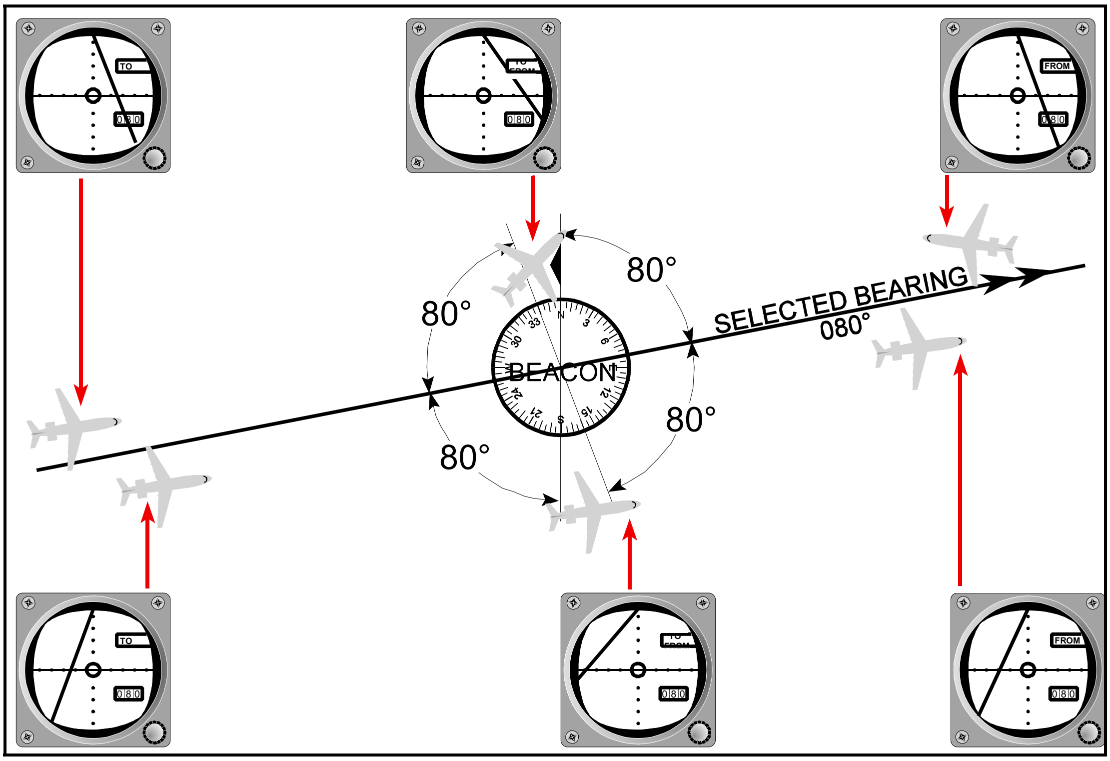


Figure 8.11 To / From Indications

Figure 8.11 depicts the deviation indicator in the various sectors about the VOR beacon. It should be remembered that the six indications in Fig 5.11 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 in a slot in the face of the indicator close to the Left / Right needle.

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, centralised, 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°W 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.

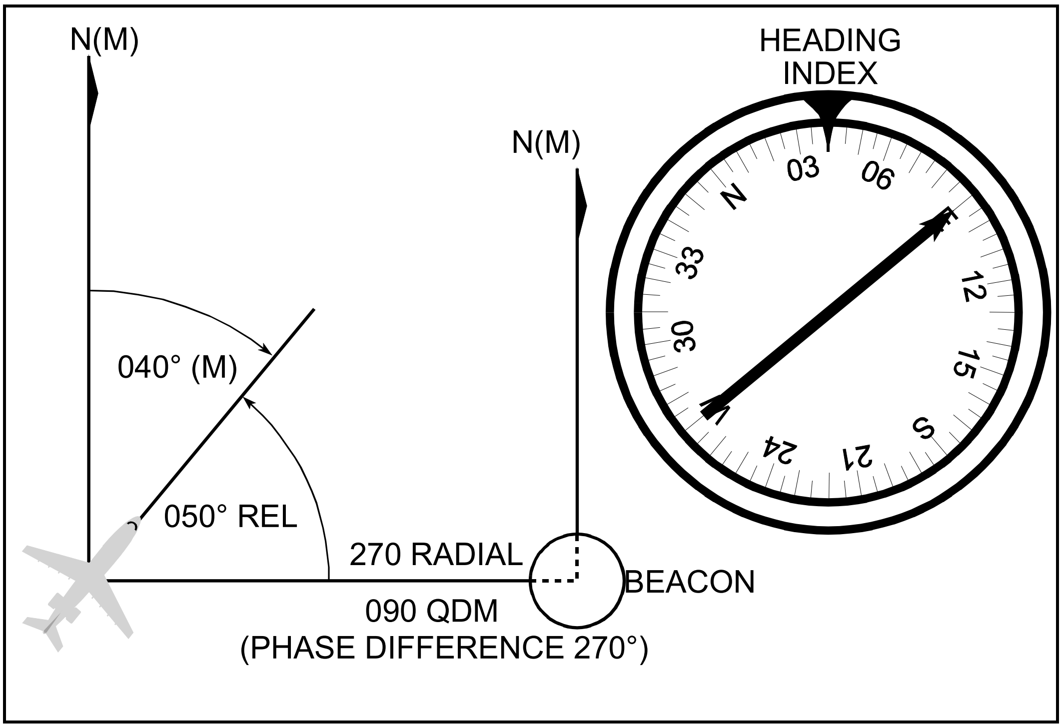


Figure 8.12 VOR QDM on the RMI

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.

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 RMI's, 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.

IN-FLIGHT PROCEDURES

Typical uses of VOR by an aircraft equipped with both OBI-type deviation indicator and an RMI are illustrated in Figure 8.13.

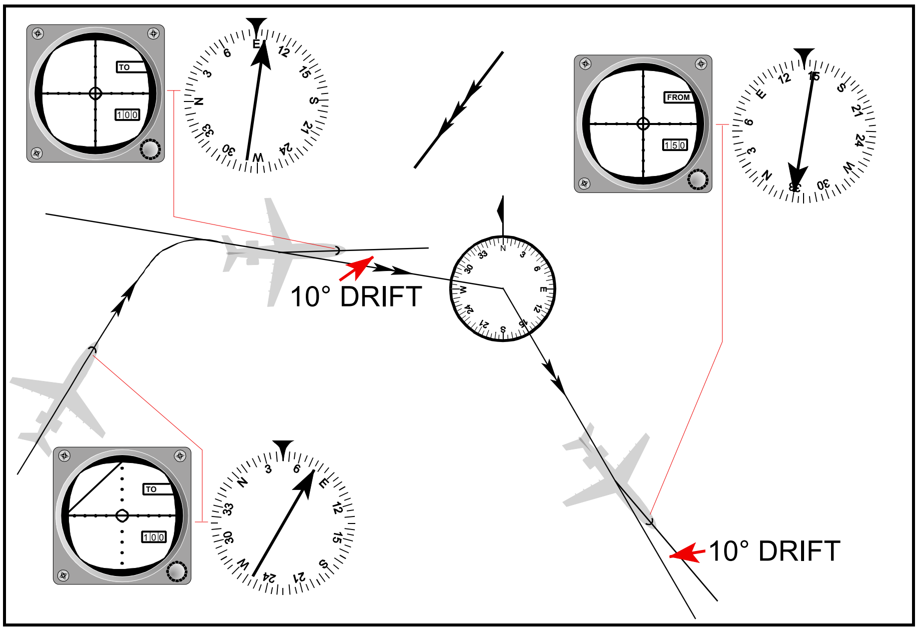


Figure 8.13 In-Flight Procedures

Radial Interceptions
In Figure 8.13. 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.

He intends to turn on to a heading of 090°(M) allowing 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 1½ 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 8.13. 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 visualising 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 feet.

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 8.13. The indications are ideal, the TO/FROM flag showing 'FROM', and the centralised 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

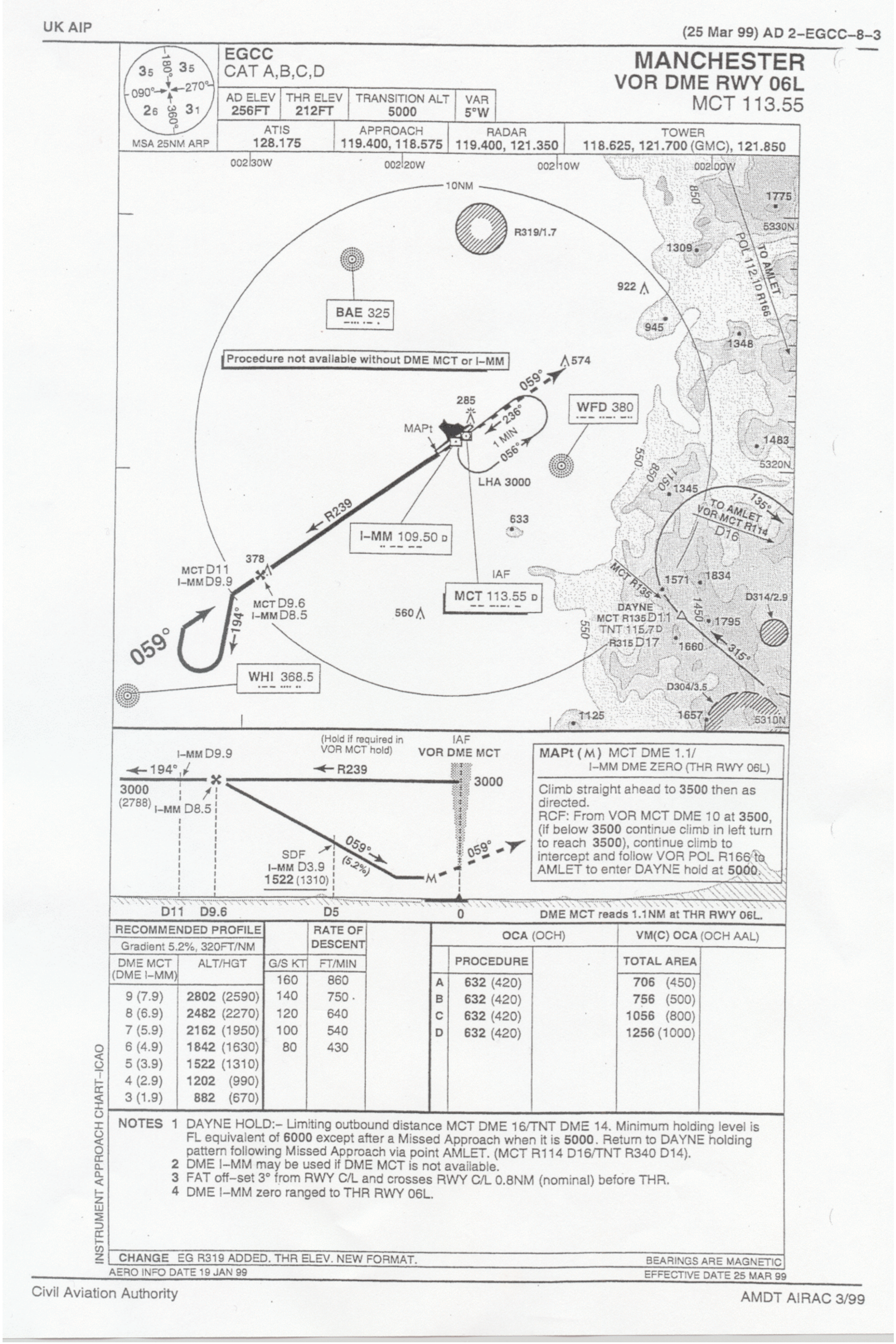


Figure 8.14 Example of a VOR DME Approach Pattern

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

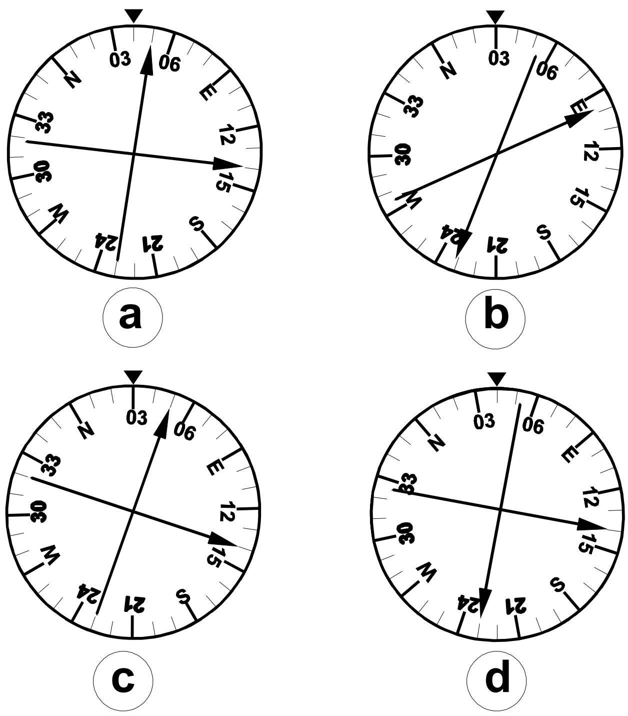
1. Assuming the maximum likely error in VOR to be 5.5°, what is the maximum distance apart that beacons can be situated on the centre line of a UK airway in order that an aircraft can guarantee remaining within the airway boundary?

   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 Air Pilot:

   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 feet above mean sea level?

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

5. A Conventional VOR:

   a. has an FM reference signal and an AM variable signal
   b. has a 150Hz reference signal and a 90Hz 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 nms 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 feet 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. In a Doppler VOR (DVOR) the reference signal is _________, the bearing signal is _________ and the direction of rotation of the bearing signal is _________:

   a. AM, FM, anti-clockwise.
   b. AM, FM, clockwise.
   c. FM, AM, anti-clockwise.
   d. FM, AM, clockwise.

11. 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.

12. 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.

13. What is the approximate maximum range that an aircraft flying at 25000′ would expect to obtain from a VOR beacon situated 900′ above mean sea level?

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

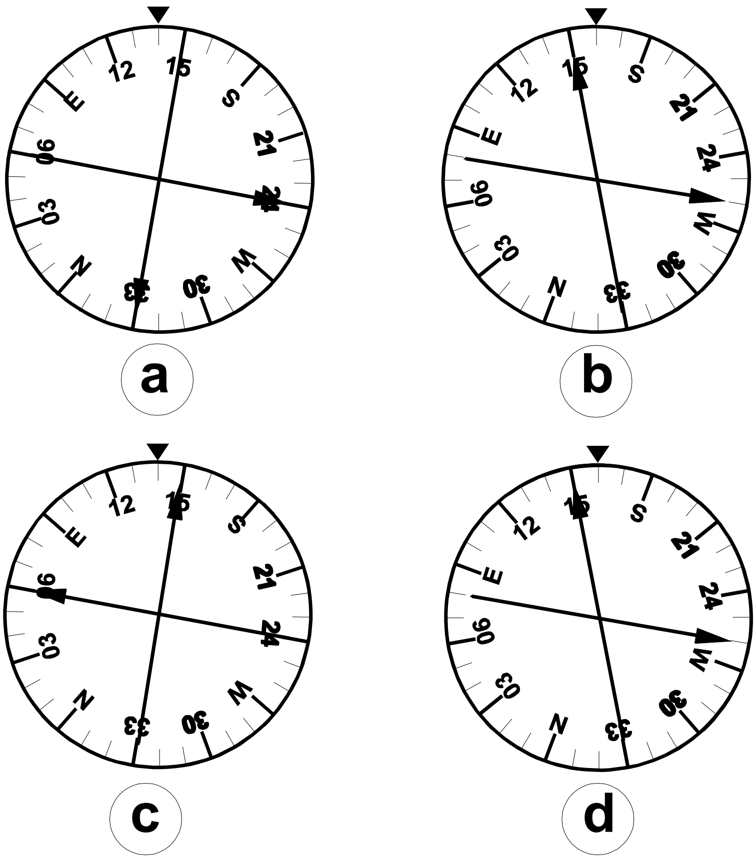
14. An aircraft is on the airway boundary range 100 nm from a VOR marking the airway centre line. Assuming that each dot equates to 2° how many dots deviation will be shown on the deviation indicator?

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

15. 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.

16. 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?



17. 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. 60nm
b. 100nm
c. 120nm
d. 150nm

18. 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

19. 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.

20. 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

21. 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°

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

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

23. 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.

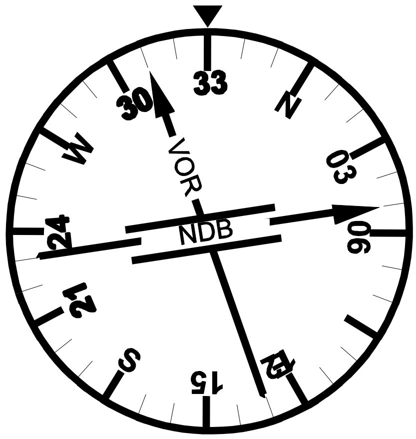
24. A VOR receiver in an aircraft measures the phase difference from a DVOR as 220°. Which radial is the aircraft on?

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

25. 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:

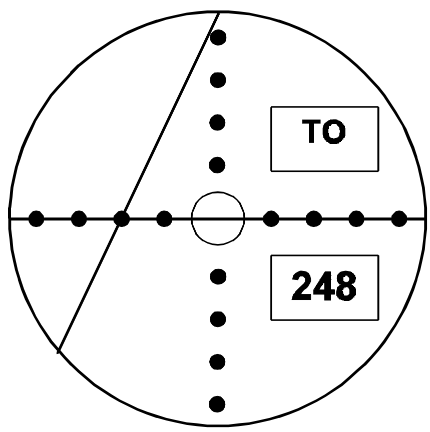
	NDB	VOR
a.	beacon position	aircraft position
b.	beacon position	beacon position
c.	aircraft position	beacon position
d.	aircraft position	aircraft position

26. 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.

27. 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 below. At the same time the DME gave a range of 90nm from the facility. At the time of the observation, the aircraft's radial and distance from the airway centre-line were:

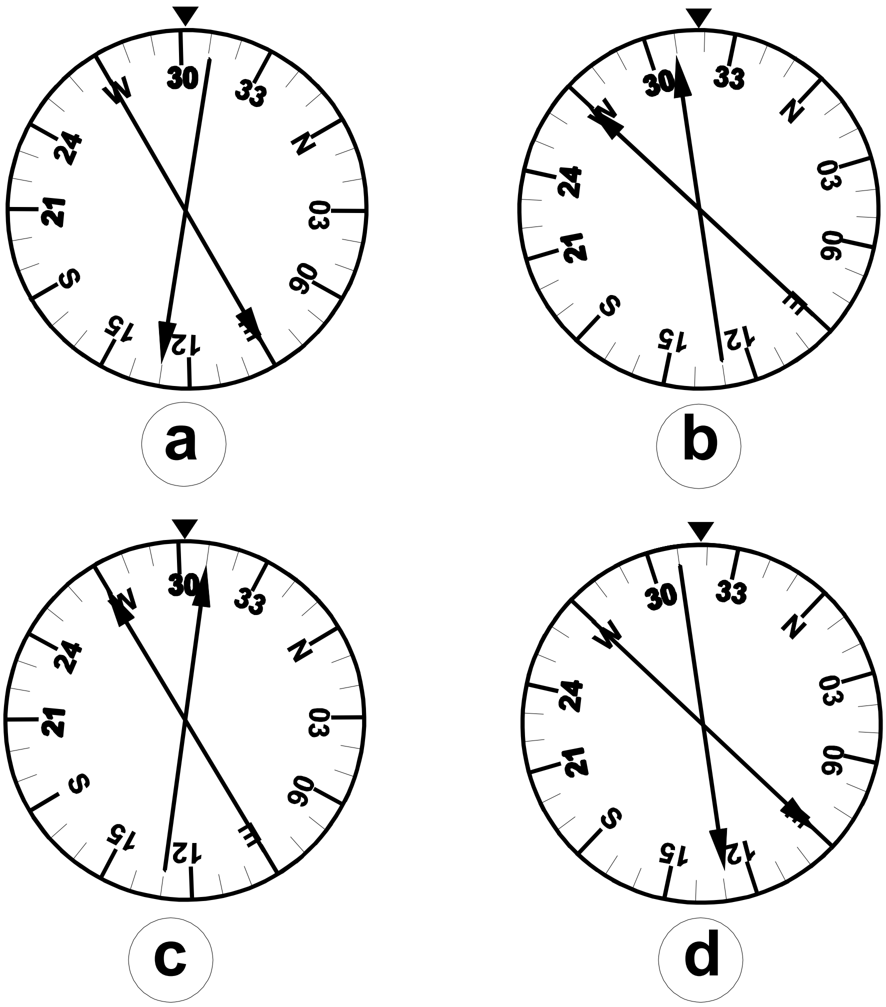


a.	062 radial	9 nm
b.	074 radial	6 nm
c.	242 radial	6 nm
d.	254 radial	9 nm

28. 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°

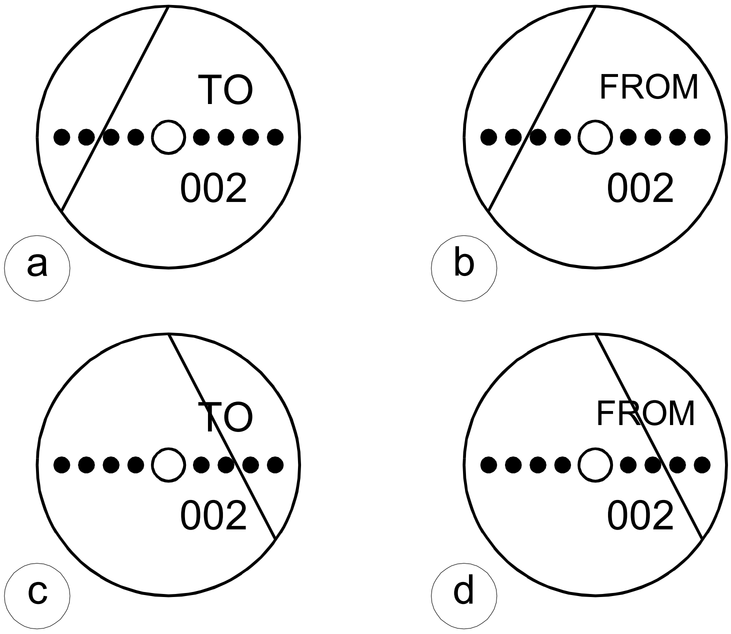
29. An aircraft is tracking away from VOR "A" on the 310° radial with 8° starboard drift; NDB "X" is north of "A". Which diagram below illustrates the RMI when the aircraft is on its present track with a QDR from "X" of 270°?



30. 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.

31. 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°)



ANSWERS

1	B	11	C	21	C	31	A
2	C	12	B	22	C		
3	D	13	C	23	A		
4	A	14	D	24	D		
5	A	15	B	25	C		
6	A	16	A	26	D		
7	D	17	C	27	A		
8	C	18	C	28	C		
9	A	19	B	29	A		
10	A	20	C	30	A		

CHAPTER NINE

INSTRUMENT LANDING SYSTEM (ILS)

Contents

INTRODUCTION

The Instrument Landing System (ILS) has been in existence for over 40 years but it is today still the most accurate approach and landing aid that is used regularly by the airliners. 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 glidepath and extended runway centre-line (localiser) 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.

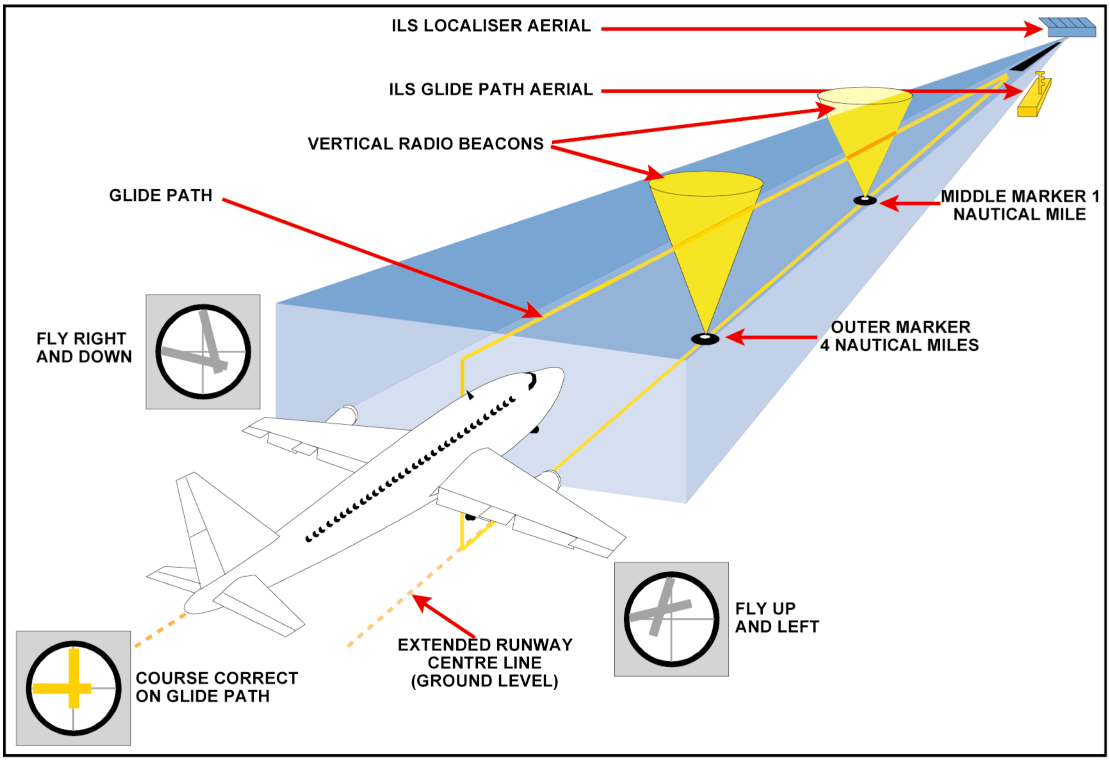


Figure 9.1 The Instrument Landing System (ILS)

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 localiser, glide path and marker beacons; in some installations a back course may also be available.

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

The glide path (GP) transmitter operates in the UHF band, and is frequency paired with the localiser. It is located 300m in from the threshold and about 200m 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 localiser 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

Localiser. The Localiser operates in the VHF band between 108 and 111.975MHz 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 ILS frequencies have an odd number in the first decimal digit.

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

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 localiser and selection of the frequency is automatic. The Localiser and Glide Path transmissions are frequency paired in accordance with the list published at ICAO e.g. 108.1MHz is paired with 334.7MHz. and 111.95MHz is paired with 330.95MHZ. 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 localiser service area up to 25,000 feet. 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 localiser and glidepath transmissions as the localiser and glidepath frequencies are paired. The selection of the localiser VHF frequency automatically energises the glide path receiver circuits.

The Ident on the localiser 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 localiser 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 localiser, it should have an identification signal that is clearly distinguishable from the front course markers.

The radiation patterns for ILS marker beacons is vertical and appears lens shaped or bone shaped in plan view. Figures 9.2a and 9.2b 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.

FAN MARKERS

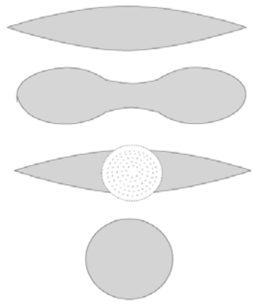


Figure 9.2a Marker Beacon Radiation Patterns

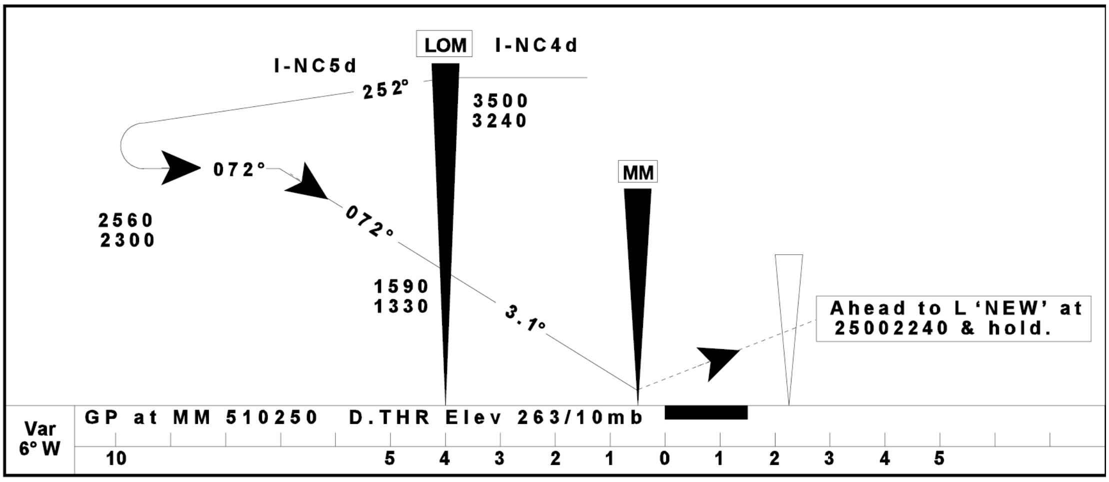


Figure 9.2b The Outer Marker and the Middle Marker.

	Cockpit Light	Ident	Modulating Frequency	Pitch	Touchdown Range
OM	**BLUE**	2 dashes/sec	400 Hz	**Low**	6.5 – 11.1 km (3.5 – 6nm)
MM	**AMBER**	Alternate dots and dashes 3/sec	1,300 Hz	**Medium**	1050m ± 150m (3,500' ± 500')
IM	**WHITE**	6 dots/sec	3,000 Hz	**High**	75 - 450m (250' – 1,500')

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

- the localiser at the reference datum shifts from the runway centre-line by more than 35' for Cat I, 25' for cat II or 20' for cat III;
- the Glide path angle changes more than 0.075 x 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 stand-by 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

Localiser. The localiser coverage sector extends from the transmitter to distances of:

- 25 nm (46.3km) within plus or minus 10° from the centre-line;
- 17 nm (31.5km) between 10° and 35° from the centre-line;
- 10 nm (18.5km) 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 (18.5km) in sectors of 8° in azimuth on each side of the centre-line.

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

ILS coverage is illustrated in Figures 6.3a, 6.3b and 6.3c.

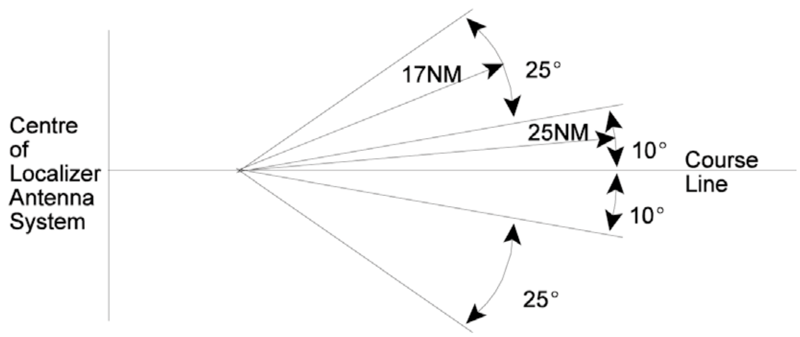
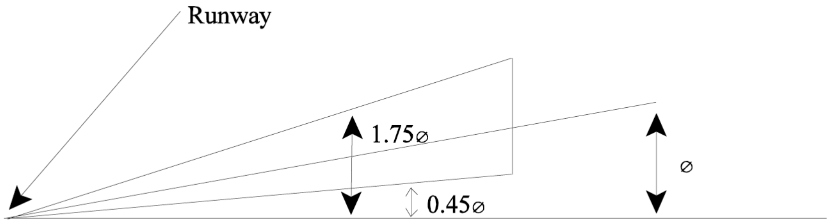


Figure 9.3a Localiser Coverage



(Or to such lower angle, down to 0.30⌀, as required to safeguard the promulgated Glide Path Procedure).

Figure 9.3c   Glide Path Vertical Coverage

ILS PRINCIPLE OF OPERATION

The Localiser

The localiser antenna produces two overlapping lobes along the runway approach direction (QDM) as shown in Figure 9.4. 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 150Hz modulation
- the left hand lobe (the yellow sector) has a 90Hz modulation

The depth of modulation 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 energises 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 90Hz 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 localiser 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 glidepath indications are incorrect (they would, if used guide the aircraft to the wrong end of the runway.
- The CDI needle (localiser) is sense reversed. (Flying to R/W).
- There are no range-check markers.

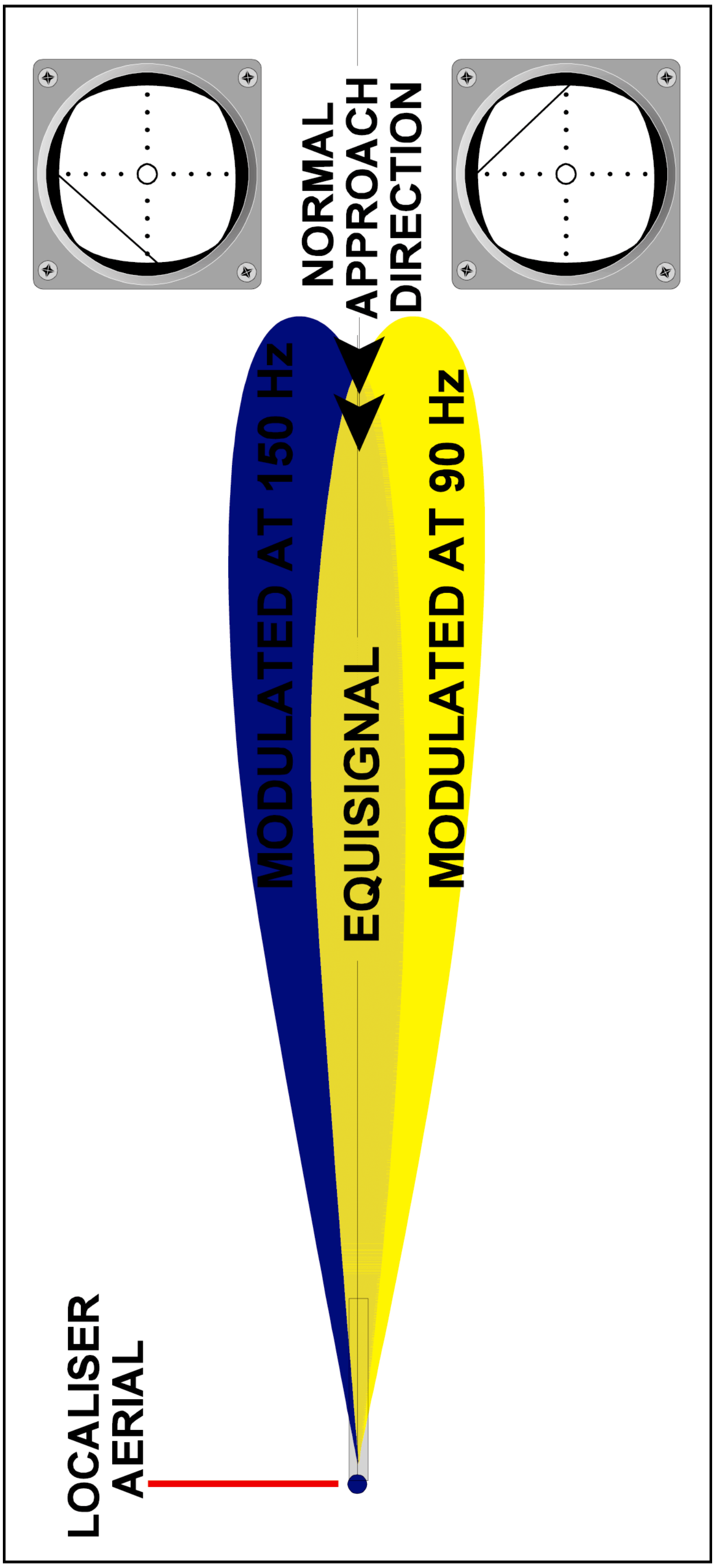


Figure 9.4 Localiser Radiation Pattern

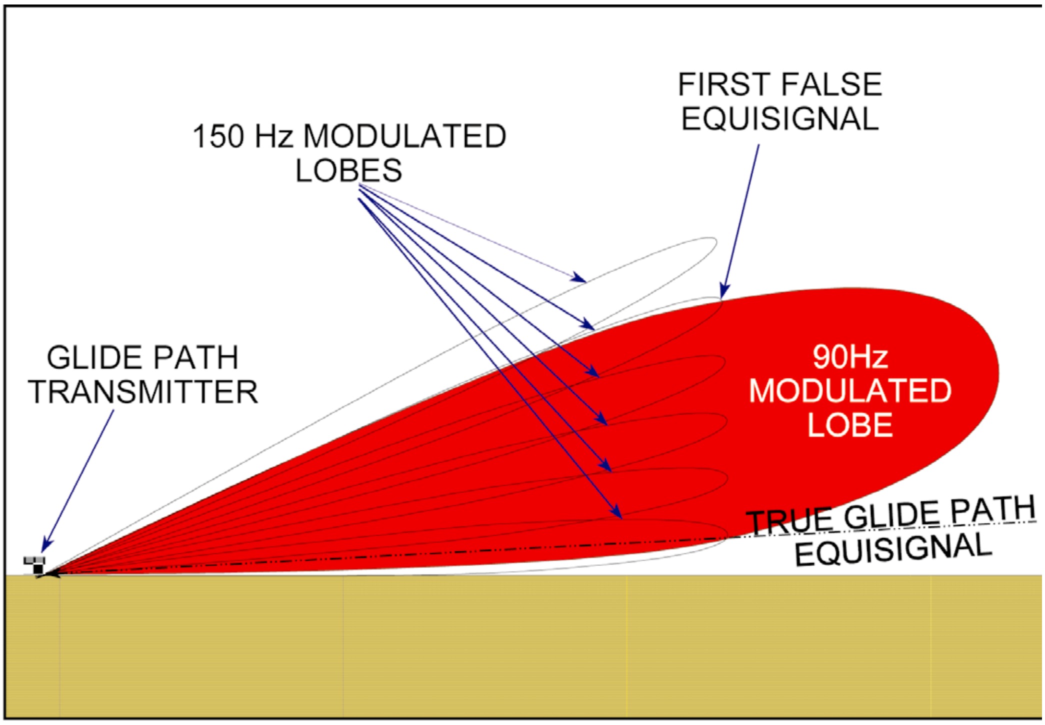


Figure 9.5 Glide Path Radiation Pattern.

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

The same principle is used as for the localiser, but a UHF carrier wave is used and the lobes are in the vertical plane. The upper lobe (large lobe) has a 90Hz 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 9.5.

False Glideslope(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 glideslope occurs at approximately twice the glide path angle, 6° above ground for a standard 3° glide path. False glideslopes always occur above the true glideslope and should not constitute a danger but pilots should be aware of their presence.

Normal flying practice is to establish on the localiser and intercept the glideslope 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 glideslope 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 glidepath 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. Localiser 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 9.6. The HSI display is shown at Figure 9.7. 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.

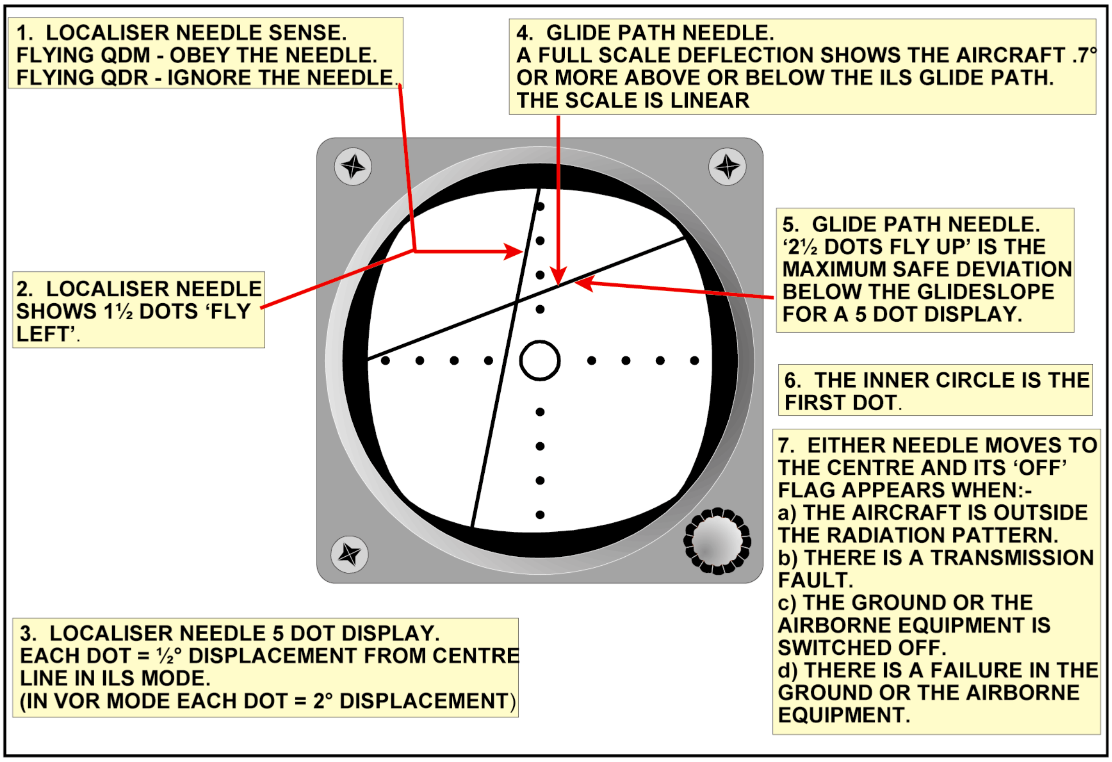


Figure 9.6 ILS Course Deviation Indicator

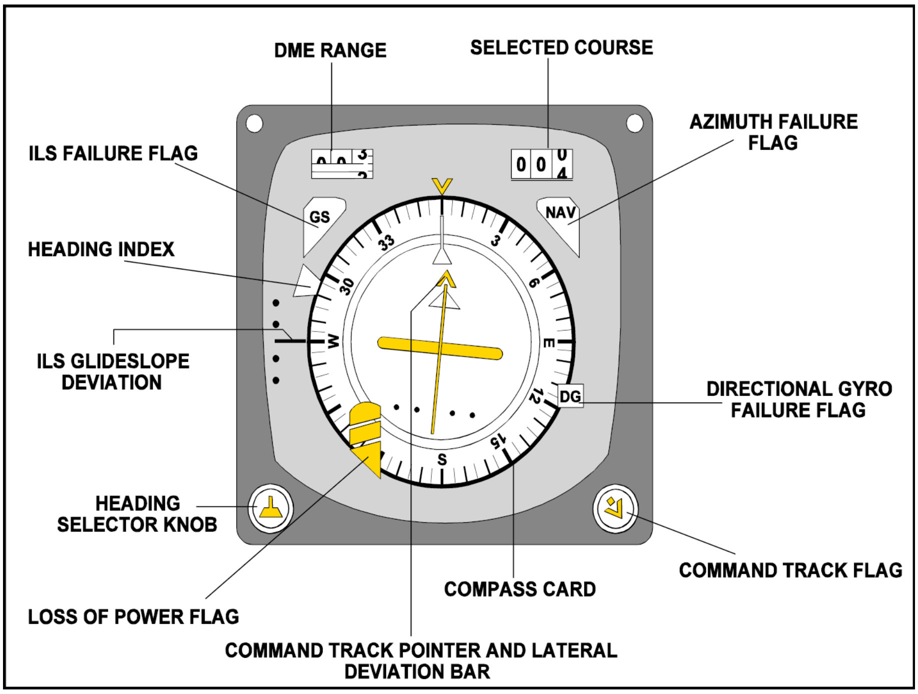


Figure 9.7 A Typical HSI

Localiser Indications
Front course approach indications for fly left and right are shown in Figure 6.7. 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 localiser 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.

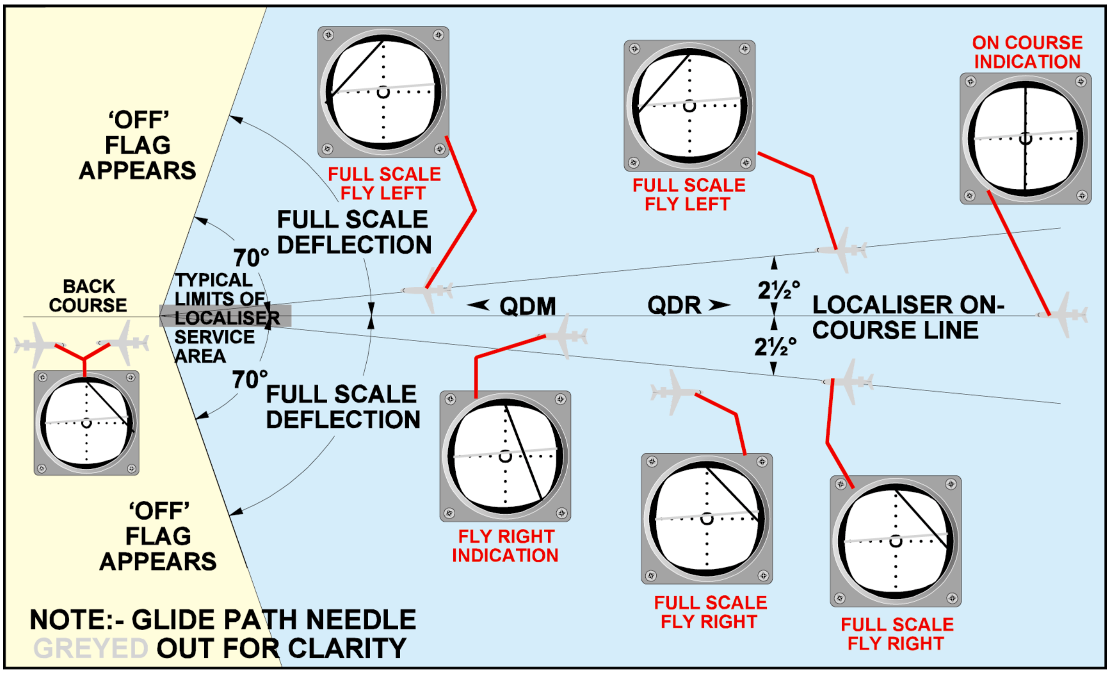


Figure 9.8 Localiser

Glide Path Indications

The glide path indication for fly up or fly down is shown in ?Figure 9.9. Full scaledeflection 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.

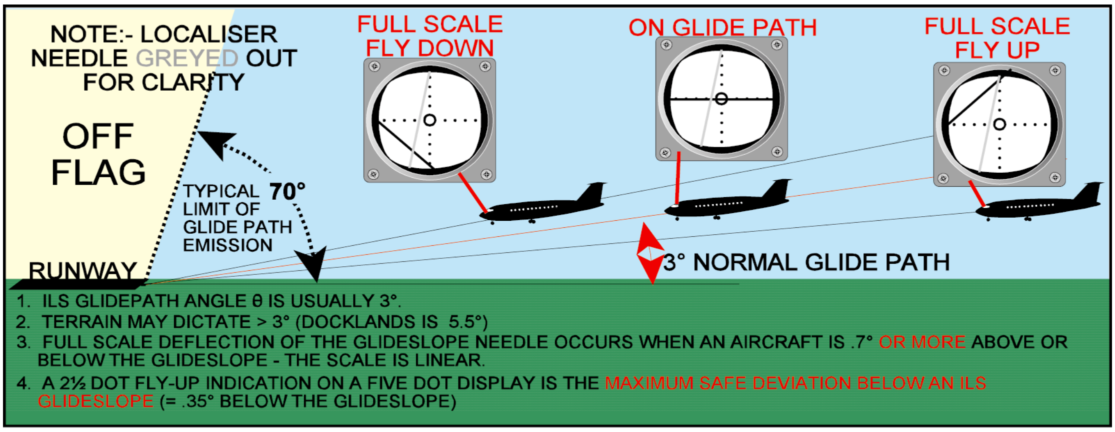


Figure 9.9 Glide Path

ILS CATEGORIES

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 localiser course line intersects the ILS glidepath 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 localiser course line intersects the ILS g/path at a height of 50ft (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 1 An Instrument Approach and landing with :

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

Category 2 A precision Instrument Approach and landing with

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

Category 3A A precision instrument approach and landing with:

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

Category 3B A precision instrument approach and landing with:

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

Category 3C No DH and no RVR limitations.

The acceptance of Category 2 or 3 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/HIS 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 minimise 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 localiser 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
Multi-path 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 localiser and glide path antennas 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.

ILS APPROACH CHART

An Instrument Approach Chart for an ILS Approach is shown in Figure 9.10. 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.

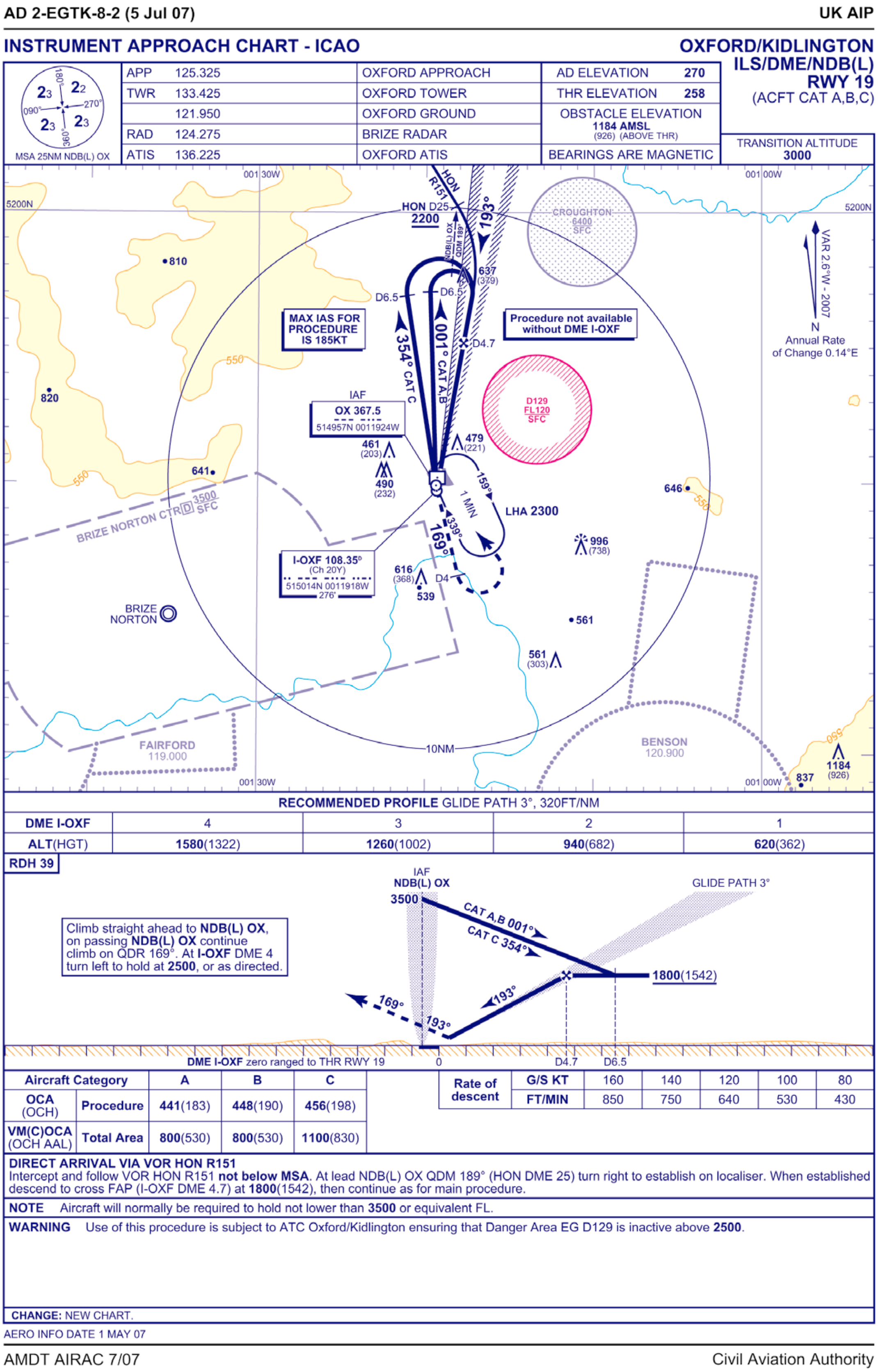


Figure 9.10 ILS Approach to Runway 27 at East Midlands Airport

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 glidepath. These can be simply achieved by using the 1:60 rule.

Example: An aircraft is at 4 nm from touchdown flying a 3° glidepath 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:

$$Height = \frac{Glidepath\ Angle\ \ x\ \ Range}{60}\ \ x\ \ 6076\ ft$$

This can be simplified to:

$$Height = Glidepath\ Angle\ \ x\ \ Range\ \ x\ \ 100$$

This gives: **Height = 3 x 4 x 100 = 1200 ft**

The trigonometric solution, using accurate values gives a height of 1274 feet, 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° glidepath:

$$ROD = \frac{Glidepath\ Angle\ \ x\ \ 1}{60}\ \ x\ \ 6076\ \ x\ \ \frac{Groundspeed}{60}\quad \text{feet per minute}$$

$$= 3\ \ x\ \ 100\ \ x\ \ \frac{Groundspeed}{60}\quad \text{feet per minute}$$

$$= 5\ \ x\ \ Groundspeed\quad \text{feet per minute}$$

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° glidepath. For any other glidepath angle, calculate for a 3° glidepath then divide by 3 and multiply by the glidepath angle (or calculate on your Navigation Computer).

ILS SUMMARY

Components and frequencies:

Localiser	VHF - 108 to 111.975 MHz (40 channels). Aerial at upwind end.
Glide path	UHF - frequency paired. Aerial abeam touchdown.
Markers	VHF - 75 MHz. Fan shaped vertical radiation. OM, MM and IM.
Back beam	From localiser. Non-precision approach.
Locator	Low power NDB at OM.
DME	Freq paired. Possibly in place of markers. Zero-referenced to threshold.
Ident:	2 or 3 letters, 7 groups/min. Suppressed when ILS u/s. Continuous tone during maintenance

Markers

OM:	blue	2 dashes/s	400 Hz	6.5 - 11.1 km
MM	orange	3 characters per second, alternate dots and dashes 1300 Hz		1050m
IM	white	6 dots/s	3000 Hz	75 - 450m

Ground monitoring
Localiser within 35′ (Cat I) at ref datum. GP within 0.075 ϕ.
Power within 50%
Otherwise: Cease radiation, remove ident or lower category

ILS Coverage
LLZ: 25nm ± 10°, 17nm ±35°
GP: 10nm ± 8°, 0.45 to 1.75 x glidepath angle.

Principle of Operation:

Localiser	LH lobe - 90 Hz, RH lobe -150 Hz; DoM increases away from c/l DDM is zero on c/l
Back course	If approved use for non-precision approach. Reverse readings on CDI. HSI can operate in correct sense if front course QDM set
Glide path	Upper lobe - 90 Hz, lower lobe - 150 Hz. DoM increases away from ϕ DDM is zero on ϕ
False GP	at multiples of glidepath angle. Be aware.
Ref datum	height of GP over threshold
PAPIs	same angle as ϕ but meht is higher than ref datum

Indicators
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°)

ILS Categories:

		I	II	III/IIIA	IIIB	IIIC
Ground:		< 200′	< 50′	0′		
Operational:	DH	200′	100′	< 100′ (if any)	< 50′ (if any)	0
	RVR	550m	300m	200m	75m	0

Errors: beam bends, scalloping, beam noise;
restricted vehicle movements during low vis ops;
check failure flags;
monitor ident

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 localiser 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°glidepath 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 synchronised blue light.
   b. continuous high pitched dots with synchronised amber light.
   c. alternating medium pitch dots and dashes with amber light.
   d. one letter in Morse with synchronised 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 centreline and on the glidepath are to fly:

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

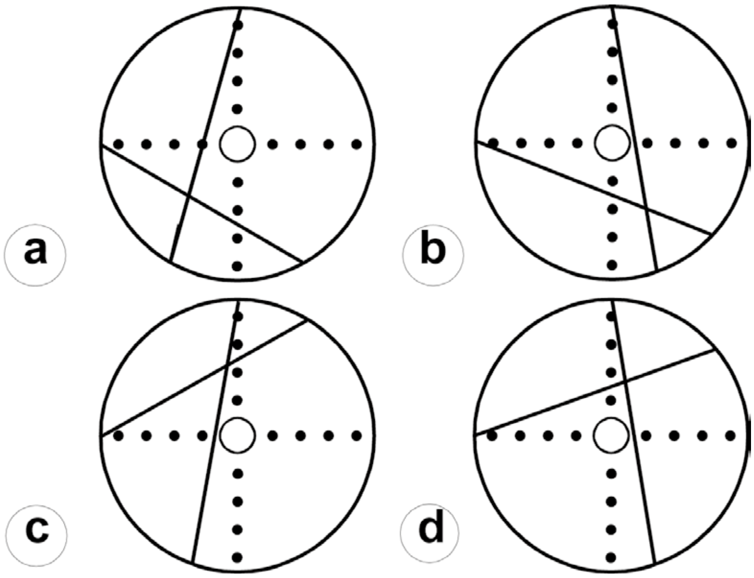
6. In elevation the upper and lower limits of an ILS glide path transmitter having a 3.0 degree glide slope are:

   a. 0.35° 0.70°
   b. 3.000 at least 6°
   c. 5.25° 1.35°
   d. 10.0° 35.0°

7. A category 2 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 ?



9. An aircraft tracking to intercept the ILS localiser 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 glideslope needle the captain may be receiving false course and reverse sense indications and from the localiser 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 localiser needle the captain may be receiving false course and intermittent indications and from the glideslope needle reverse sense and incorrect indications.
d. From the localiser needle the captain may be receiving false course and reverse sense indications and from the glideslope needle intermittent and incorrect indications.

13. The coverage of the ILS glideslope in azimuth is:

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

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

a. north of the localiser and below the glideslope.
b. south of the localiser and above the glideslope.
c. north of the localiser and above the glideslope.
d. south of the localiser and below the glideslope.

ANSWERS

1	C
2	A
3	A
4	C
5	B
6	C
7	A
8	D
9	A
10	D
11	B
12	D
13	A
14	B

CHAPTER TEN

MICROWAVE LANDING SYSTEM (MLS)

Contents

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 glideslope 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 minimise interference with the localiser and glideslope beams.
- Vehicles, taxying aircraft, low-flying aircraft and buildings have to be kept well away from the transmission sites to minimise localiser and glideslope 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 glideslopes from .9° to 20° can be selected. The usable range is 20-30 nm from the MLS site; 20nm 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 MHZ. This enables it to be sited in hilly areas without having to level the site. Course deviation errors (bending) of the localiser and glidepath 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 utilisation and be beneficial to helicopters and STOL aircraft.
- The MLS has a built-in DME.
- MLS is compatible with conventional localiser and glidepath 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 localiser and glideslope 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.

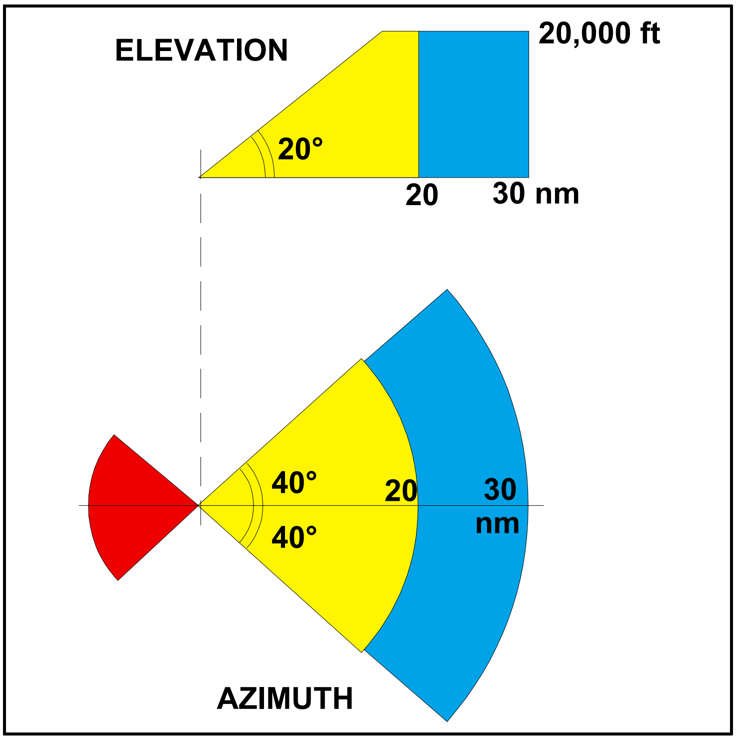


Figure 10.1 MLS Coverage

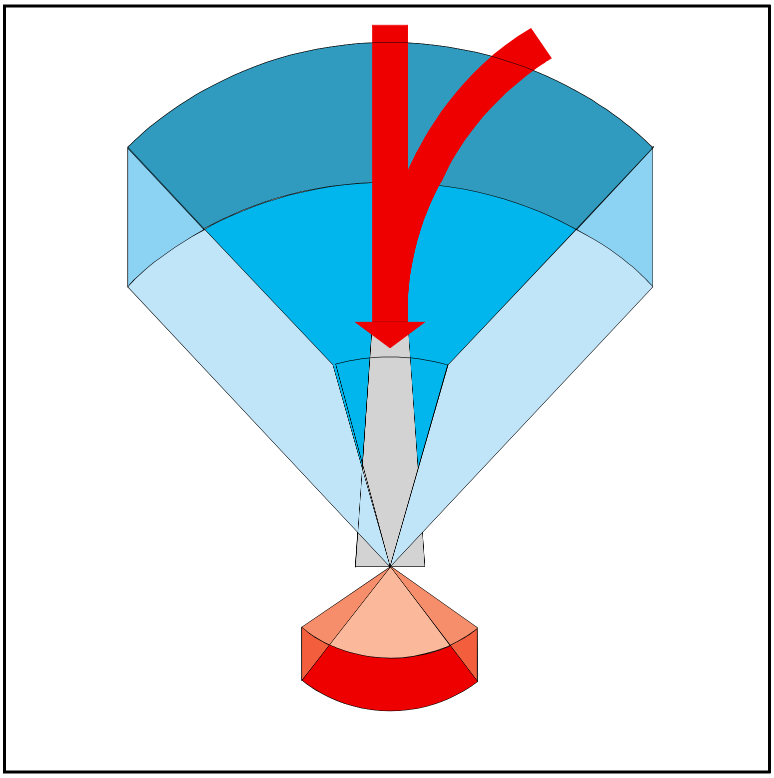


Figure 10.2 Approach Coverage Volume

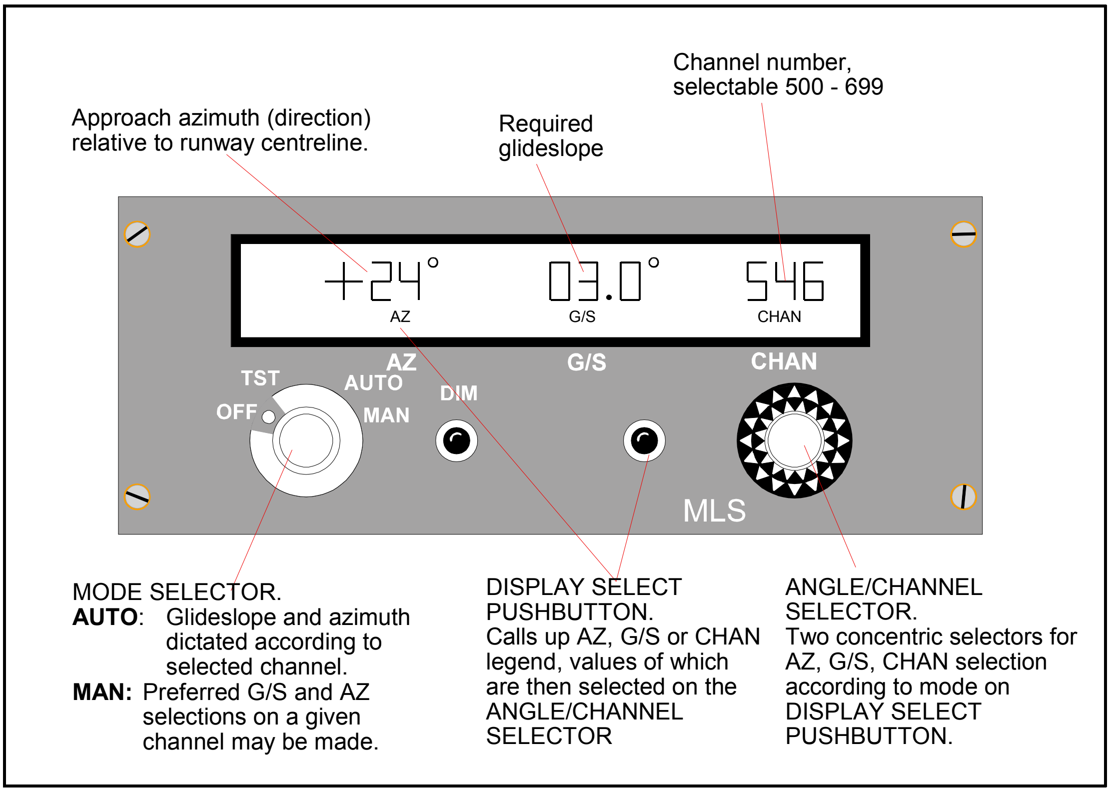


Figure 10.3 Typical MLS Flight Deck Control Panel

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 synchronised to assure interference free operations on the common radio frequency.

- **Azimuth location.** Time referenced scanning beam (TRSB) is utilised 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 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).

- **Glideslope location.** Another beam scans up and down at a uniform speed within its elevation limits. The aircraft's position in relation to its selected glideslope 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 overshoot 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 auxillary data. This consists of:

    > station identification
    > system condition
    > runway condition
    > weather information

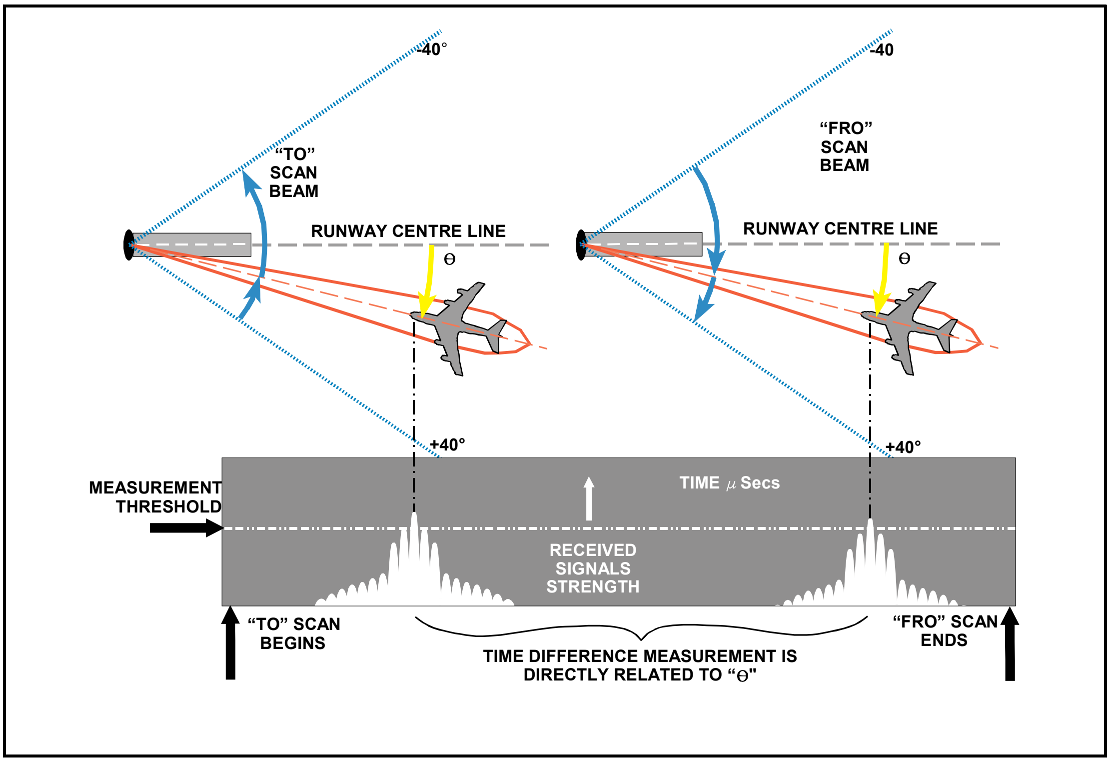

-40°
"TO"
SCAN
BEAM
RUNWAY CENTRE LINE
Θ
-40
"FRO"
SCAN
BEAM
RUNWAY CENTRE LINE
Θ
+40°
+40°
MEASUREMENT
THRESHOLD
TIME μ Secs
RECEIVED
SIGNALS
STRENGTH
"TO" SCAN
BEGINS
TIME DIFFERENCE MEASUREMENT IS
DIRECTLY RELATED TO "Θ"
"FRO" SCAN
ENDS

Figure 10.4

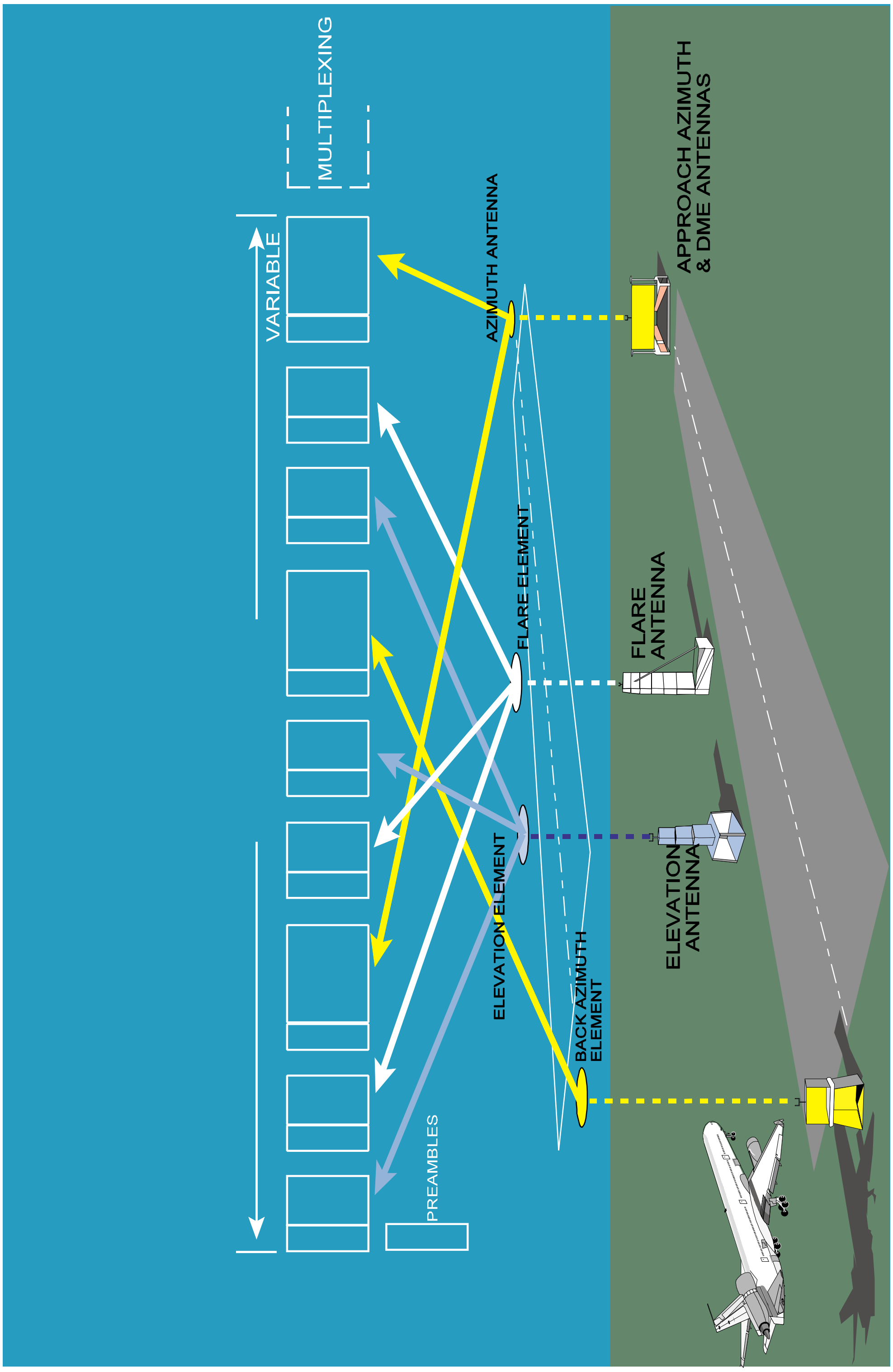


Figure 10.5 TRSB Component Site

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.

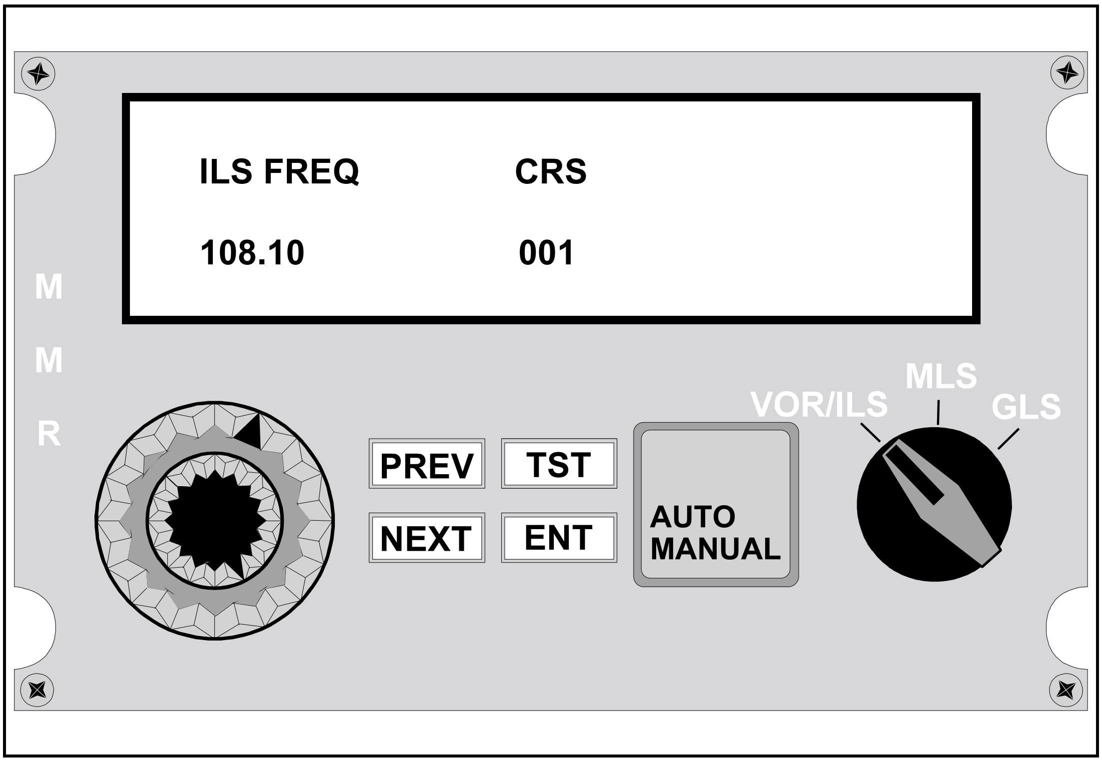


Figure 10.6 MMR Control Panel

QUESTION

1. The coverage of the Micro-wave Landing System in the UK extends to ______nm up to a height of ______and ______degrees either side of the on course line.

a) 20nm; 20,000ft; 40 degrees.
b) 35nm; 5,000ft; 40 degrees.
c) 35nm; 5,000ft; 20 degrees.
d) 17nm; 2,000ft; 35 degrees.

ANSWER

1	A

CHAPTER ELEVEN

RADAR PRINCIPLES

Contents

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** 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.

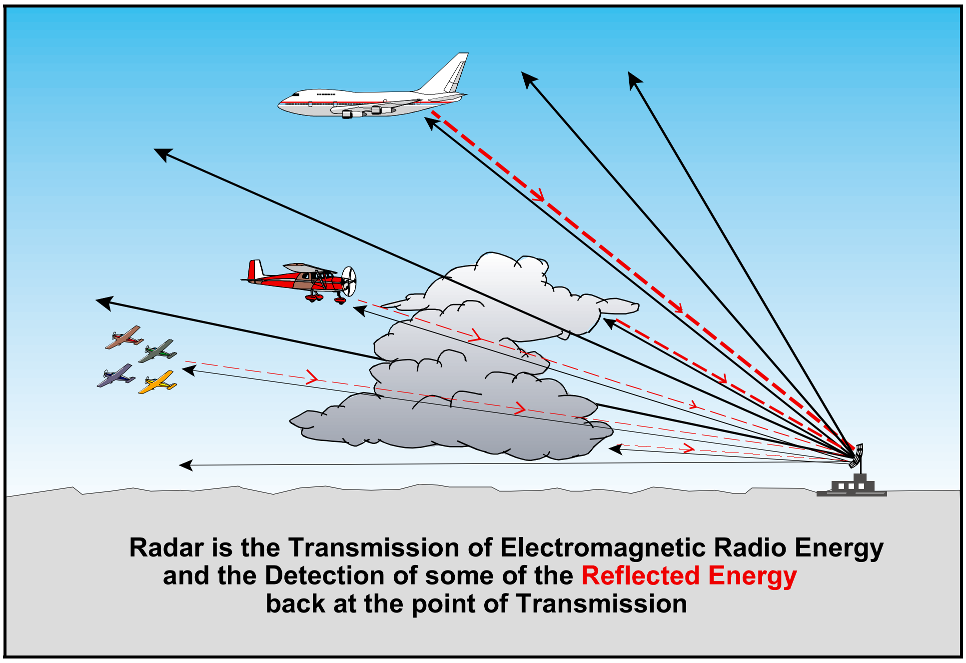


Figure 11.1

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 utilising **an interrogator** and **transponder;** the transponder can be located in the aircraft or on the ground.

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 callsign, 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.
- **Doppler Radar**. This is a self-contained airborne system, needing no ground based equipment, which provides a pilot with a continuous indication of the aircraft's drift and groundspeed.

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, secondary, and Doppler 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 pre-determined 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.

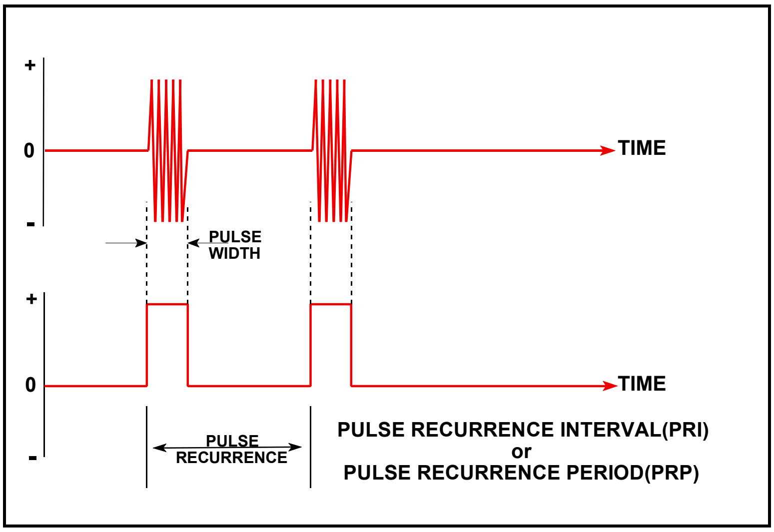


Figure 11.2 Pulse Technique

Pulse Recurrence Interval (PRI) is the **time interval** between two pulses. It is also known as the **Pulse Recurrence Period (PRP)**

Pulse Recurrence Frequency (PRF) is the number of pulses transmitted in one second **(PPS).** It is also known as the **Pulse Recurrence Rate (PRR).**

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

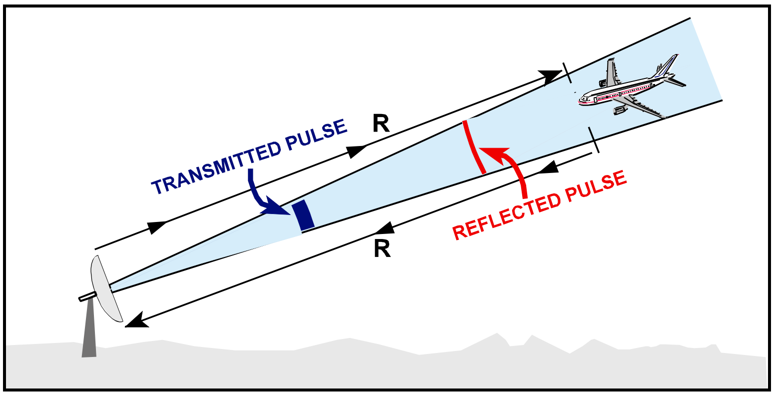


Figure 11.3

The distance to an object is found by timing the interval between 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 500μs then:

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

$$= 75{,}000 \text{ m} = 75 \text{ km}$$

or

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

$$= 40.5 \text{ nm}$$

c = 300,000,000 m/sec or 162,000 nm/s)

Other methods of calculating the range are:

- $\text{Range} = \frac{500 \times 300}{2} = 75\text{km}.$ $\text{Range} = \frac{500 \times 300}{2 \times 1852} = 40.5 \text{ nm}$

- A radar mile (one nm out and back) = 12.34 μs.

$$\text{Range} = \frac{500}{12.36} = 40.5 \text{ nm}$$

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 x 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 1,246 μs after the first.

   PRF (pps) = 1/ PRI = 1/ 1,246 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 energised 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

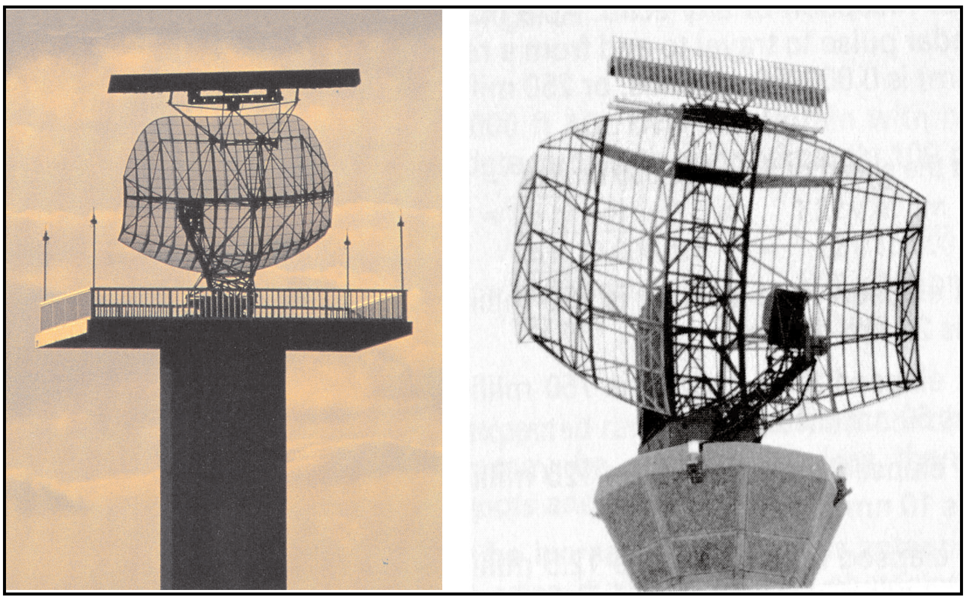


Figure 11.5 Typical Radar Antennae

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 polarisation 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) = 1.25 x ($\sqrt{H_{TX}} + \sqrt{H_{RX}}$)

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

- **Wavelength and Attenuation by Raindrops**

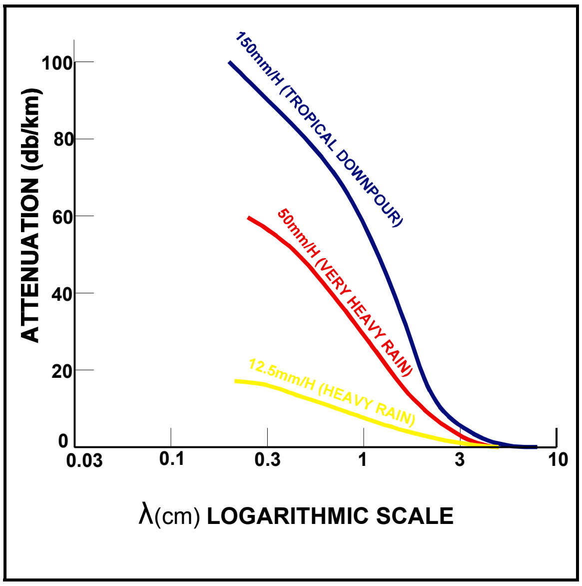


Figure 11.6 Attenuation by Raindrops

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 10cm the attenuation is negligible. If the wavelength is between 10cm and 4cm the attenuation is significant only in tropical rain. However, with wavelengths less than 4cm, attenuation is significant in rain in the temperate latitudes. One conclusion is that wavelengths less than 3cm should not be used for long range systems. Airfield Surface Movement Indicator **(ASMI)** radars operate at **1.75 to 2cm** wavelengths. Airborne Weather Radars **(AWR)** and Precision Approach Radars (**PAR)** use **3cm** wavelengths. **Surveillance radars** (ground) use **10, 23 or 50cm** 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.

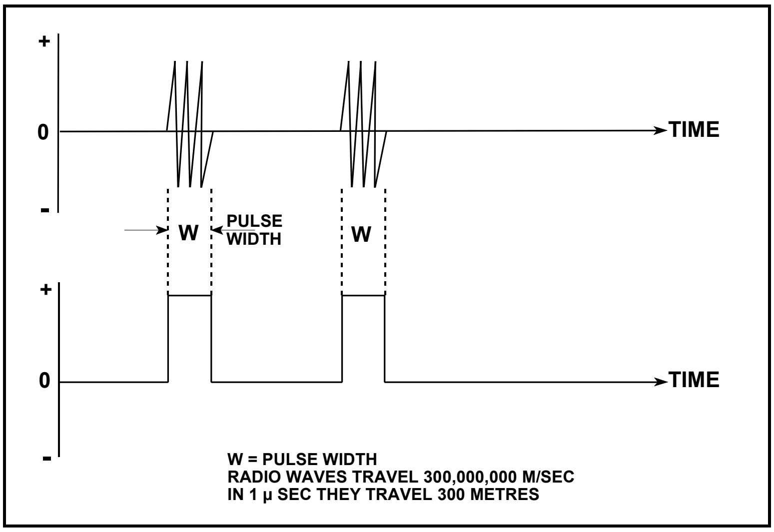


Figure 11.7 Pulse Width Decides Minimum Range

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 1μ sec 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. 0.1μs.

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

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

Answer 3.3μs

RADAR MEASUREMENTS

Bearing. Bearing measurement is obtained by using the search light 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 synchronised 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. This has already been discussed earlier.

Harmonisation. In order that bearing and range information can be determined from the radar system it is necessary to harmonise 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 beam width and the spot size.

The **radial resolution** is dependent upon **half the pulse length**. For example, a pulse length of 1μs would stretch the target by 150 metres (distance that an electromagnetic wave travels in 0.5 μs). If two targets happen to be within the 150 m 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 beam width**. 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 beam widths. 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. Beam widths 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 weaker 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 Figures 11.8 and 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.

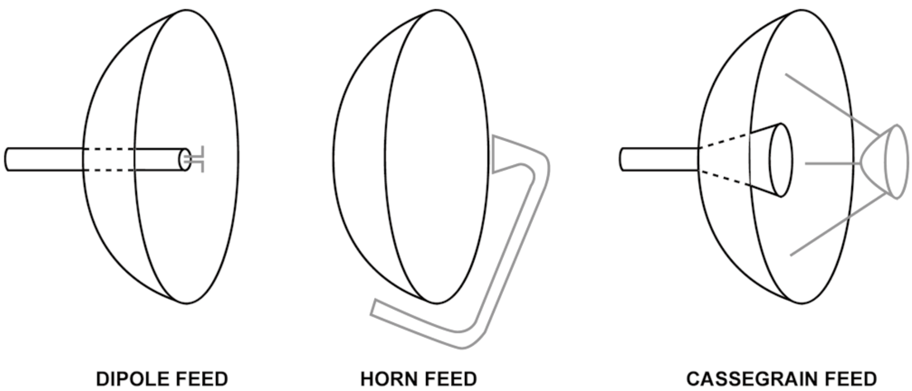


Figure 11.8 Radar Antennae

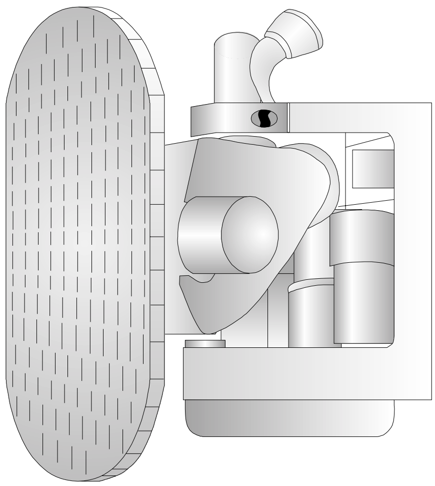


Figure 11.9 Airborne Weather Radar Antenna

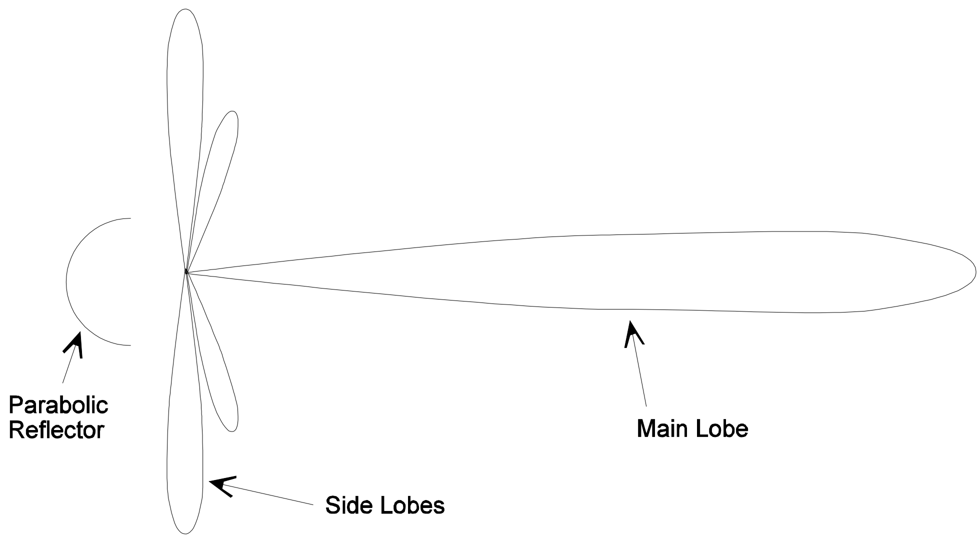


Figure 11.10 Typical Radiation Pattern

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 pss

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 beam width
   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 sidelobes 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. 25000 pps
   b. 6700 pps
   c. 12500 pps
   d. 13400 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	A
2	C
3	C
4	D
5	B
6	D
7	A
8	A
9	D
10	A
11	C
12	B
13	C
14	B

CHAPTER TWELVE

GROUND RADAR

Contents

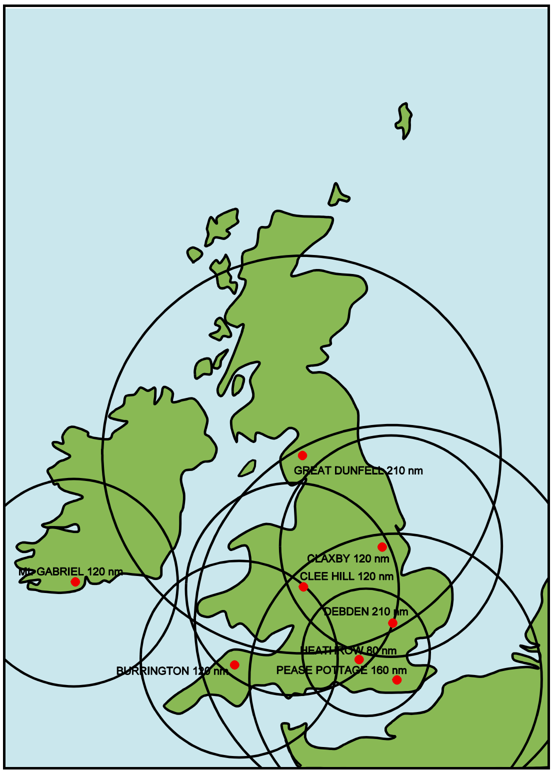
INTRODUCTION

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 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)

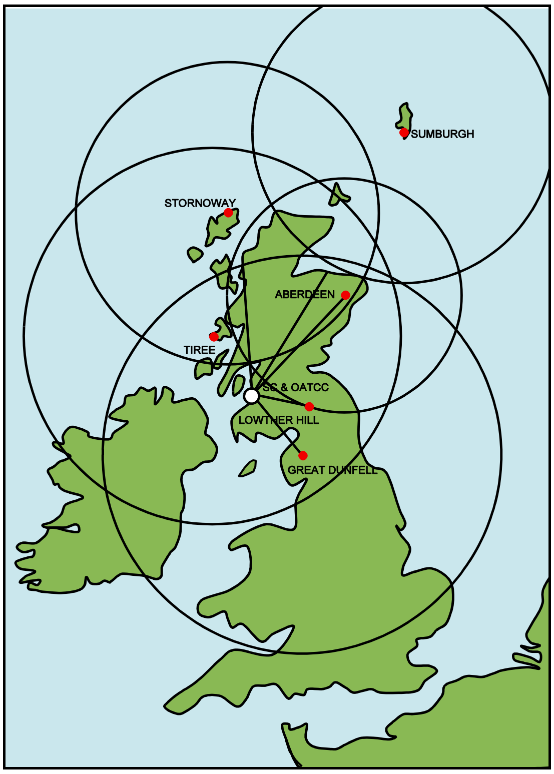
AREA SURVEILLANCE RADARS (ASR)

These are long range radars (200 to 300nm) 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

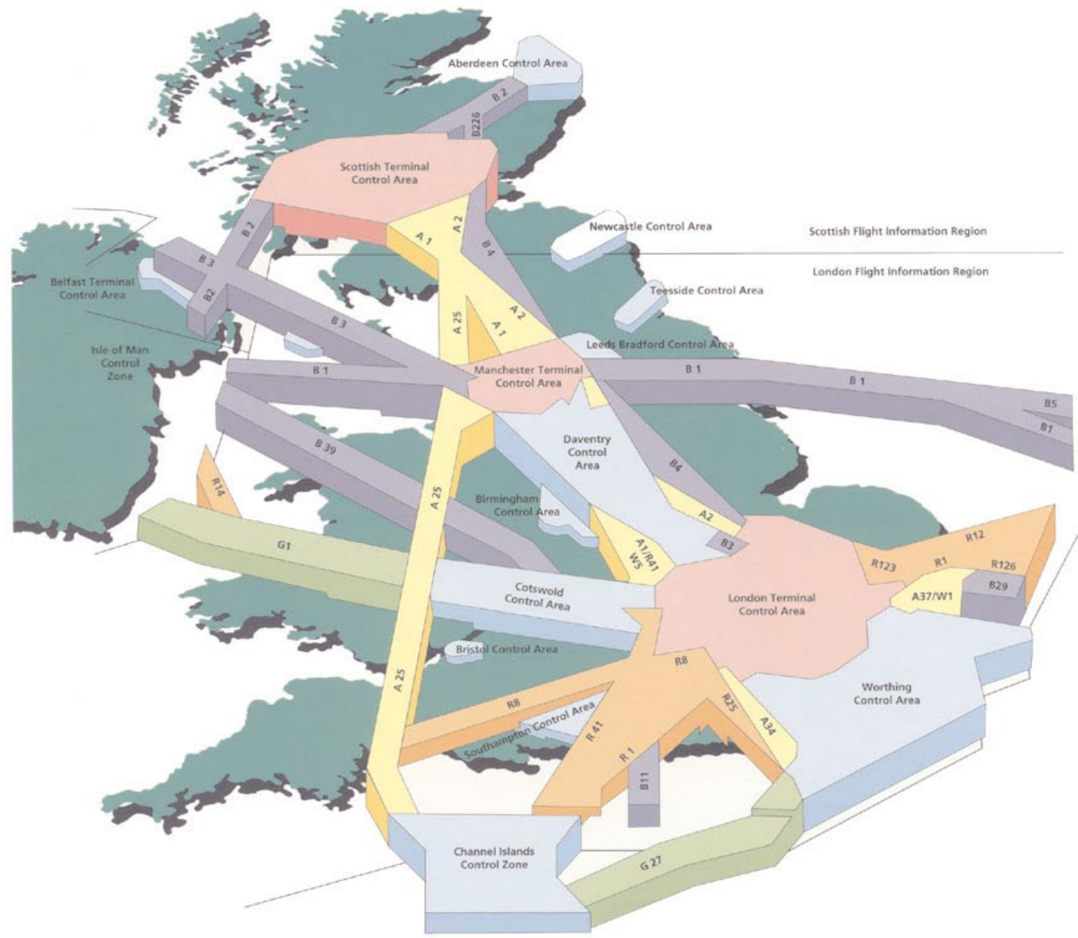


Figure 12.3 Airways in UK Airspace

For the long range radars the wavelengths and pulse lengths are relatively long (10 to 50 cm and 2 to 4μs 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 75nm, used for controlling traffic in TMAs. (Additional information is provided by Secondary Surveillance Radar - SSR).

Typical wavelengths are 10cm, 23cm and 50cm with pulse widths 1 to 3μs.

In the UK horizontal radar separation minima may be reduced to 3nm (5.6km) within 40nm (or in certain circumstances 60nm) of the radar head and below FL 245 where the procedure has been officially approved.

AERODROME SURVEILLANCE APPROACH RADARS

These are short range radars providing positional information up to 25nm. Their wavelengths are 3cm or 10cm with pulse widths of .5 to 1μs. They provide:

- Positional information and control of aircraft in the aerodrome vicinity, Approach Radar (RAD)
- Radar Vectoring to the ILS
- Surveillance Radar Approach (SRA)

RADAR VECTORING TO ILS

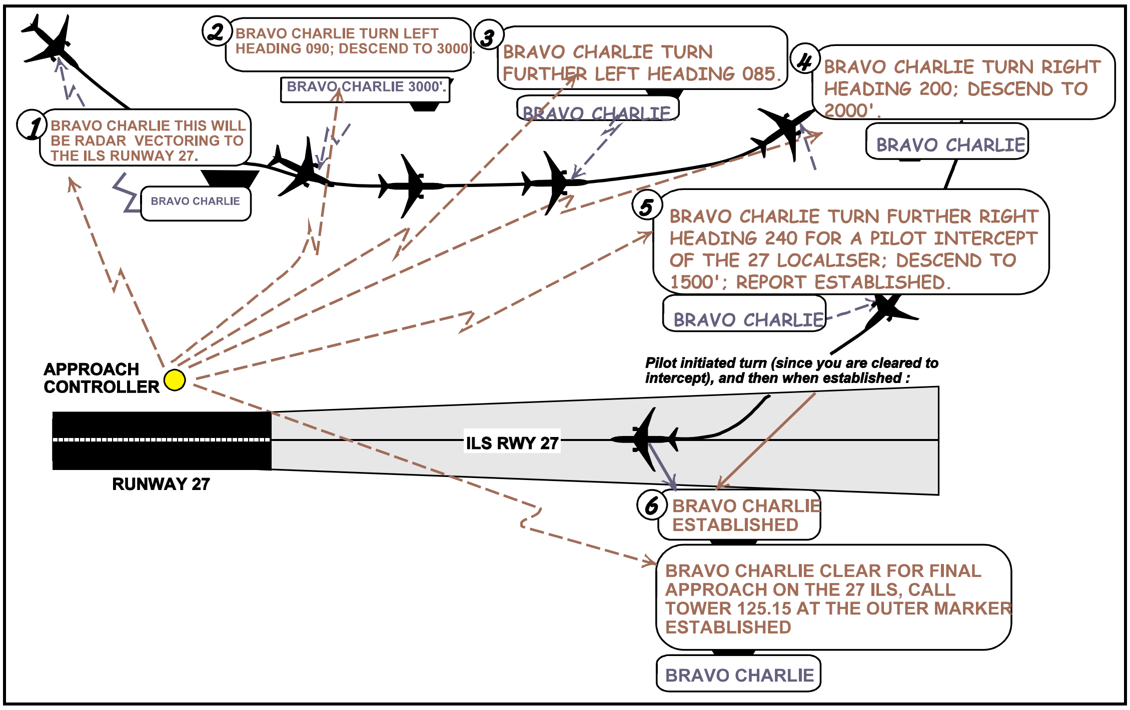


Figure 12.4 Radar Vectoring to ILS

An aircraft being positioned for final approach will be given a heading to close with the localiser at a range of at least 5nm from the runway threshold and at a level below the glide-path.

SURVEILLANCE RADAR APPROACH (SRA)

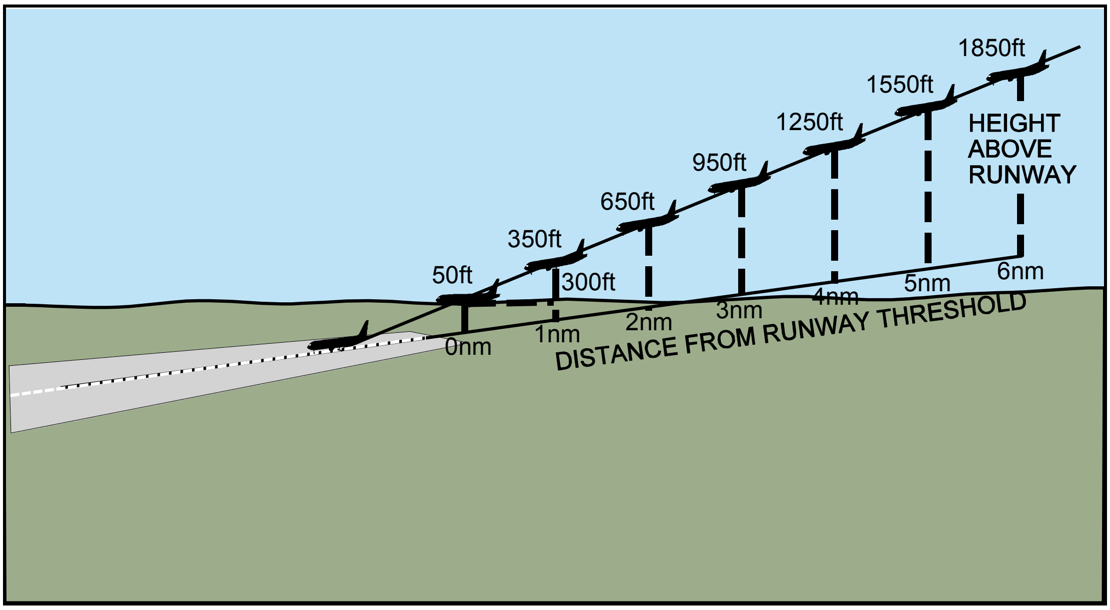


Figure 12.5 SRA Approach

- Whilst the pilot flies the radar approach the controller passes him:
  - tracking instructions in the form of turns to make and headings to fly: **"Turn right 5 degrees - Heading 265"**
  - descent instructions in the form of **advisory heights for range: "Range 5miles - height should be 1550"**
- The descent slope is usually 3° - approximately 300ft/nm
- The heights are worked backwards from **50ft above the threshold which is the reference point**.
- The heights are usually based upon **QFE**.
- **A non-high resolution Surveillance Radar Approach** shall be terminated **2nm before touchdown** except where a termination range of 1nm has been specially approved.

HIGH RESOLUTION SURVEILLANCE RADAR

Certain approved Surveillance Radar Equipment (SRE) can provide final approach guidance of better quality. The approval of **High Resolution SRE** procedures is based upon an operational and technical evaluation of the equipment. In all cases:

- There is a **continuous talkdown from 4nm** with **ranges and advisory heights** being given **every .5nm.**
- The approach controller providing final approach guidance is allocated full time to the task.
- The accuracy, resolution, antenna rotation rate, low level cover and extent of permanent echoes are assessed as capable of giving a high probability of a successful approach with a **termination range of .5nm or less.**

PRECISION APPROACH RADAR

The **PAR** is a **runway approach** aid available only at **military airfields.** It transmits on a frequency of 10GHz (λ 3cm) and provides the controller with very accurate azimuth and elevation information (i.e. an electronic glide-path) on two screens positioned one on top of the other; the glide-path is normally a standard 3°. The system therefore has two antennae. A pilot is "talked down" by the controller to his Decision **Height.** This procedure has now been withdrawn from most UK civil aerodromes and is only available at certain military airfields.

Figure 12.6 shows the PAR procedure. When the pilot has been handed over to the PAR controller and established radio contact, he will be told not to acknowledge any further instructions and to check that his landing gear is down and locked. Thereafter the controller maintains a continuous flow of instructions to the pilot e.g. "You are 3½nm, slightly above the glideslope, increase your rate of descent; turn left 3°, heading 272". Ranges are usually given every mile until 4nm to go; thereafter at every ½nm. From 2nm ranges are given every ¼nm. **The talkdown terminates at ½ nm, or less.**

The PAR display screen has two separate parts indicating the position of the aircraft both in relation to the centre-line as well as in relation to the glide-path as shown in Figure 12.7.

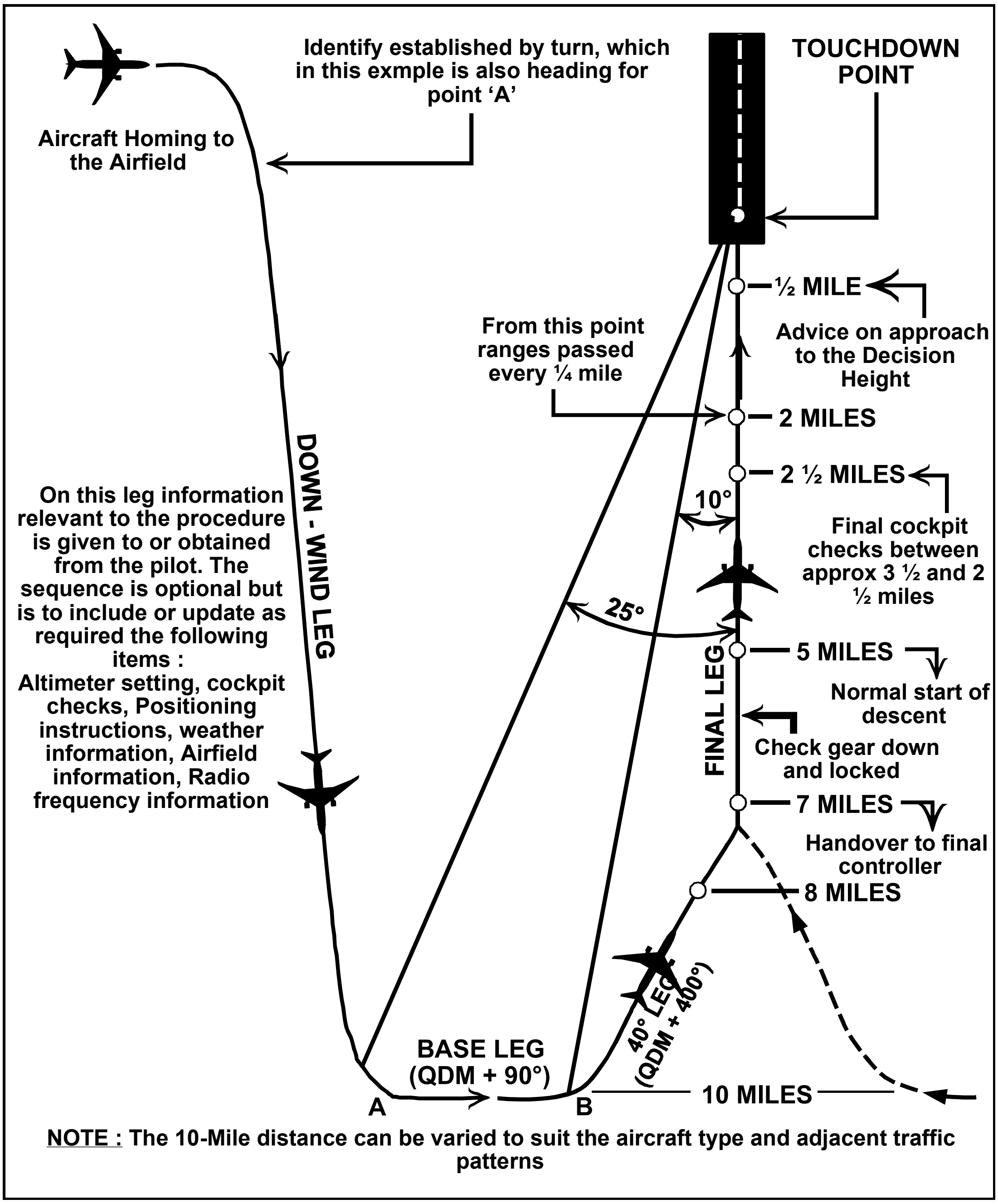


Figure 12.6 The PAR Approach

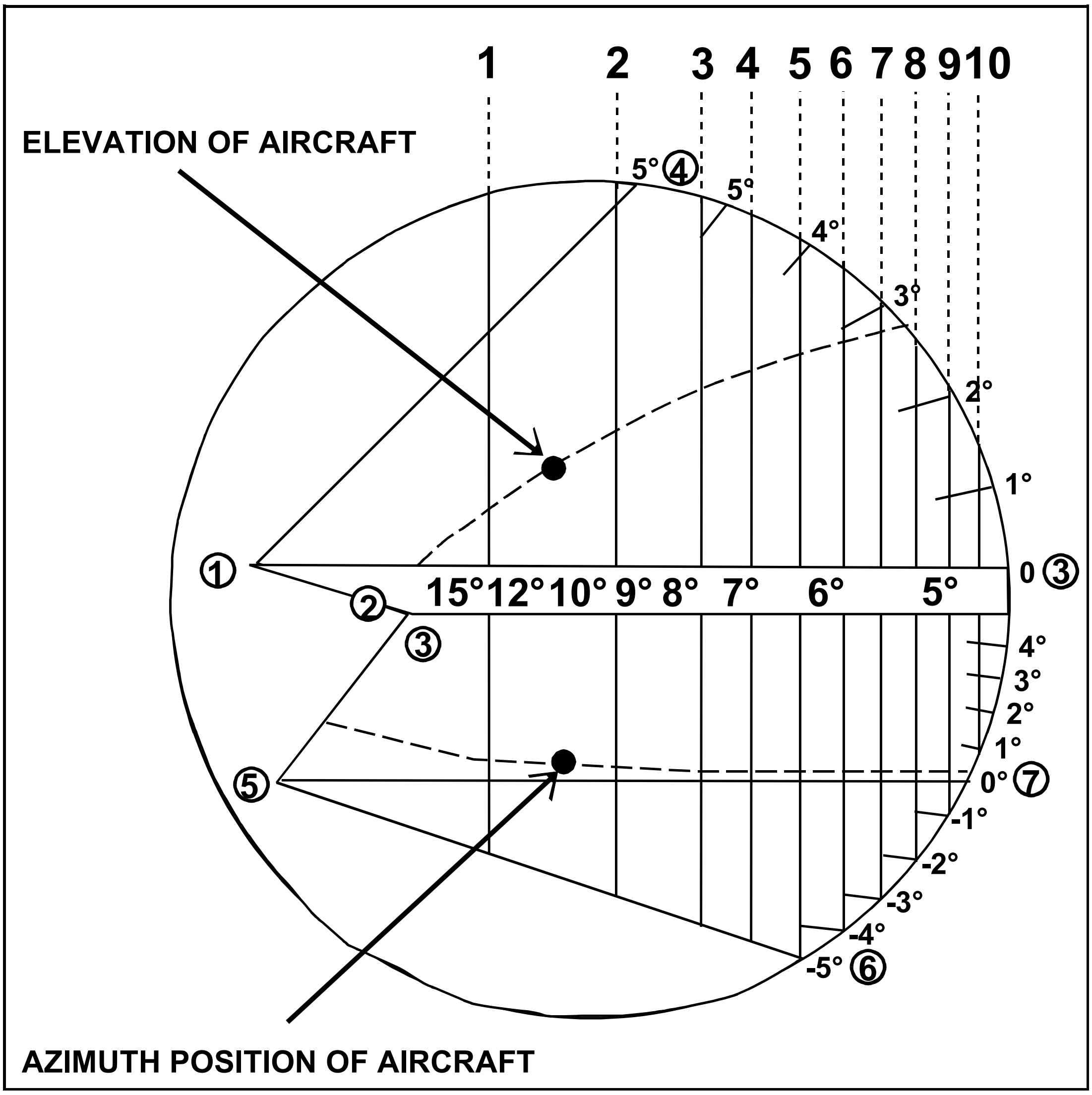


Figure 12.7 The PAR Display

USE OF QFE / QNH APPROACH AND LANDING

When an aircraft descends from a Flight Level to an altitude, preparatory to commencing approach for landing, the aerodrome QNH will be set following the final Flight Level vacating report. Thereafter, the pilot will continue to fly on the aerodrome QNH until established on final approach when QFE or any other desired setting may be used.

Except at certain military aerodromes (see note below), **ATC will assume that an aircraft is using QFE on final approach when carrying out a radar approach** and any heights passed by the radar controller will be related to the QFE datum. It should be noted that the **Obstacle Clearance Height is always given with reference to the aerodrome or threshold elevation**.

Note: At USAF operated aerodromes QFE is not used. All procedures below the Transition Altitude will be based upon aerodrome QNH, and all vertical displacements given as altitudes. Aerodrome QFE will be available on request.

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, taxi-ing, 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 taxi-ways 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 taxi-ways. Processing can remove selected fixed features leaving targets on runways and taxi-ways, etc., clearly visible. This is shown in Figures 12.8 and 12.9; 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 60rpm.
- a PRF in the order of 4,000 to 20,000pps.
- pulse widths in the order of .03 μsec.
- frequencies of 15 to 17 GHz (SHF), 2 to 1.76cm wavelengths.
- ranges of 2.5 to 6nm 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.

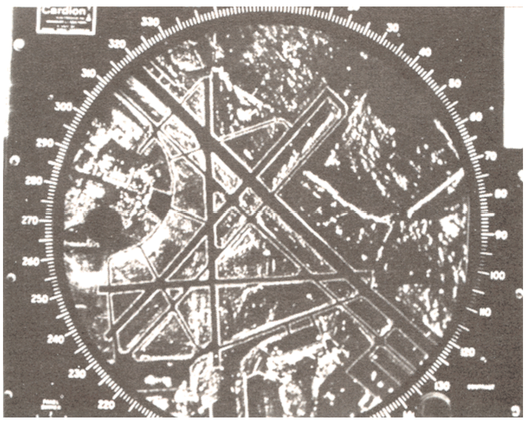


Figure 12.8. ASMI with fixed features

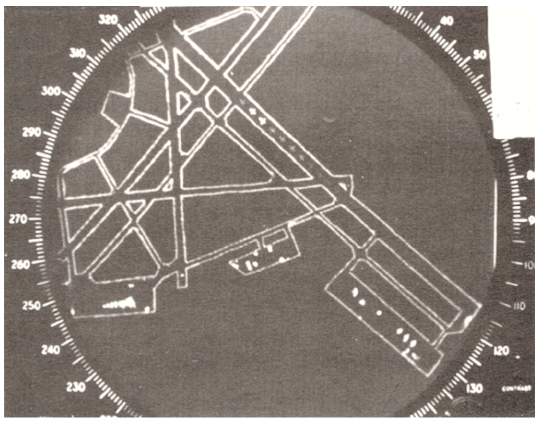


Figure 12.9 Processed ASMI with DC9 taking off.

CHARACTERISTICS OF CONTEMPORARY RADARS

The following table compares the major properties of primary radars such as SRE, PAR and ASMI. Particular note should be taken of the differences between ASMI radars and SREs .

When comparing the beam widths of SSRs (2.3° to 4.8°) and SREs (1.1° to 1.7°) it is apparent that the SREs provide better bearing resolution and target discrimination, whereas the wider SSR beam provides the identity for a particular primary radar response.

CHARACTERISTICS OF CONTEMPORARY RADAR EQUIPMENTS

TITLE	TYPE	PEAK POWER	WAVE LENGTH	BEAM WIDTH	PULSE LENGTH	RANGE (APPROX)	PRF PPS	SCAN RATE	MISCELLANEOUS INFORMATION
Thomson CSF TA10M	SRE	500 kw	10 cm	1.5°	0.8μs	60nm	1000	15	Magnetron Tx
Thomson CSF TR23MR	SRE		23cm	1.7°	1.5μs	120nm	500	variable 6 to 15	Klystron Tx
Thomson CSF LP23K	SRE		23cm	1.1°	3μs	220nm	340	5/6	Klystron Tx
Thomson CSF ASTRE	ASMI	30kw	1.8cm	.33°	.04μs	6nm	10000	60	Inverted cosec aerial. TV router display
Thomsom CSF	SSR	2.5kw		4.8° or 2.3°		200 + nm		As for assoc SRE	Adaptable to monopulse or Mode S operation
Thomson CSF TRS2310	PAR	30kw	3cm	AZ1.1° EL .6°	.5μs			120	Mechanical aerial scanning Scan coverage 10° in elevation and 20° azimuth
Marconi Messenger	SSR	0.5kw up to 2.0kw		2.45°		up to 250nm		As for assoc PRI SRE	Monopulse adaptable Mode S

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. When flying a Precision Approach Radar in the UK, vertical displacement is based upon:

   a. Regional QNH
   b. QFE
   c. QFF
   d. Airfield QNH

4. The frequency band and rate of scan of Airfield Surface Movement radars are:

   a. SHF; 60RPM
   b. SHF; 200RPM
   c. EHF; 100RPM
   d. EHF; 10RPM

5. When carrying out a precision radar approach, talkdown normally ceases at _______ nm from touchdown:

   a. 0.5 nm
   b. 2 nm
   c. 3 nm
   d. 5 nm

6. A ground based radar with a scanner rotation of 60rpm, a beam width in the order of .5° and a PRF of 10000pps would be:

   a. an Airfield Surface Movement Indicator with a theoretical range of 8nm.
   b. a Precision Approach Radar.
   c. an Airfield Surface Movement Indicator with a theoretical range of 16nm.
   d. a high resolution Surveillance Approach Radar.

7. The SHF band has been selected for Airfield Surface Movement Indicator (ASMI) radars in preference to the EHF band because:

   a. the EHF band causes unacceptable radiation hazards to personnel.
   b. the attenuation caused by precipitation is greater in the EHF band and reduces the radar's effective range and usefulness.
   c. the EHF band is not suitable for the provision of the very narrow beams needed for an ASMI radar.
   d. target discrimination using the SHF band is better.

ANSWERS

1	A
2	B
3	b
4	A
5	A
6	A
7	B

CHAPTER THIRTEEN

AIRBORNE WEATHER RADAR

Contents

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 **stabilised in pitch and roll**. (Figure 13.1)
- Indicator. (Figures 13.1, 13.2, 13.3 and 13.4)
- Control unit. (Figure 13.1 and 13.5)

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

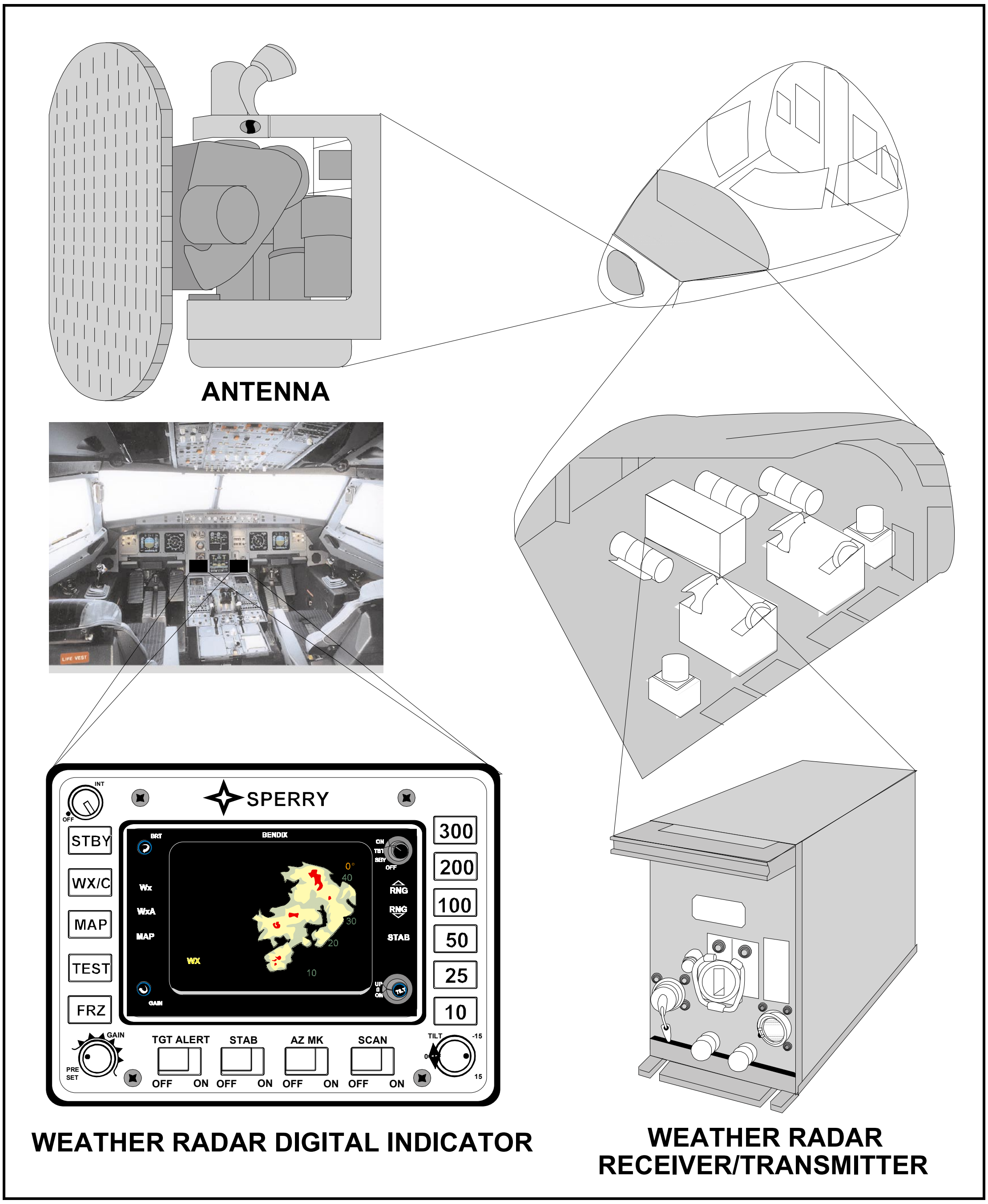


Figure 13.1 AWR Components

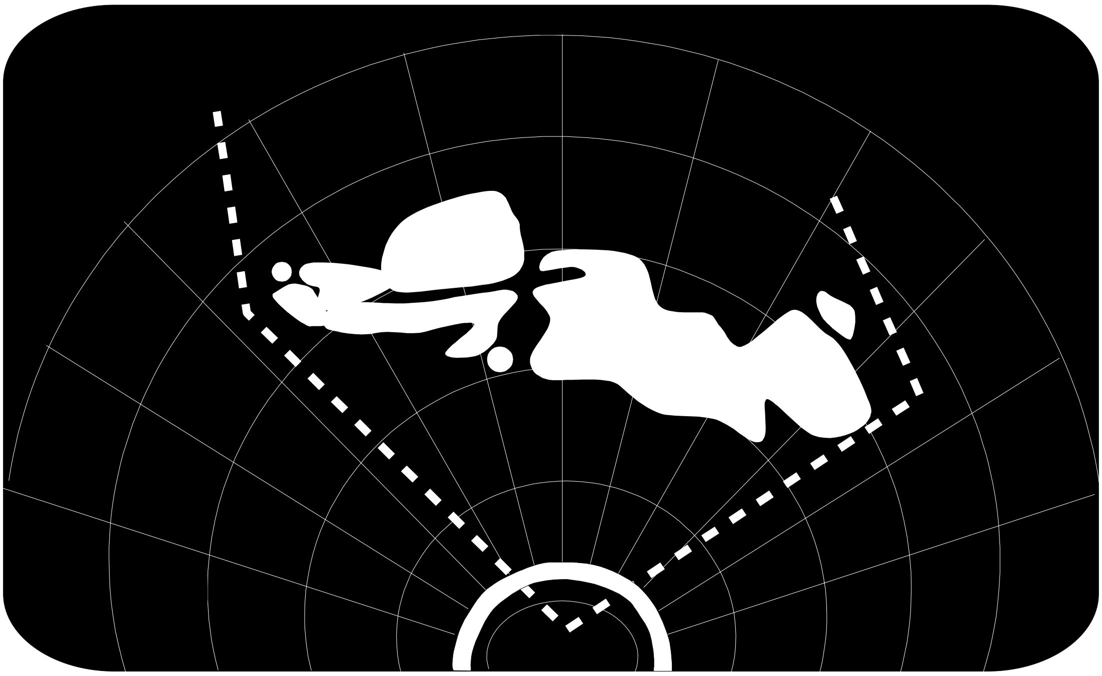


Figure 13.2 Monochrome Cloud Display And Avoidance Courses

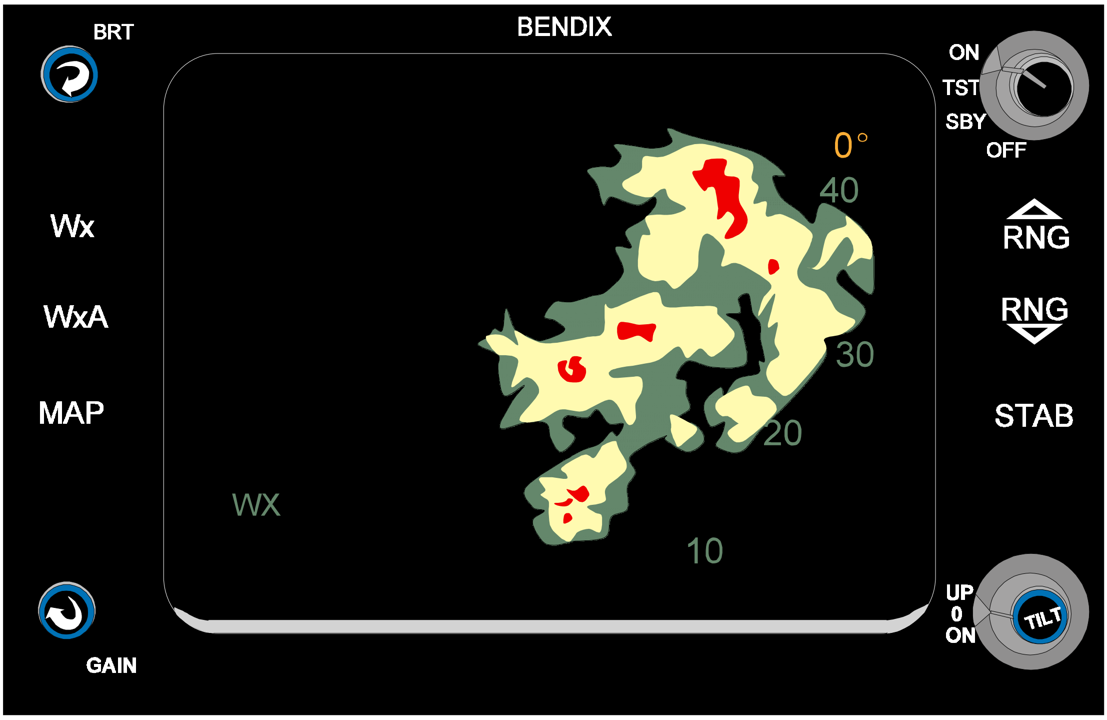


Figure 13.3 Colour Weather Display

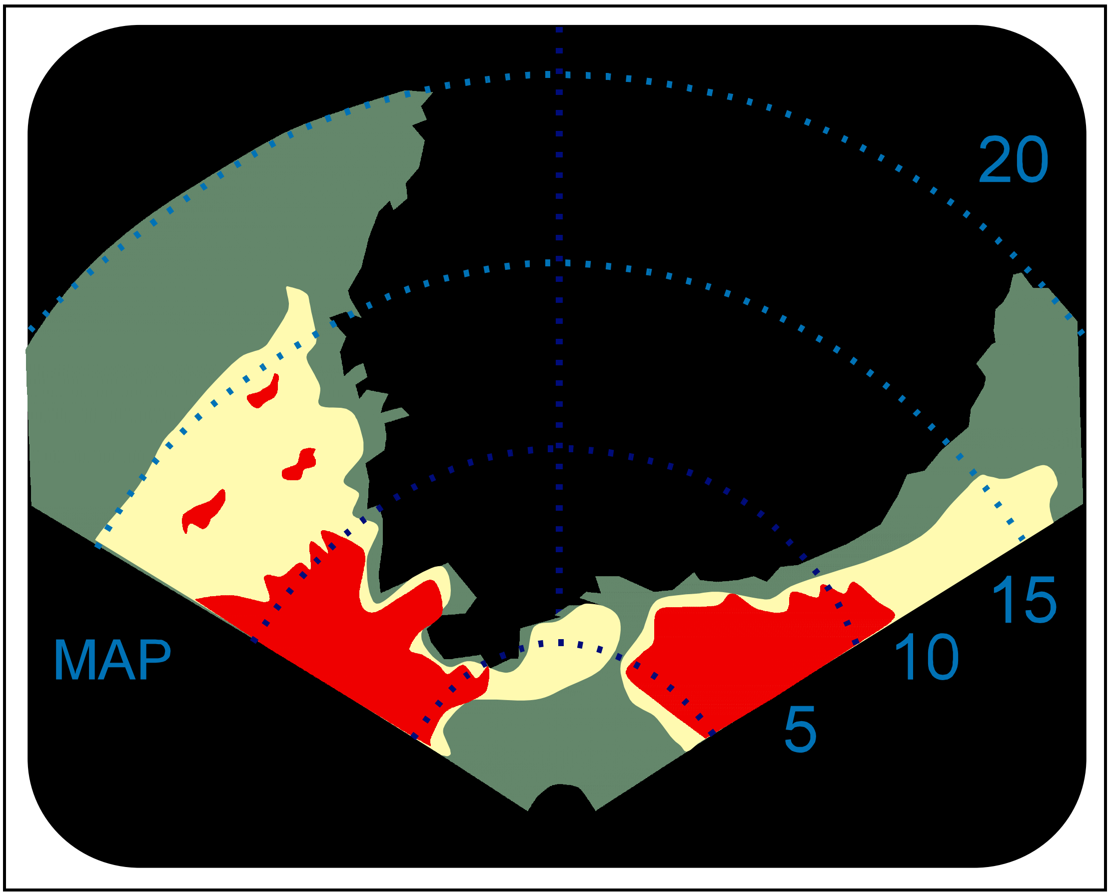


Figure 13.4 Terrain Mapping Display

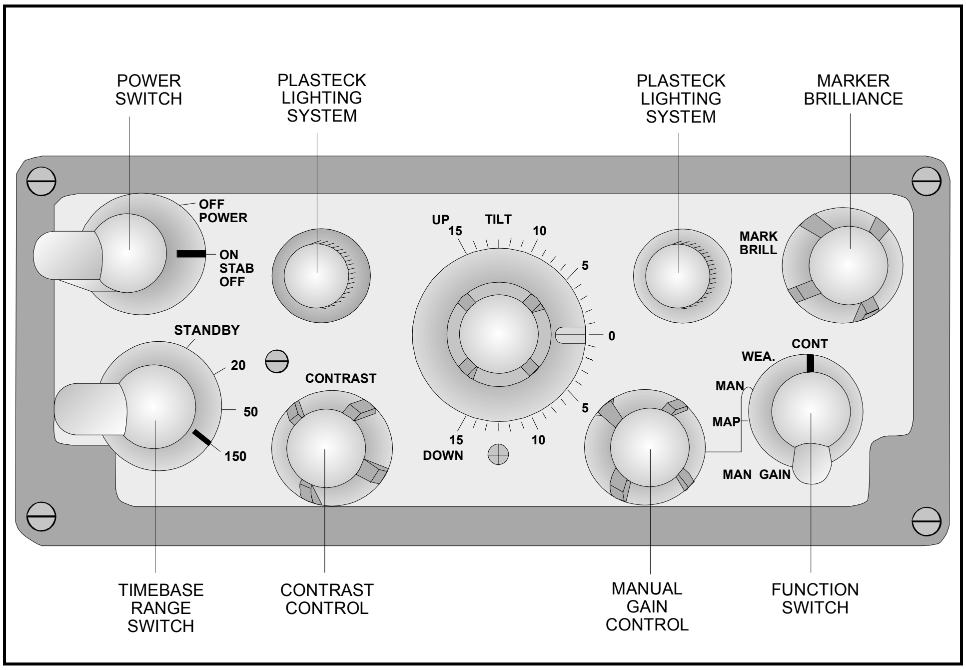


Figure 13.5 Control Unit

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 13.10). 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 square 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-stabilised** 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 width of the radar beam can be calculated using the formula:

Beam width (degrees) = 70 x wavelength / antenna diameter.

Example: Calculate the beam width of a 3 cm radar using a 45 cm diameter antenna.

Answer: Beam width = 70 x 3 / 45 = 4.7°

The **beamwidth** must be as **narrow as possible** for efficient target resolution. For example, two clouds at say 100nm might appear as one large return until, at a closer range, they are shown correctly in Figure 13.6, 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**.

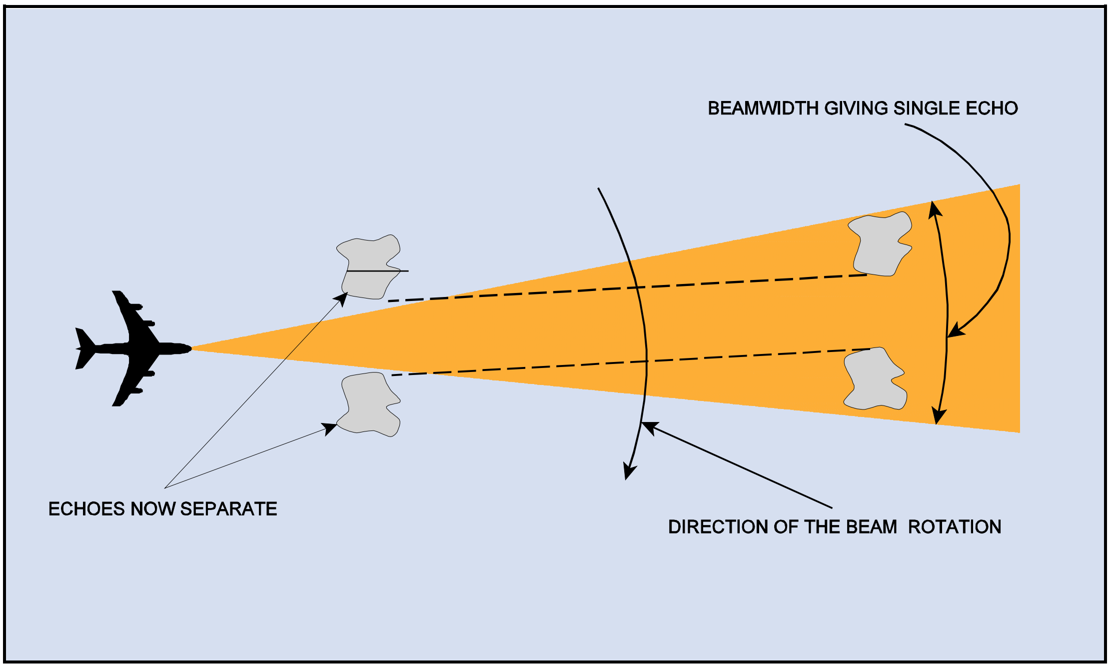


Figure 13.6 Effect of Beam Width

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:

$$\lambda = \frac{300}{9375} \text{ m} = \mathbf{3.2\ cm}$$

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.

Beam Coverage

Using the above wavelength of 3.2 cm the following beam widths and coverage are obtained:

Scanner Diameter	Beam Width	Coverage at 100nm
30″ (76cm)	3°	32, 000′
18″ (46cm)	5°	53, 000′
12″ (30.5cm)	7 °	74, 000′

Figure 13.7. shows the coverage for a 3° beam increases at various ranges. The area illuminated by the beam increased with range.

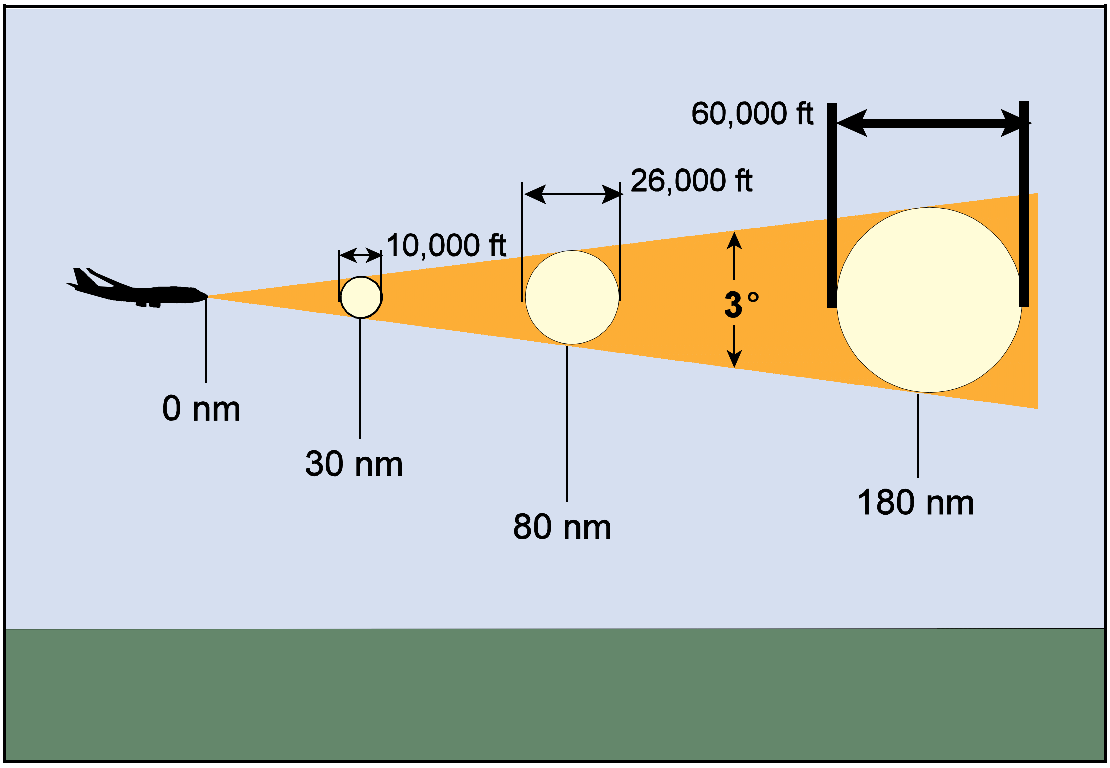


Figure 13.7 Radar Beam Coverage At Varying Ranges

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 severest 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 13.8 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.**

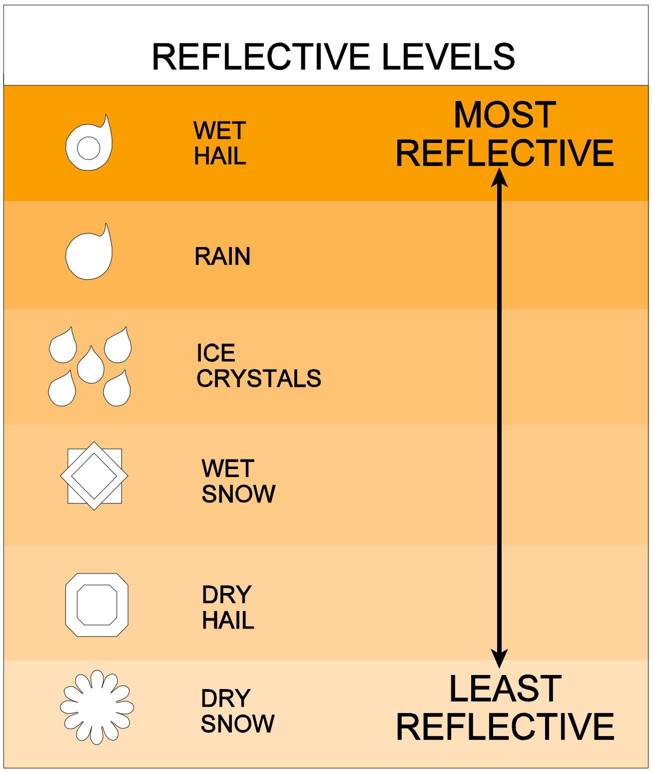


Figure 13.8 Reflective Levels

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 0.7mm/hr.
GREEN	Light returns	0.7 - 4mm/hr.
YELLOW	Medium returns	4 - 12mm/hr.
RED	Strong returns	Greater than 12mm/hr.
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 Figure 13.9 : **U-shapes, Fingers, Scalloped edges and Hooks**. These are areas to avoid.

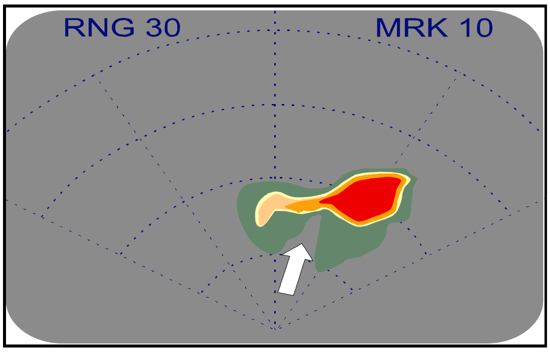


Figure 13.9a U-Shape indicating Hail Activity

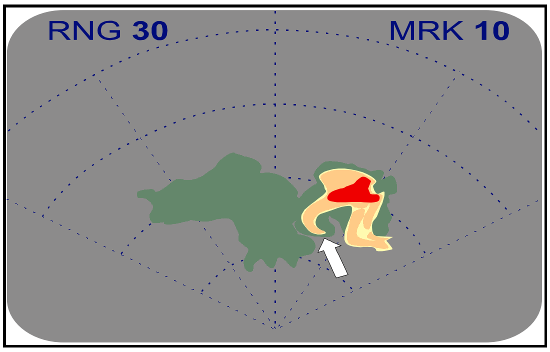


Figure 13.9b Finger indicating Hail Activity

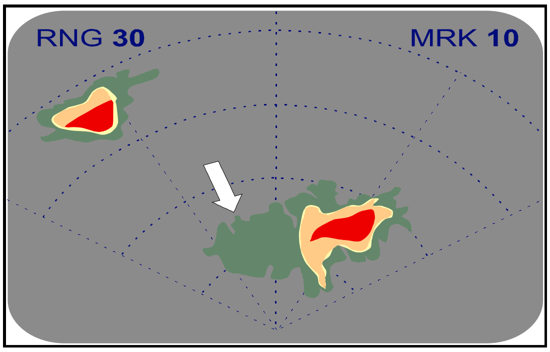


Figure 13.9c Scalloped Edge indicating Hail Activity

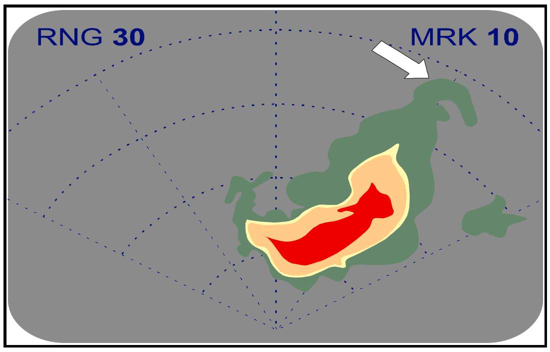


Figure 13.9d Hook indicating Hail Activity

MONOCHROME CONTROL UNIT

Figure 13.10 illustrates a basic control unit for a monochrome AWR with range scales 20, 50 and 150 nm; its various functions are described below.

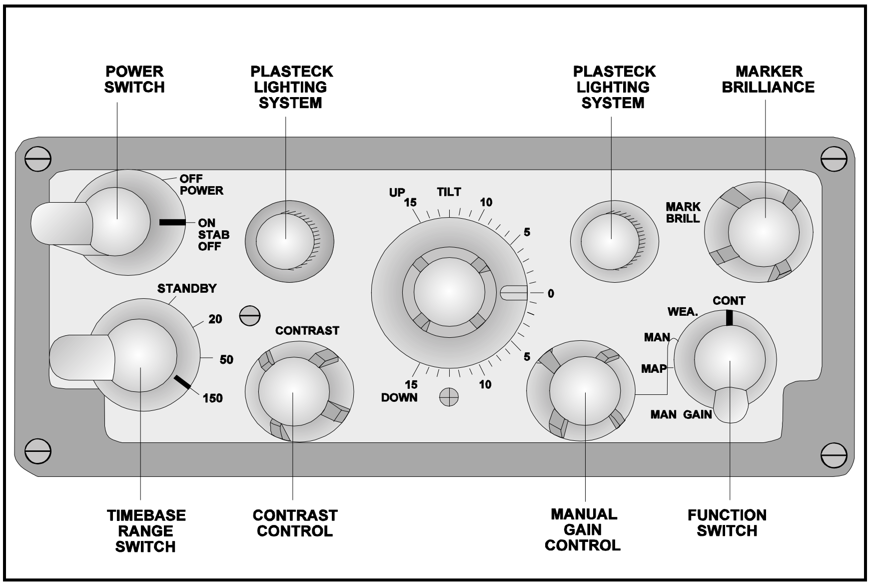


Figure 13.10 Control Unit

Power Switch
In the **ON** position the system is energised and the **aerial** is **automatically stabilised in PITCH and ROLL.** A lopsided or asymmetric display probably indicates that the stabilisation 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 energises 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 - 20nm 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 13.11).

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 13.12.

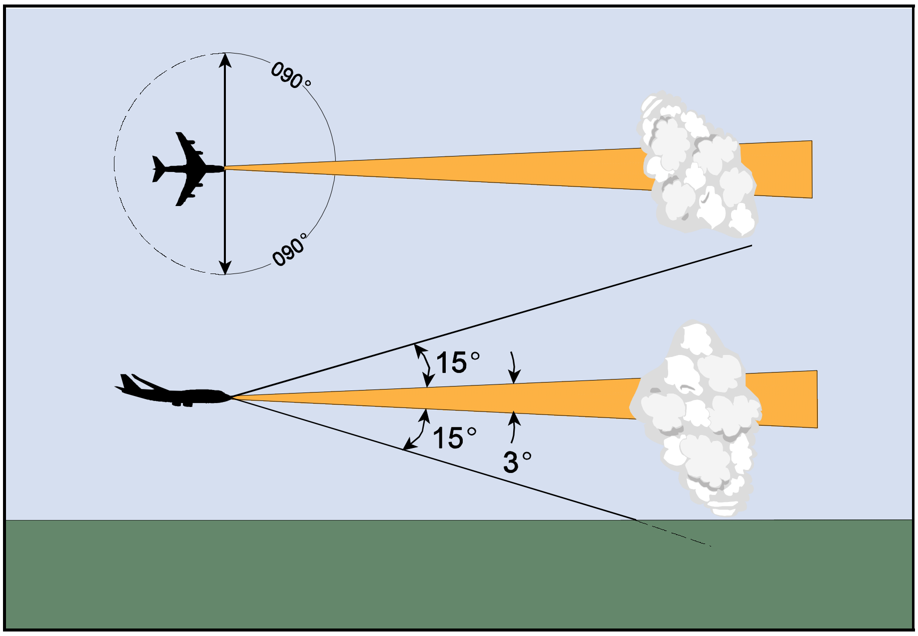


Figure 13.11 Projected Radar Beam and Tilt Angle

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 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 (15nm) and **maximum (60 to 70nm)** mapping ranges depend upon the aircraft's height and type of terrain. To map **beyond 70nm the conical pencil beam** should be used by selecting the MANUAL position; this enables the gain to be adjusted, for ground mapping. See Figure 13.12.

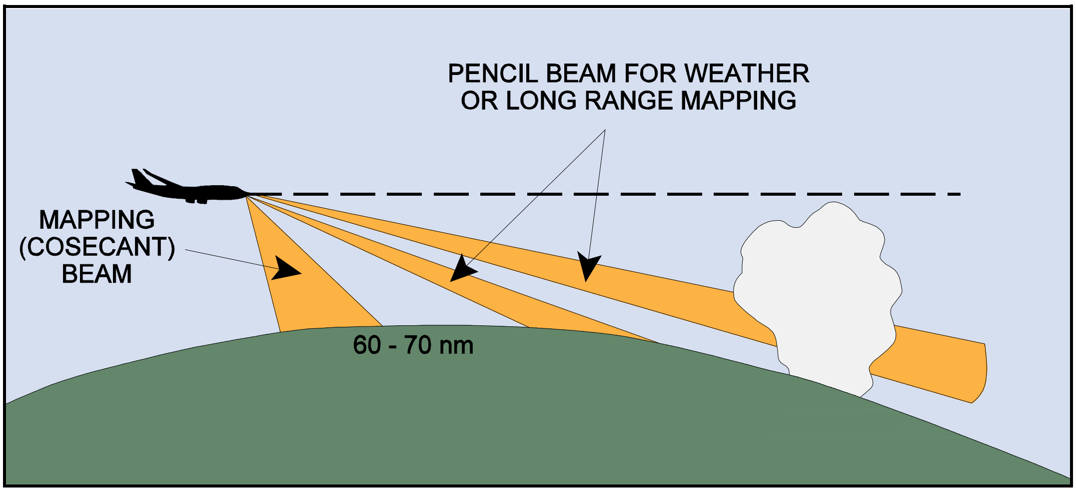


Figure 13.12 AWR Beam Shapes

MAN
This is used for cloud detection and mapping between about 70 and 150nm 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 13.11.) 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 25nm** and ensures that the intensity (brilliance) of display of a particular cloud is independent of range. Thus a small cloud at 5nm does not give an increasingly stronger return than a larger and more dangerous cloud at 20nm; all clouds up to about 25nm are thus compared on equal terms.

CONT
Figure 13.13. is a cloud formation presentation with **CONT** (CONTOUR) selected for a black and white display; the **black holes indicate dangerous areas** of concentrated rainfall and potential turbulence. Figure 13.14. shows the same cloud formation with CONT deselected. The position, therefore, is used to indicate storm intensity, turbulence and areas to avoid.

The degree of danger depends upon the steepness of the rainfall gradient. Therefore, the narrower the paint surrounding a black hole, 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.

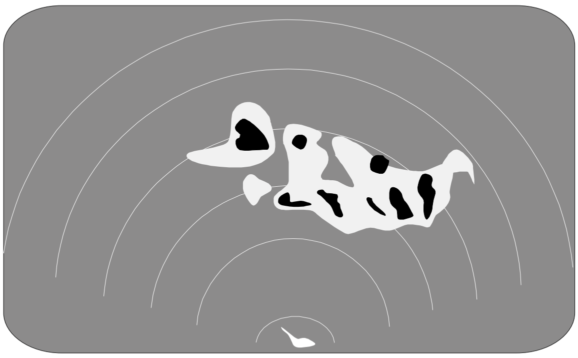


Figure 13.13 Typical Cloud Display With Contour On

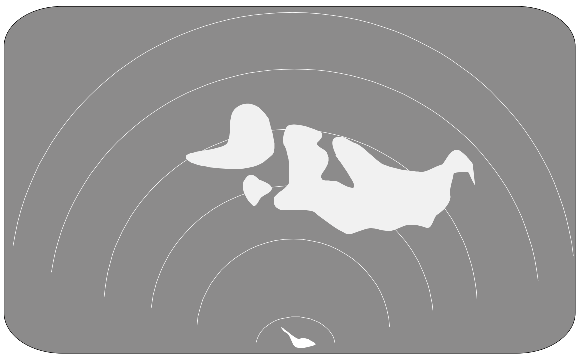


Figure 13.14 Typical Cloud Display With Contour Off

MAPPING OPERATION

For the basic monochrome AWR with a maximum range of 150nm, **the cosecant (fan-shape) beam is used for mapping up to about 70nm** 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 13.15).

Hill shadow (may give a false impression of water)

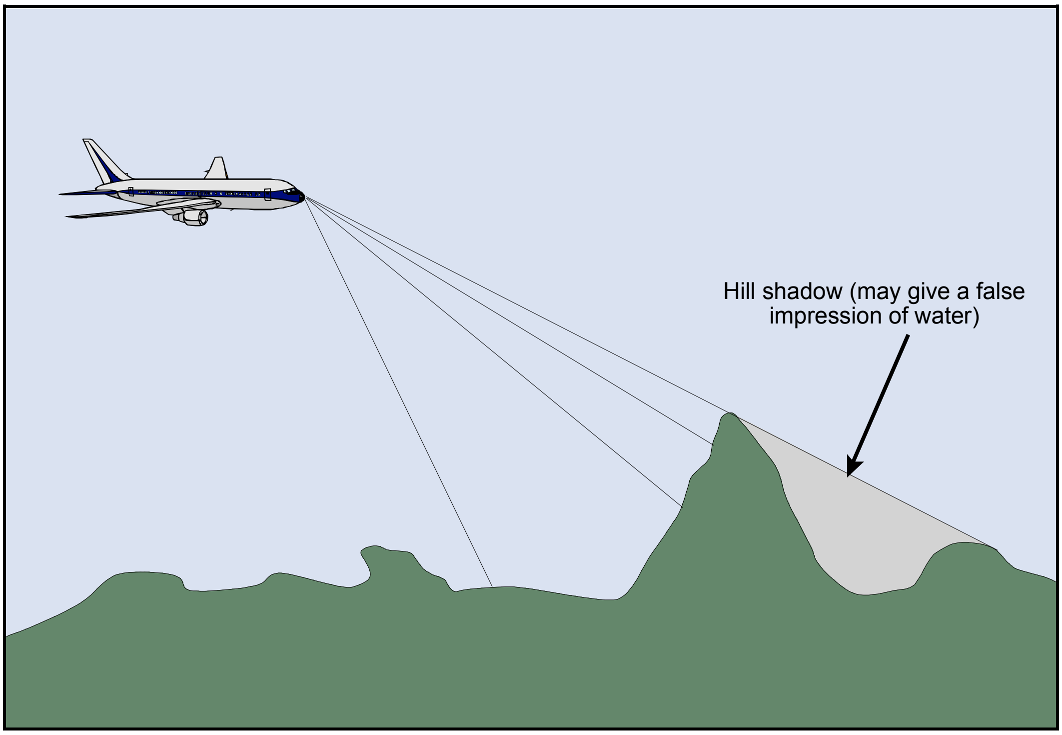


Figure 13.15 Hill Shadow

PLOTTING A NAVIGATION FIX

The range of a ground feature will be its **slant range.** For example a feature almost immediately below the aircraft (i.e. ground range approximately 0nm) will appear on the screen at a range approximately equivalent to the aircraft's height. The Pythagoras theorem is therefore needed to convert slant ranges to approximate ground distances. A fix may be obtained by plotting a **QTE and range from a prominent terrain feature**. (Figure 13.16.)

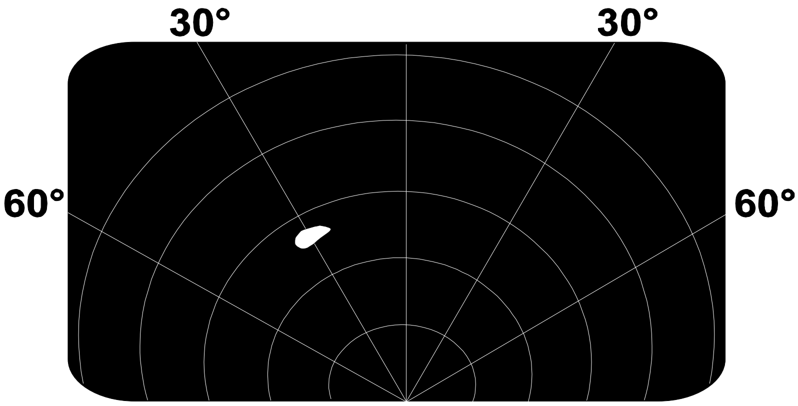


Figure 13.16 0 - 25 Scale

An aircraft at 42,560ft is heading 216° (M); variation is 17°E

Calculate the QTE and range to be plotted from the centre of the island as shown on the AWR screen.

True heading	=	216° - 17° = 199°
True bearing TO island	=	199° - 30° = 169°
QTE to plot	=	169° + 180° = 349°
Ground Range (nm)	=	$\sqrt{(S^2 - H^2)} = \sqrt{169 - 49} = \sqrt{120}$
	=	11 nm

[S = slant range (nm) and H = height (nm)]

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 as shown in appendix A.

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.

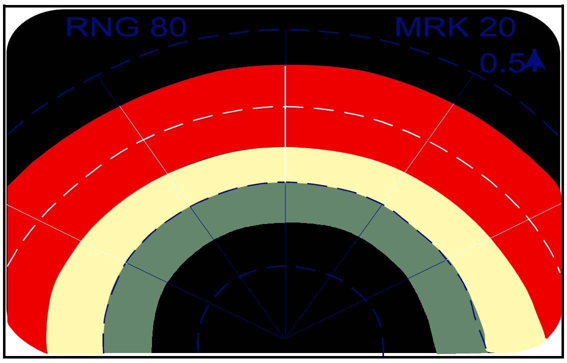


Figure 13.17
Typical Radar System Test
Pattern for PP1 Indicators

Hold
This allows the display to be frozen so that storm movements can be assessed. When a storm is located, at say 100nm, 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 160nm 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.

CALCULATING APPROXIMATE CLOUD HEIGHT

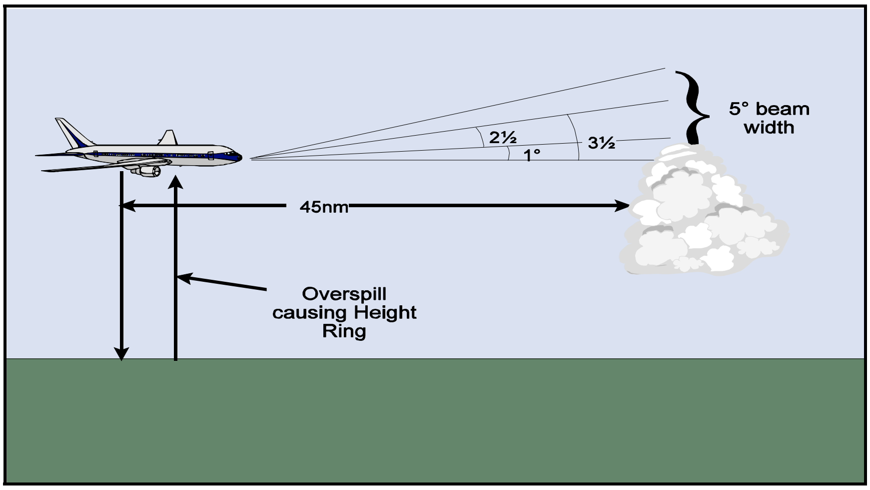


Figure 13.18 Finding Cloud Height using 1 in 60 rule

To determine the altitude of the cloud tops, move the tilt until the returns from the clouds just disappear from the screen. The lower edge of the beam is now just clear of the tops of the cloud. Note the TILT angle and the range of the cloud.

Example: Determine the altitude of the cloud tops given: range 45nm, tilt angle 3.5°, beamwidth 5° and aircraft at FL350.

The angle measured from the horizontal which gives the cloud tops is along the lower edge of the beam, the TILT gives the centre of the beam, so the angle required is:

$$TILT - \frac{BEAMWIDTH}{2}$$

Using the 1:60 rule to find the height of the cloud tops above the aircraft:

$$Height = \left(TILT - \frac{BEAMWIDTH}{2} \quad x \quad \frac{Range}{60}\right) \; x \;\; 6076 \;\; feet$$

This can be simplified to:

$$Height = \left(TILT - \frac{BEAMWIDTH}{2}\right) \; x \quad Range \quad x \;\; 100 \; feet$$

The height (above the aircraft) is: $(3.5 - 5/2\,) \; x \;\; 45 \;\; x \;\; 100 \; = \; 4{,}500 \; feet$

Giving an altitude of the cloud tops of 39,500 ft

Note: *using the formula as given and taking UPTILT as positive and DOWNTILT as negative will yield either a positive or negative number which when applied to the altitude of the aircraft will give the correct altitude of the cloud tops.*

AWR SUMMARY

Components	Tx / Rx, antenna, indicator, control unit.
Functions	Turbulence, navigation
Principle of Opereation	Echo for range, sweep for relative bearing. Pencil beam for weather and long range (>60nm) mapping. Cosecant beam for short range. Antenna attitude stabilised. Beam width dependent on antenna size. Beam width = 70 x λ / diameter. 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 60nm MAN - Manual gain with pencil beam to map > 60nm WEA - Pencil beam with AGC CONT - Black holes indicate turbulence.
Mapping	Tilt down for best target presentation. Beware hill shadows.
Navigation	QTE from prominent feature. Use slant range when near (< 3 x Ht)
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. A prominent island is identified on the 30° right bearing line and the 10 nm range marker of an airborne weather radar. If the heading is 045° (T) and the aircraft is at FL360 what range and bearing should be plotted in order to obtain a fix?

a. 10nm 030° (T)
b. 10nm 075° (T)
c. 8nm 075° (T)
d. 8nm 255° (T)

6. 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.

7. 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.

8. An aircraft heading 017° (T) has a small island showing on the AWR at 45nm range on the 60° left azimuth line. To obtain a fix from this information you should plot:

a. range 45nm and QTE 060 from the centre of the island.
b. range 45nm and QTE 240 from the centre of the island.
c. range 45nm and QTE 317 from the centre of the island.
d. range 45nm and QTE 137 from the centre of the island.

9. An aircraft heading 137° (M) has a small island showing on the AWR at 45nm range on the 30° left azimuth line. Local variation is 12° W. To obtain a fix from this information you should plot:

a. Range 45 nm and QTE 095 from the centre of the island.
b. Range 45 nm and QTE 275 from the centre of the island.
c. Range 45 nm and QTE 107 from the centre of the island.
d. Range 45 nm and QTE 287 from the centre of the island.

10. Airborne weather radar operates on a frequency of:

a. 8800 MHz because gives the best returns from all types of precipitation
b. 13300 MHz
c. 9375 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.

11. The mapping mode of Airborne Weather Radar utilises:

a. a pencil/weather beam from 70 nm to 150 nm.
b. a cosecant/fan shaped beam which is effective to 150 nm.
c. a pencil/weather beam with a maximum range of 70 nm.
d. a cosecant/ fan shaped beam effective 50 nm to 70 nm.

12. 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.

13. The antenna of an Airborne Weather Radar is stabilised:

a. in pitch, roll and yaw.
b. in pitch and roll.
c. in pitch and roll whether the stabilisation is on or off.
d. in pitch and roll but only when 0° tilt has been selected.

14. The centre of a small island is identified at the intersection of the 60° left bearing line and 15nm range arc of an airborne weather radar. If the aircraft's heading and height are 035° (M) and 42,500ft what QTE and range should be plotted in order to obtain a fix from the island? (variation is 20°W)

a. 175 15nm
b. 135 15nm
c. 135 13nm
d. 155 14nm

15. 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.

16. The radar in an aircraft at FL370 detects a cloud at 60 nm. The cloud disappears when the tilt is selected to 2° UP. If the beamwidth of the radar is 6°, at what altitude are the tops of the clouds?

a. 6,000 ft
b. 31,000 ft
c. 43,000 ft
d. 49,000 ft

ANSWERS

1	B
2	A
3	B
4	D
5	D
6	C
7	B
8	D
9	B
10	C
11	A
12	B
13	B
14	C
15	D
16	B

CHAPTER FOURTEEN

SECONDARY SURVEILLANCE RADAR (SSR)

Contents

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 be discussed in chapter 16.

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 250nm.
- 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 realised. 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 callsign or flight number, pressure altitude or flight level, ground speed and destination.

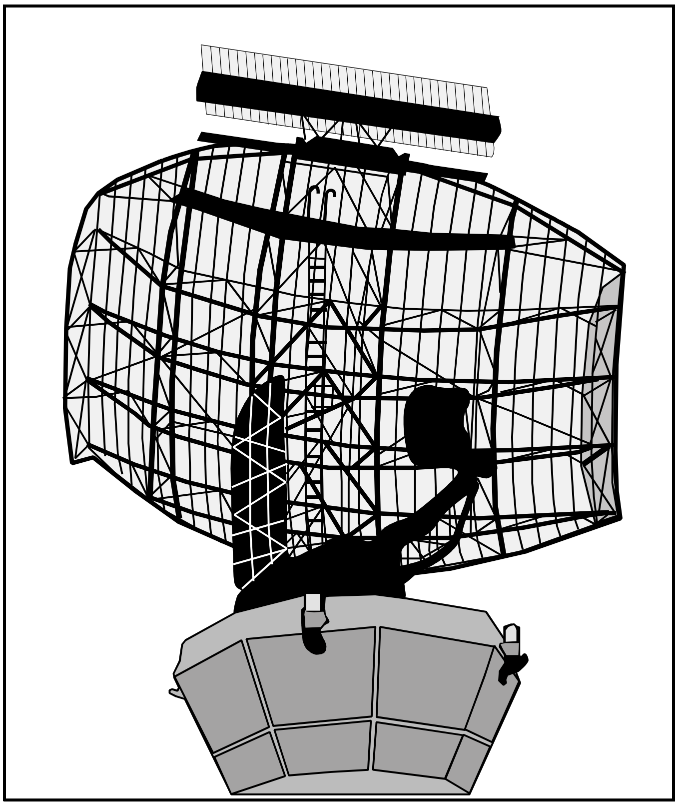


Figure 14.1 SSR aerial mounted on top of a 23cm Primary Radar aerial.

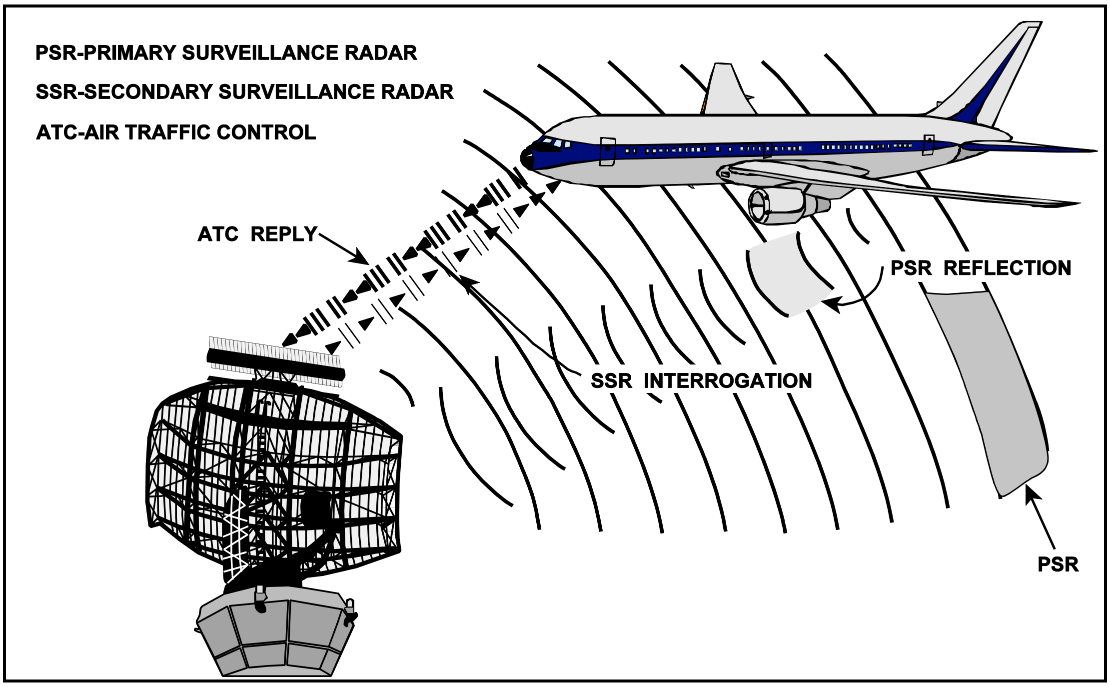


Figure 14.2 Primary and Secondary Radar used for ATC

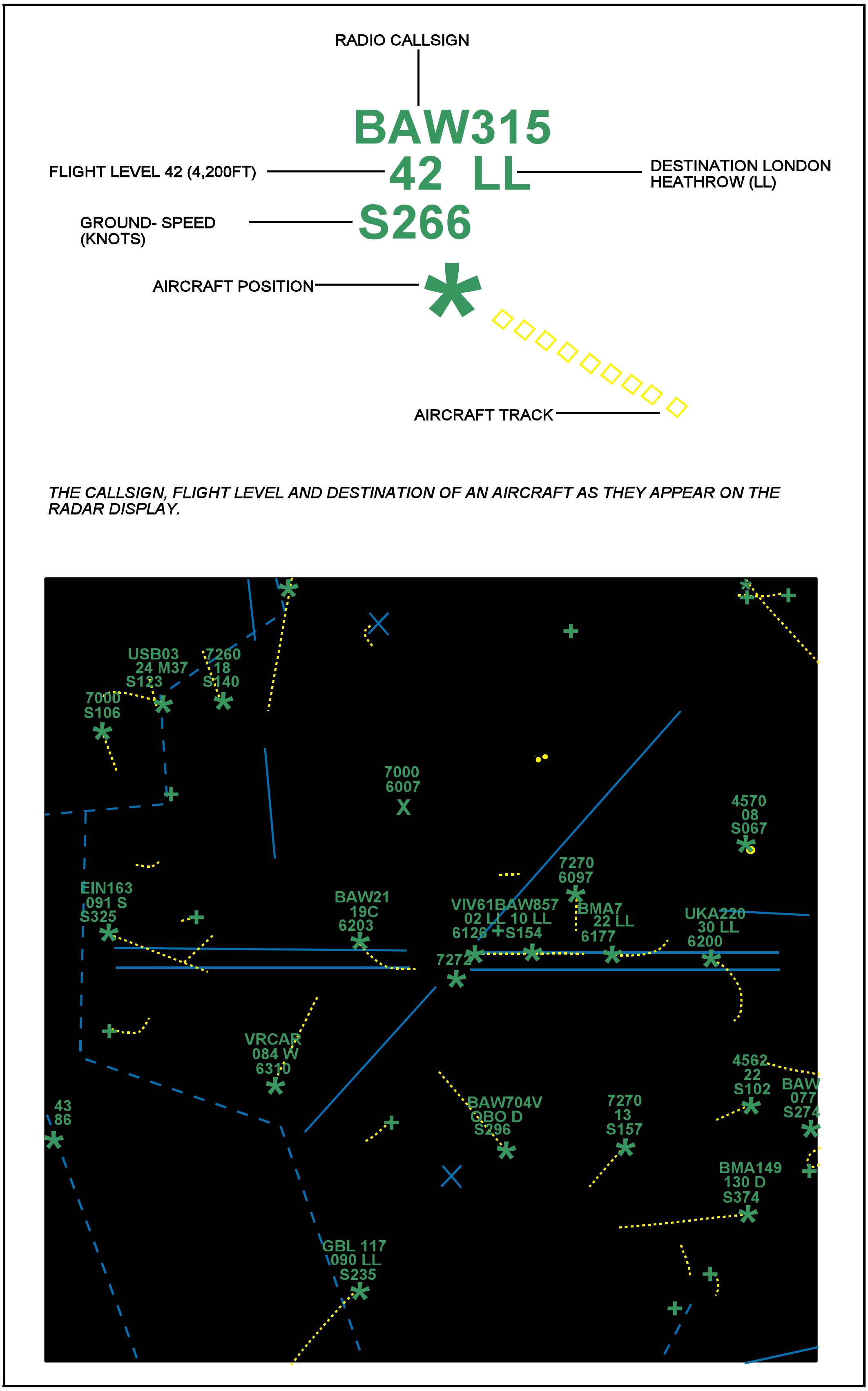


Figure 14.3 A Radar Display Showing Positions of Aircraft in the London TMA

SSR FREQUENCIES AND TRANSMISSIONS

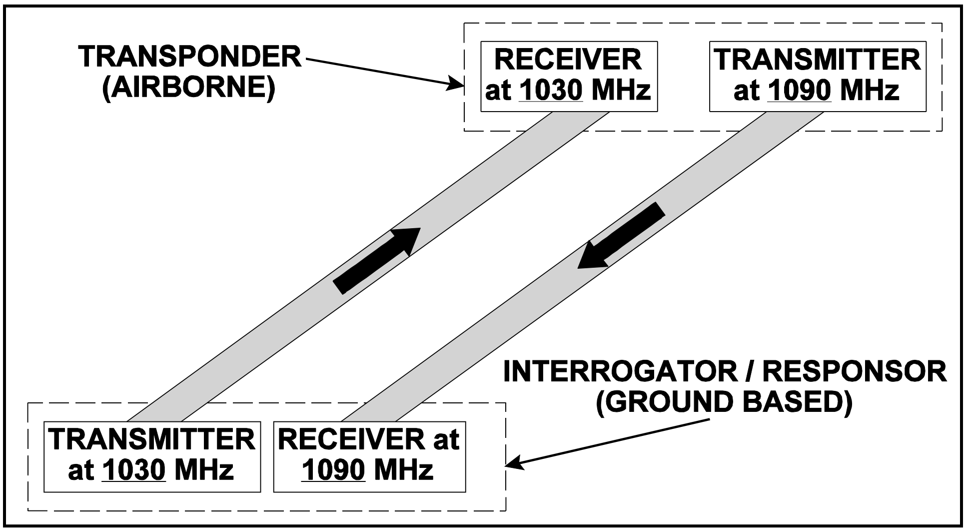


Figure 14.4 SSR operates in the UHF Band

The ground station **transmits/ interrogates** on **1030MHz** and **receives** on **1090MHz**. The aircraft **receives** on **1030MHz** and **transmits/transponds** on **1090MHz**. 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 pre-determined series of pulses on the carrier frequency of 1030MHz; its transponder then transmits a coded reply on a carrier frequency of 1090MHz. 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 2μsec. The spacing between P1 and P3 is 8μsec for a Mode A and 21μsec for a Mode C interrogation.

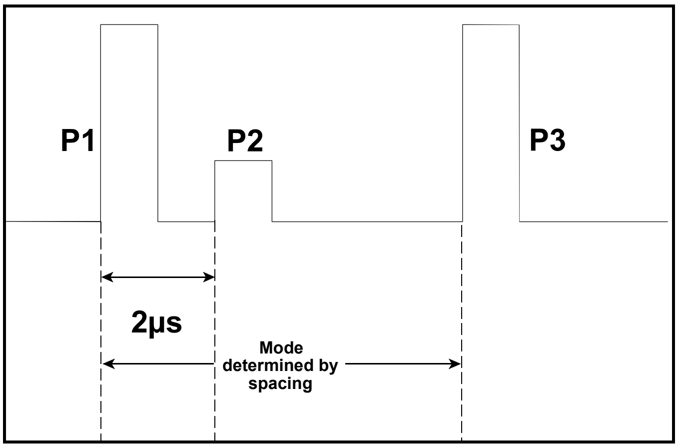


Figure 14.5 Modes

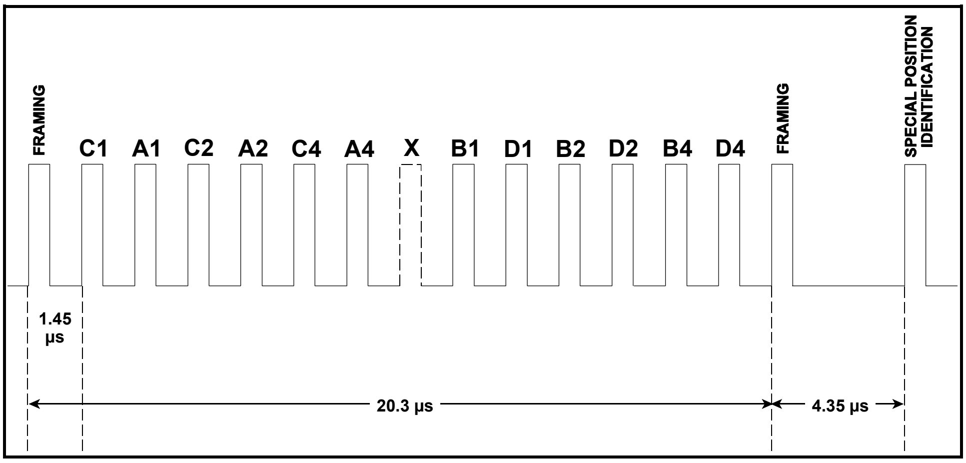


Figure 14.6 SSR Reply Pulse Patterns

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, 20.3μsec 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**".

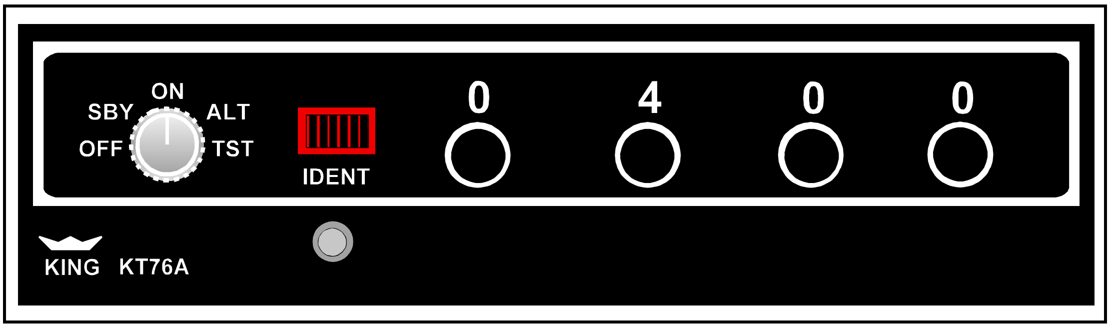


Figure 14.7 Transponder Controls and Indicators

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 1013.2mb**, 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 128,000ft, with an output change (based upon 50ft increments or decrements) **every 100ft** 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 6450ft to 6445ft 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 100ft. 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 300ft** between the level readout 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 ± 200ft 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.

- **2000** To provide recognition of an aircraft which has not received any instructions from ATC units to operate the transponder e.g when entering the United Kingdom airspace from an adjacent region where the operation of transponders has not been required.

Conspicuity Code in the UK
When operating at and **above FL100** pilots shall select code **7000** and 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 code 7000 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 Readout
This will be in 25ft 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.

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 25ft 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 25ft intervals there is no intention to change the existing practice of displaying altitude information to the controller in 100ft increments.*

APPENDIX 11 A
[NOT STATED IN JAA OBJECTIVES]

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 (callsign used in flight).
- Transponder Capability Report.
- Altitude reporting in 25ft 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 callsign, pressure altitude or FL, groundspeed, 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 (20.6 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 100ft (±50ft from given level) Switch off if difference > 300ft (200ft UK)
Special codes	7700 - emergency, 7600 - radio failure, 7500 – hijacking 2000 - when no instructions given, 7000 - conspicuity code in UK.
Disadvantages	Garbling - overlapping replies if aircraft <1.7nm apart **of SSR** Fruiting - interference caused by replies to other interrogation. Limited codes (4096), Ghosts, Shielding.
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 readout in increments of 25ft .
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 _______, entering UK airspace _______, unlawful interference with the conduct of the flight ________.

    a. 7700; 7600; 2000; 7500.
    b. 7700; 7600; 7500; 2000.
    c. 7600; 7500; 2000; 7700.
    d. 7500; 7600; 2000; 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, 4.35μ sec before the last framing pulse.
    c. an identification pulse is automatically and continuously transmitted for 10 seconds, 4.35μ sec after the last framing pulse.
    d. an identification pulse is automatically and continuously transmitted for 20 seconds, 4.35μ sec 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 ______ feet 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. The SSR code which is appropriate for a UK FIR (inbound. crossing, where no other "squawk" has been allocated is:

    a. 7500
    b. 7600
    c. 7700
    d. 2000

6. 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	A
2	D
3	D
4	B
5	D
6	C

CHAPTER FIFTEEN

TRAFFIC COLLISION and AVOIDANCE SYSTEM (TCAS)

Contents

INTRODUCTION

Today's higher traffic densities and greater speed differences have generated a need for an Airborne Collision Avoidance System. Although ICAO named it ACAS it is usually known as Traffic Alert and Collision Avoidance System (TCAS). The system is designed to provide an additional margin of safety and keep commercial aircraft clear of conflict, independently of Air Traffic Control. An aircraft must carry a transponder and have the facility to interrogate other aircraft transponders. Of the four proposed systems, TCAS I, II, III and IV, TCAS I and II fulfill present and future requirements. Aircraft built to carry more than 30 passengers must have an approved system for flight in the USA.

TCAS I

TCAS I is a first generation collision avoidance system and simply warns the crew of other traffic in the vicinity of their aircraft. It will detect and display range and approximate relative bearing. If the TCAS display aircraft and the intruder are carrying Mode C relative altitude will also be displayed. It encourages flight crew to look for the conflicting traffic by generating visual and aural warnings - TRAFFIC ADVISORIES (TAs):

"Traffic, Traffic"

It does not give any resolution advisory information. i.e a course of action to follow. The FAA requires smaller aircraft, with 30 or fewer seats, to carry TCAS I.

TCAS II

TCAS II detects intruders in the TCAS aircraft's vicinity, assesses the collision risk and presents warnings to the crew in the form of TAs and Resolution Advisories (RAs) e.g.:

"Climb" "Increase Climb" Descend" "Increase Descent" Monitor Vertical Speed"

Thus, RAs offer manoeuvring advice in the vertical plane to resolve conflict. If your aircraft and the intruder both have Mode S data-link transponders the system will co-ordinate the RAs to provide complimentary vertical avoidance instructions. The rest of this chapter deals with TCAS II only and discusses both visual and audible TAs and RAs in detail.

PRINCIPLE

TCAS II operates on the secondary radar principle using the normal SSR frequencies of 1030MHz and 1090MHz, but in an air to air role. Using this principle the TCAS system creates two protective three dimensional bubbles around the TCAS equipped aircraft (Figure 15.1.)

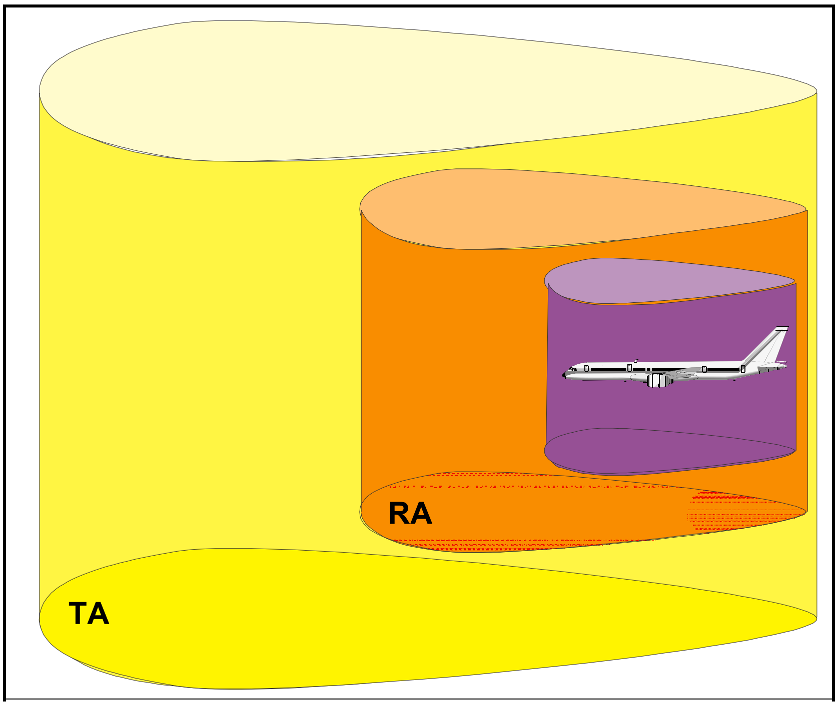


Figure 15.1

AIRCRAFT EQUIPMENT

For aircraft to be visible to a TCAS equipped aircraft they must have a minimum of A Mode "A" Transponder. If the transponder is switched off, or is unserviceable, the intruding aircraft are invisible to the TCAS equipment and a collision risk exists. Mode A transponders transmit no height information and therefore the information available to the TCAS equipment is two dimensional only and therefore can only give TAs.

Mode "C" Transponder equipped intruders broadcast height information to the TCAS equipment and the system becomes three dimensional and can now give both TAs and RAs. Mode "S" Transponder TCAS equipped intruders as well as broadcasting height information allow a discrete data link to be established between them. This data link will allow avoidance manoeuvres to be mutually resolved.

OPERATION

The range of an intruder is determined by measuring the time lapse between transmission of an interrogation and receiving the response. (Radar Principle). The bearing of an intruder is determined by a directional antenna (Figure 4.2). Because of the wavelengths involved and the necessarily small size of the antennas bearing resolution is the least accurate parameter. TCAS never offers collision avoidance commands in the horizontal plane; only in the form of climb or descend.

The relative height of an intruder is found by comparing its Mode "C" height with the TCAS equipped aircraft's height.

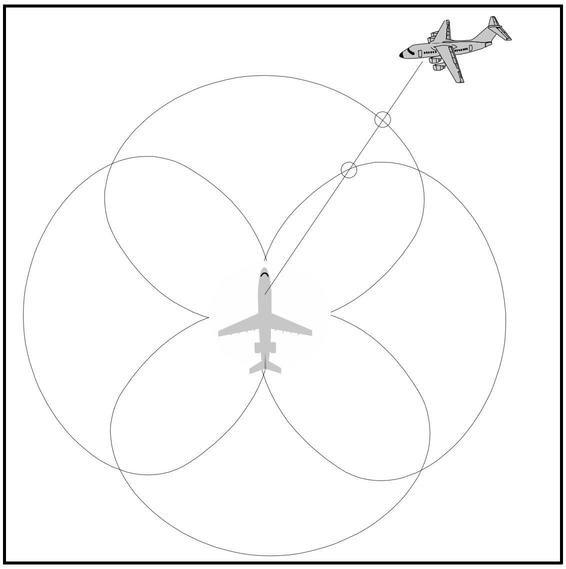


Figure 15.2 TCAS Bearing Determination

SYSTEM INTERCONNECTIONS

Figure 15.3 shows a TCAS installation in a Commuter/Feeder airliner. The heart of the system is the TCAS receiver-transmitter-computer unit controlled by a combined ATC/SSR/TCAS control panel. The TCAS displays in this installation are a dedicated TCAS Plan Position Indicator (PPI), and the red and green sectors on the Vertical Speed Tape of the Primary Flight Display (PFD) Electronic Attitude Director Indicator (EADI). A synthetic voice issues TCAS commands over the intercom system.

The TCAS upper and lower antennas are directional while the Mode "S" antennas are omni-directional.

The TCAS also has feeds from the Radio Altimeter to modify the RAs received when in close proximity to the ground i.e. there are no instructions given at all when the aircraft is below 400ft agl, no descent RAs are given below 1000 ft agl and no increase rate of descent commands below 1400 ft agl. The system will also take aircraft configuration / performance into consideration when deciding an avoiding action. When the aircraft has gear and / or flap deployed its climb performance will be poor so TCAS will avoid giving climbing demands for a RA.

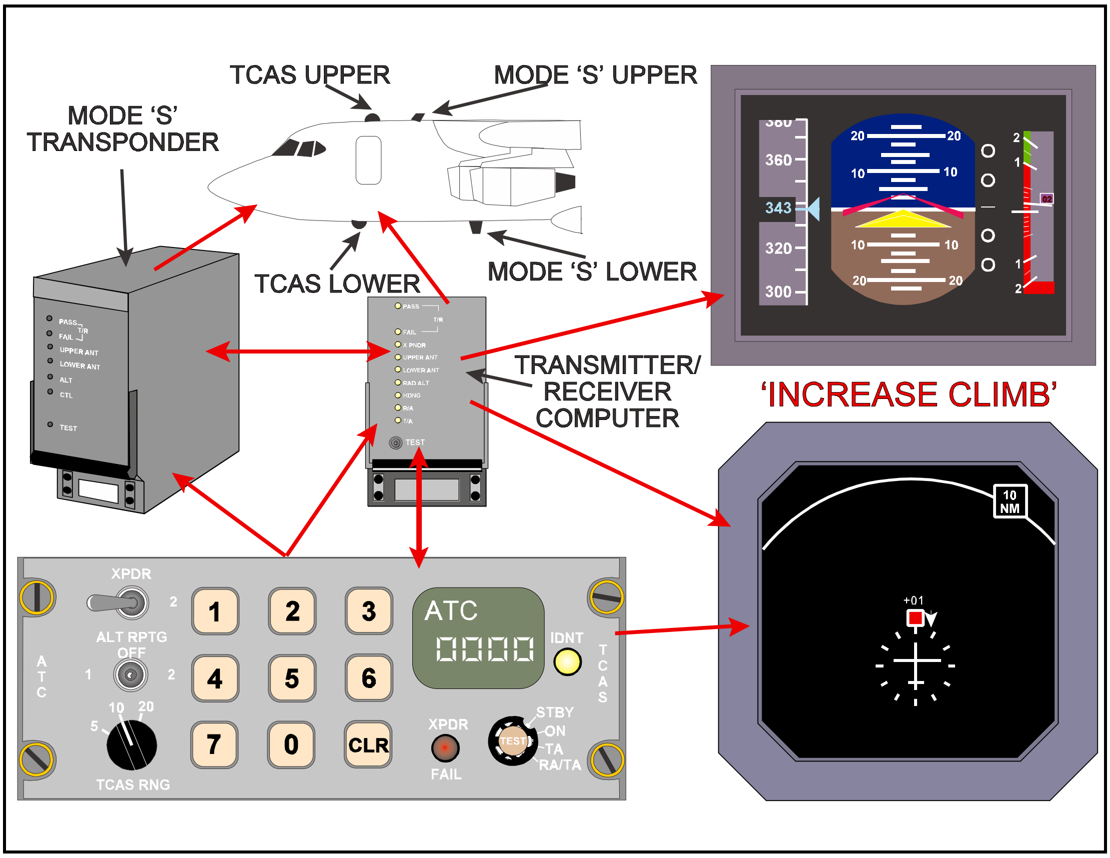


Figure 15.3 TCAS Aircraft Installation

SYNTHETIC VOICE PRIORITISATION

Modern aircraft use a synthetic voice to give warning advice to the crew. The voice is used for various systems including Windshear detection, Ground Proximity Warnings, including height call outs, and TCAS. The synthetic voice is prioritised as follows:

1. **Stall Identification/Stall Prevention**. (Stick Shake/Stick Push). The synthetic voice is inhibited during stick shake/stick push operation.

2. **Windshear.** The detection of performance decreasing windshear takes first priority with the synthetic voice, inhibiting both GPWS and TCAS warnings.

3. **Ground Proximity Warning System** (GPWS). Detection of approach to terrain takes priority over TCAS announcements.

TRAFFIC ADVISORIES (TAs) RESOLUTION ADVISORIES (RAs).

Depending upon the setting of the TCAS function switch on the control panel, the equipment level of intruder aircraft and the phase of flight of the TCAS aircraft, TCAS will generate the following.

Traffic Advisories (TAs) exist when an intruder penetrates the outer bubble caution area and is between 45 and 35 seconds from the collision area. TA's appear as solid amber circles on the TCAS display and are accompanied by the synthetic voice saying "Traffic, Traffic". This is a potential collision threat.

Resolution Advisories (RAs) exist when an intruder penetrates the inner bubble warning area and is between 30 and 20 seconds from the collision area. RA's appear as solid red rectangles on the TCAS display accompanied by various synthetic voice warnings. RA's indicate a serious collision threat.

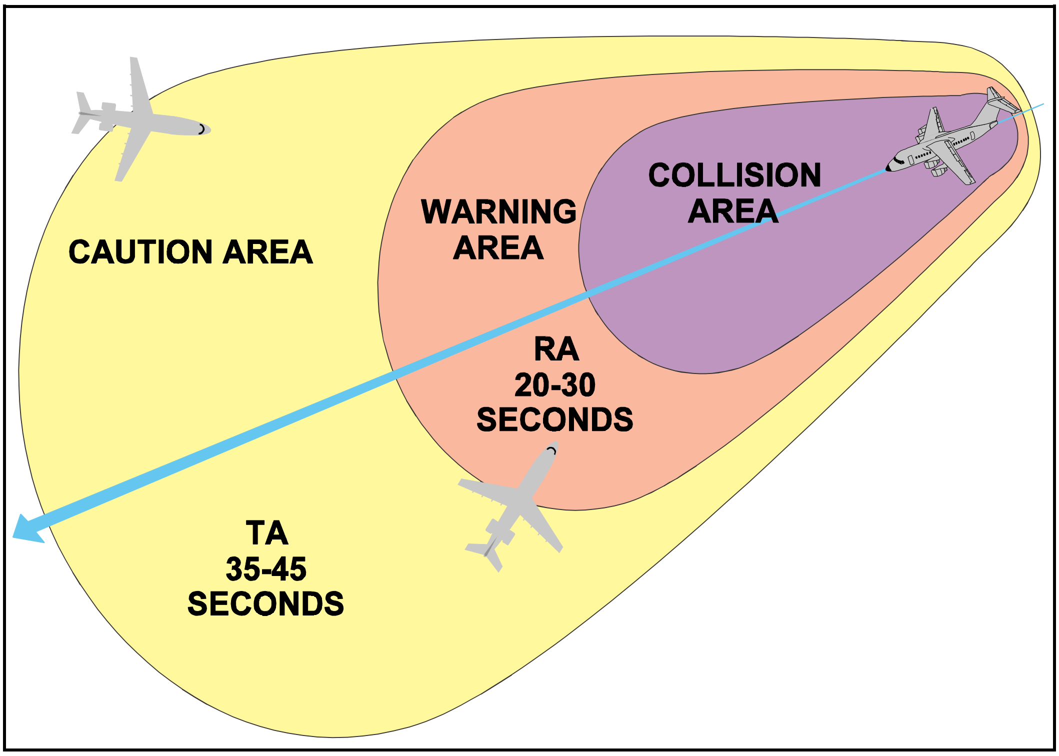


Figure 15.4

Resolution Advisories come in two forms:

Preventative Advisories are situations where no collision risk exists unless a change of level is initiated by either aircraft. The synthetic voice advisory is "Monitor Vertical Speed"

Corrective Advisories are situations where a collision risk exists and a manoeuvre is necessary to avert it. The synthetic voice produces the appropriate command.

Figure 15.5 shows examples of Preventative and Corrective RA's displayed on the Vertical Speed tape of the Primary Flight Display.

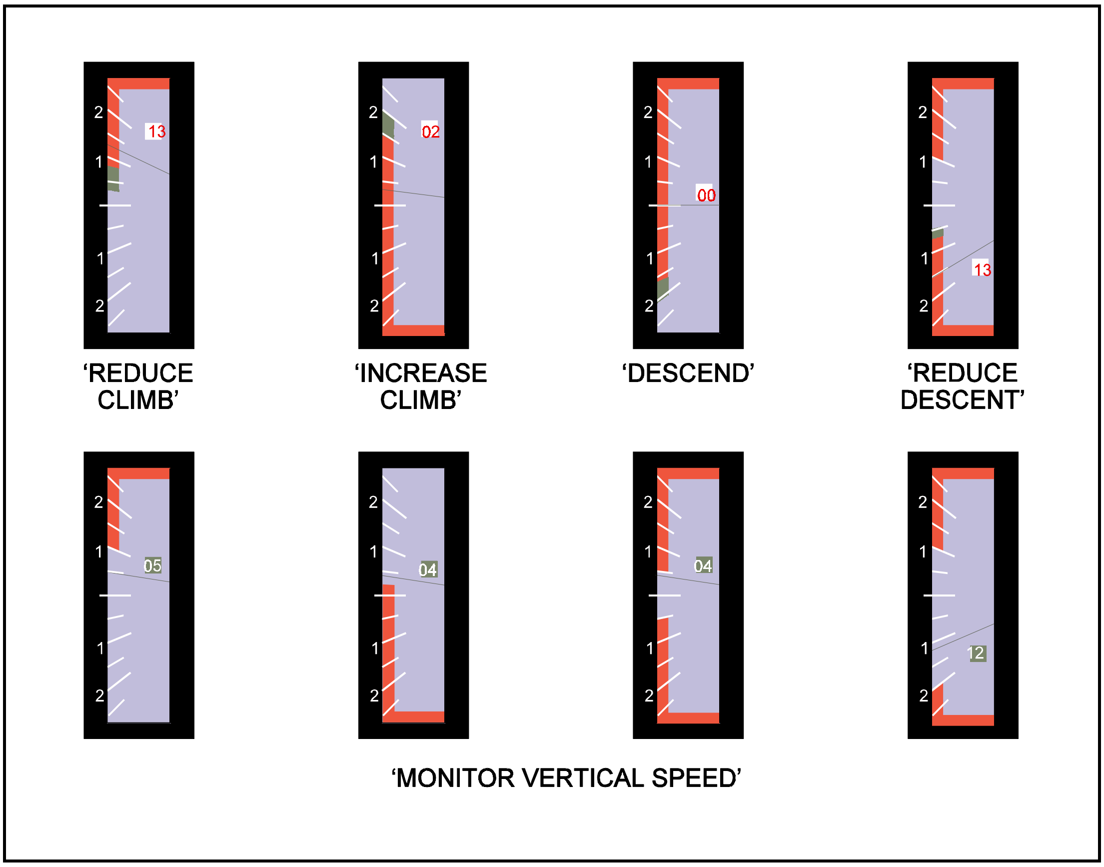
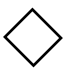


Figure 15.5 Corrective and Preventative Resolution Advisories.

PROXIMATE TRAFFIC/OTHER TRAFFIC

See Figures 15.6, 15.7 and 15.7a

Proximate Traffic appears as a solid cyan diamond and represents transponder equipped aircraft within range of the display and within +/- 1200 feet relative height. TCAS does not consider this traffic a threat and displays it to improve crew situational awareness.



Other Traffic appears as hollow cyan diamonds which represent transponder equipped aircraft within range of the display and within +/- 2700 feet relative height (+/- 8700 dependant on position of ABOVE and BELOW switch). Again it is displayed to improve situational awareness.

The predicted flight paths of Proximate and Other Traffic do not penetrate the Collision Area of the TCAS aircraft.

DATA TAG

The traffic symbols may also have an associated altitude TAG which shows relative altitude in hundreds of feet, to indicate whether an intruder is climbing, flying level or descending:

A + sign and number above the symbol means an intruder is above the aircraft.

A trend arrow ↑ or ↓ appears alongside the symbol when the intruder's vertical rate is 500 feet per minute or greater.

No altitude number or trend arrow will appear beside an intruder that is non altitude reporting. If TCAS II direction finding techniques fail to locate the azimuth of another aircraft a no bearing message appears on the screen.

OFF SCALE TRAFFIC ADVISORY

When TCAS is tracking an intruder that is outside the selected display range, but has entered the caution or warning areas, one-half of the appropriate symbol will appear at the appropriate bearing at the edge of the display area. The symbol will appear in its proper colour and have its data tag displayed providing there is room. See Figure 15.10.

TCAS DISPLAYS

TCAS range and bearing information can appear on a variety of displays:

Dedicated Plan Position Indicator

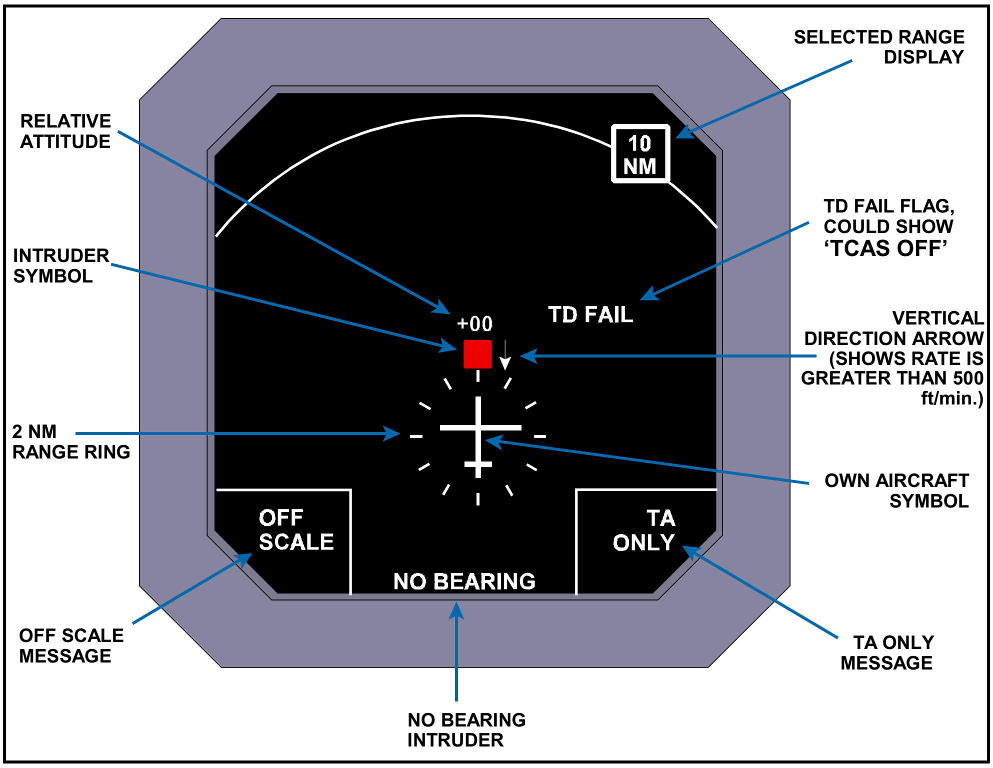


Figure 15.6 TCAS PPI

Electronic Vertical Speed Indicator

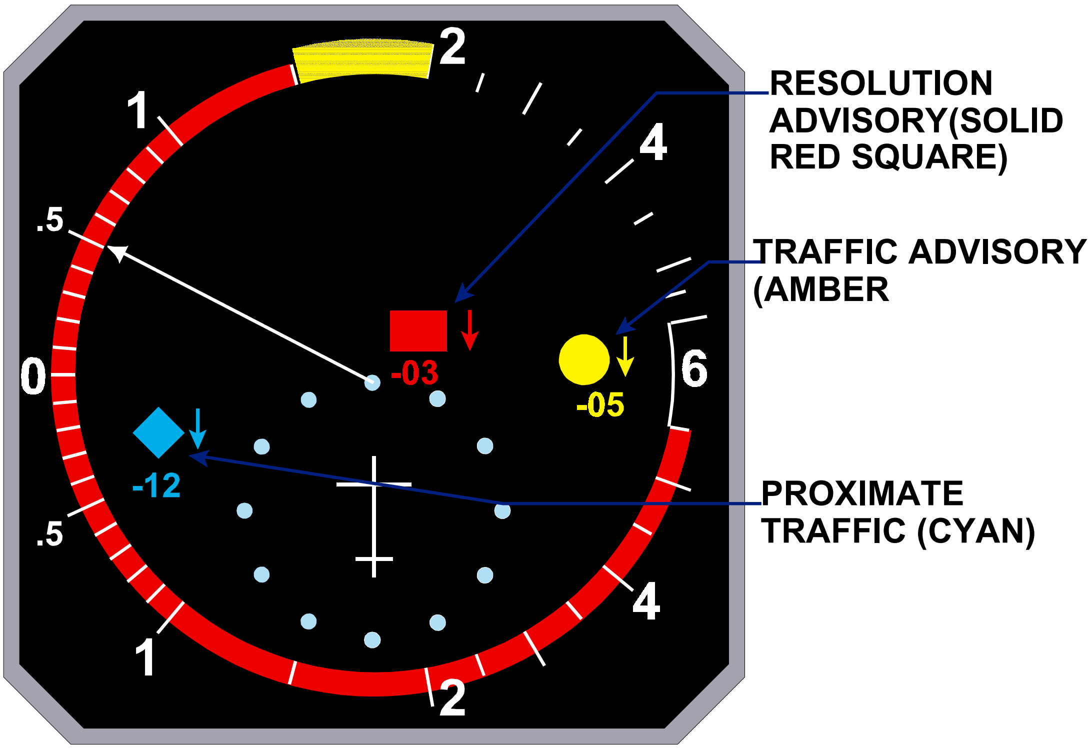


Figure 4.7 Electronic VSI.

Superimposed on Navigation Display of EFIS equipped aircraft

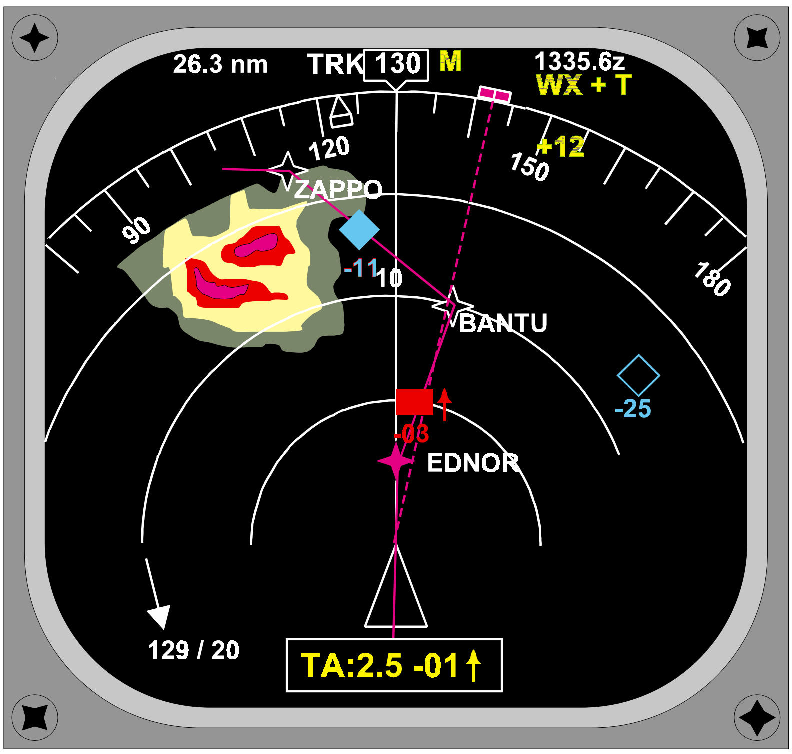


Figure 4.7a Navigation Display in MAP Mode Showing TCAS

COMBINED TCAS AND SSR CONTROL PANEL

The control panel is produced in various forms but all perform the same functions.

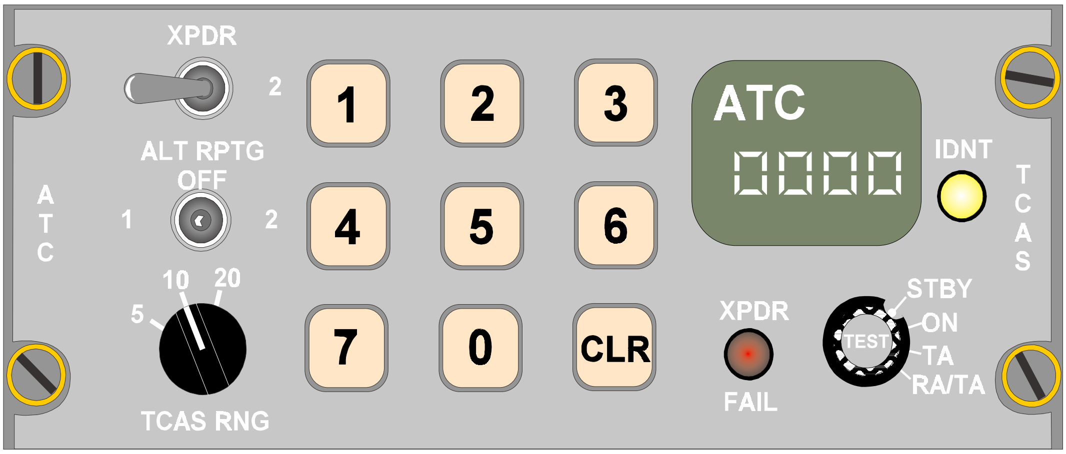


Figure 4.8 ATC Transponder/TCAS Control Panel

The TCAS controls are as follows:

Function Switch

- Standby - warm-up power is applied to the system, but it is not operational.
- On - the transponder only is operational.
- TA - the transponder and TCAS are now operational but only Traffic Advisories are generated. "TA ONLY" will be indicated on the TCAS display.
- RA/TA - the transponder and TCAS are operational and both Resolution Advisories and Traffic Advisories are generated.
- TEST - pressing the centre TEST button on the function switch initiates a full Built - in - Test Equipment (BITE) of the system. After completion of a successful test the synthetic voice will respond with "TCAS SYSTEM TEST OK". If the system test is unsuccessful the voice response is "TCAS SYSTEM TEST FAIL".

TCAS RNG (range) selects the range of the TCAS display either 5, 10, or 20nm. It does not alter the range at which aircraft are detected or when warnings are given.

TCAS TRAFFIC ADVISORIES ON ELECTRONIC VSI

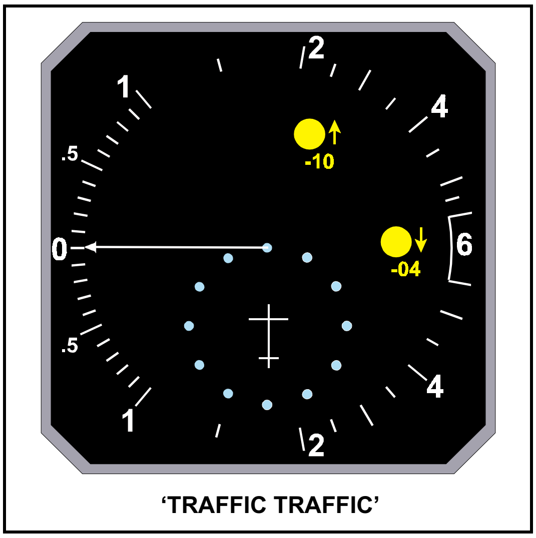


Figure 4.9 Traffic Advisory

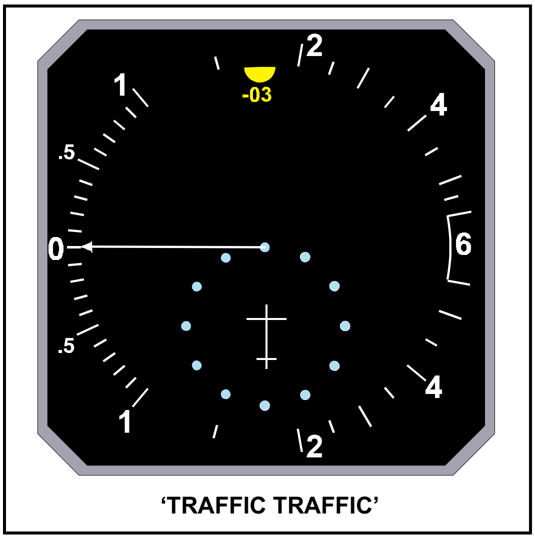


Figure 4.10 Off Scale Traffic Advisory

TCAS PREVENTATIVE RESOLUTION ADVISORIES ON ELECTRONIC VSI

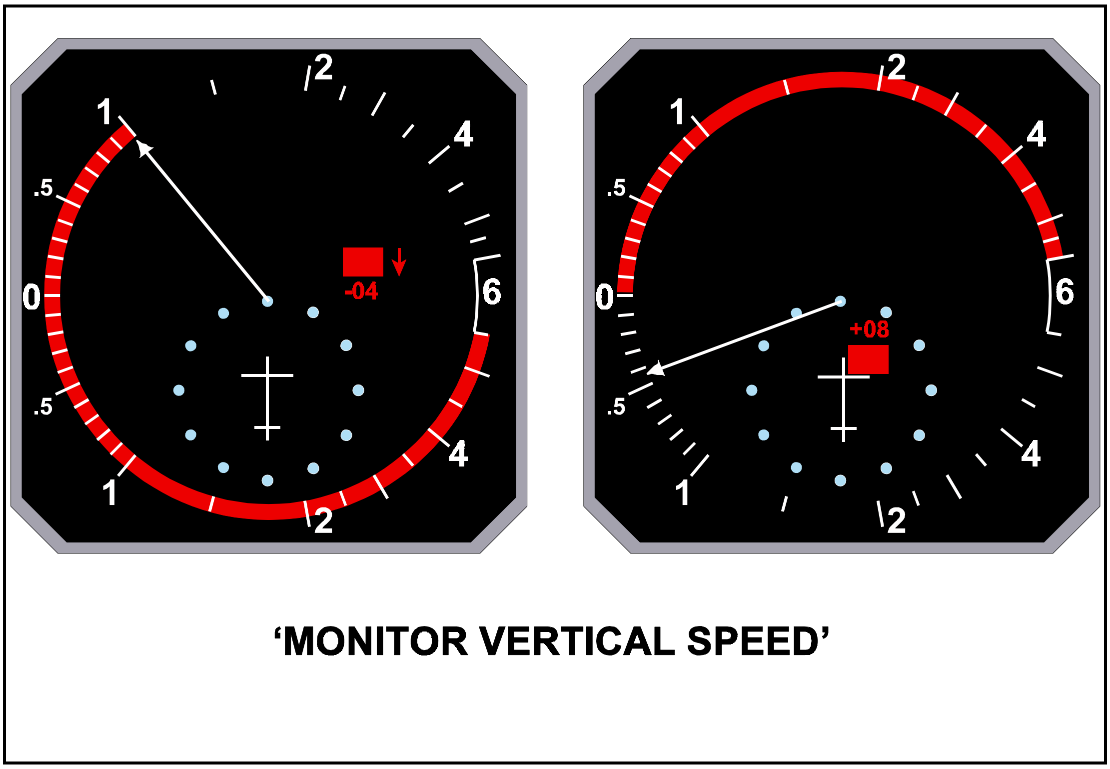


Figure 4.11. Preventative Resolution Advisories

TCAS CORRECTIVE RESOLUTION ADVISORY ON ELECTRONIC VSI

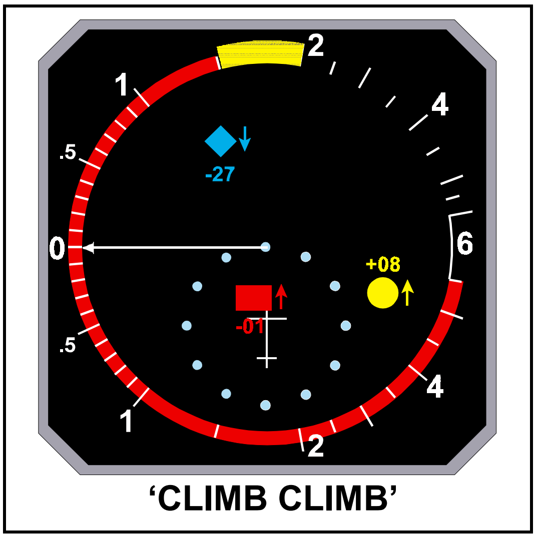


Figure 4.12 Corrective RA

TCAS TEST FORMAT ON ELECTRONIC VSI

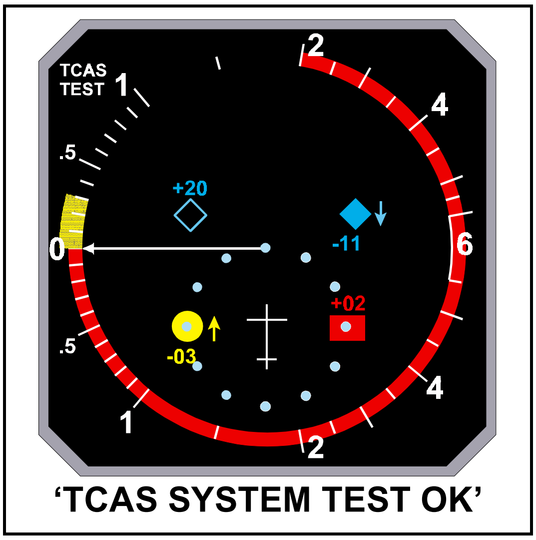


Figure 4.13 Test Display

NO BEARING ADVISORIES

If TCAS is unable to track the bearing of an intruder, possibly due to antenna screening, the RA or TA will appear lower centre of the display appropriately colour coded. Up to two lines of information can be displayed.

"TA 2.2- 04" means the intruder is creating a TA 2.2 nm away 400 below and the up arrow indicates the intruder is climbing at 500 fpm or greater.

It is important to realise that TCAS' ability to compute a Traffic or Resolution Advisory is not degraded by lack of bearing information.

Figure 4.14 No Bearing RA and TA

ACTION TO BE TAKEN ON RECEIVING TA's AND RA's

Refer to CAP 579

- Action on Receiving a TA. TAs alert flight crews to the possibility that an RA may follow, which could require a flight path change. Flight crews should assimilate the information provided by the TA and commence a visual search of that part of the sky. They should also prepare to respond to an RA if the situation worsens. If the potential threat cannot be seen and continues to give cause for concern flight crews should seek advice from ATC. (Para. 6.1.1/2)

- Action on Receiving an RA. Pilots are to initiate the required manoeuvre immediately, adjusting flight path, aircraft power and trim accordingly. Crew members not involved in executing this manoeuvre should confirm that the sky ahead is clear of other aircraft and continue the visual search for the established threat. They are to inform ATC as soon as possible of any deviation from an ATC clearance. (Para. 6.2.3)

- Disregarding RA's. Manoeuvres should never be made in a direction opposite to that given in an RA; this is because the sense may have been determined following an exchange of data with the established threat. For this reason:

  - RA's may be disregarded only when pilots visually identify the potentially conflicting traffic and decide no deviation from the current flight path is needed.

  - If pilots receive simultaneously an instruction to manoeuvre from ATC and an RA, and both conflict, the advice given by TCAS should be followed.

STANDARD R/T PHRASEOLOGY

Notification of a manoeuvre in response to an RA.

Pilot: TCAS climb (or TCAS descent).
Controller: roger.

after "clear of conflict".

Pilot: Returning to xxxxft/flxxx (details of assigned clearance).
Controller: roger; a revised clearance may then be issued.

inability to comply with ATC instruction.

Controller: climb (descend) flxxx.
Pilot: Unable to comply, TCAS RA..

Further reading: cap 579 airborne collision avoidance systems (ACAS): guidance material.

QUESTIONS

1. On receipt of a TCAS RA your action is to:

   a. initiate the required manoeuvre immediately.
   b. make a note of the details.
   c. request a flight clearance deviation from ATC.
   d. Do nothing until a TA is received.

2. Which of the following statements concerning TCAS is correct:

   a. TCAS 2 provides avoidance instructions in the vertical and horizontal planes.
   b. TCAS 2 cannot provide information on non-SSR equipped intruders.
   c. TCAS 2 requires Mode S to be fitted to other aircraft.
   d. TCAS 2 provides advice on which way to turn.

3. With reference to Traffic Collision Avoidance Systems. The difference between TCAS I and II is that:

   a. TCAS II can provide Traffic Advisories and Resolution Advisories whilst TCAS I can only provide Traffic Advisories .
   b. TCAS II can only be fitted to large aircraft which carry more than 30 passengers. Whilst TCAS I can be fitted to any aircraft.
   c. TCAS I can be fitted to aircraft which carry transponders with Mode A only whilst TCAS II can only be fitted to aircraft whose transponders include either Mode C or Mode S.
   d. TCAS II can only be fitted to aircraft which are equipped with EFIS.

4. The aural messages provided by TCAS II are:

   a. Threat, Climb; Threat, Descend.
   b. Climb left; Climb right; Descend left; Descend right.
   c. Climb; Descend; Increase climb; Increase Descent.
   d. Turn left, Turn Right, Increase Turn, Decrease Turn

5. With reference to Traffic Collision Avoidance Systems:

   a. RAs may be disregarded only when the pilot visually identifies the potentially conflicting traffic and decides that no deviation is necessary and has the clearance confirmed by ATC.
   b. RAs may be disregarded only when the pilot visually identifies the potentially conflicting traffic and decides that no deviation is necessary and has advised ATC of the other aircraft's proximity.
   c. RAs must never be disregarded.
   d. RAs may be disregarded only when the pilot visually identifies the potentially conflicting traffic and decides that no deviation is necessary.

ANSWERS

1	A
2	B
3	A
4	C
5	D

CHAPTER SIXTEEN

DISTANCE MEASURING EQUIPMENT (DME)

Contents

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)

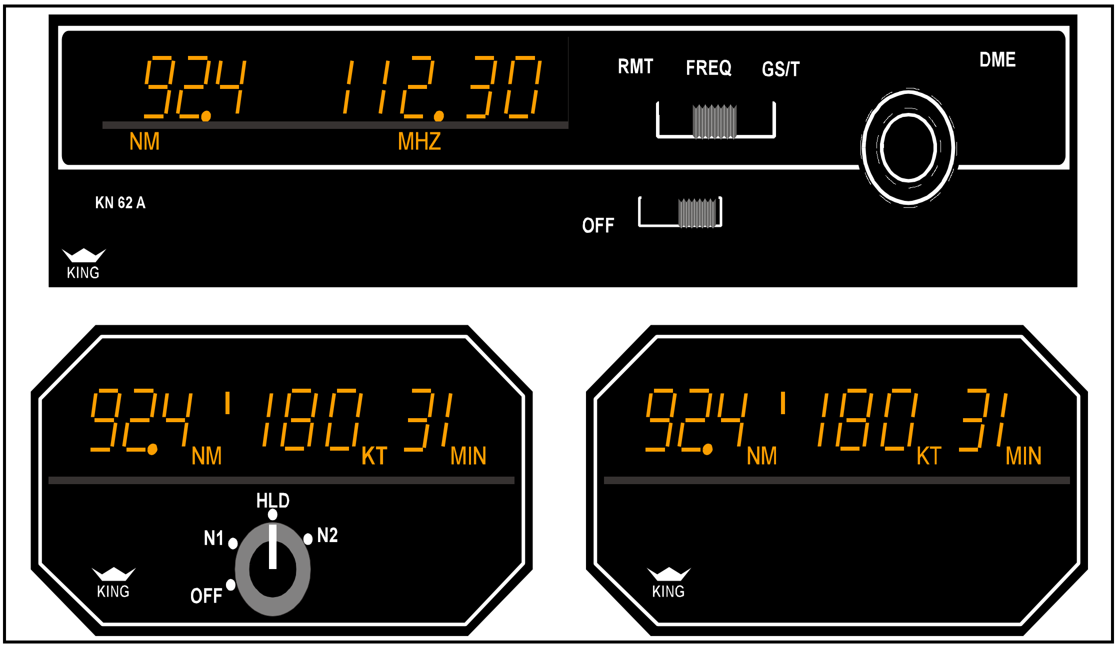


Figure 16.1 Distance Measuring Equipment

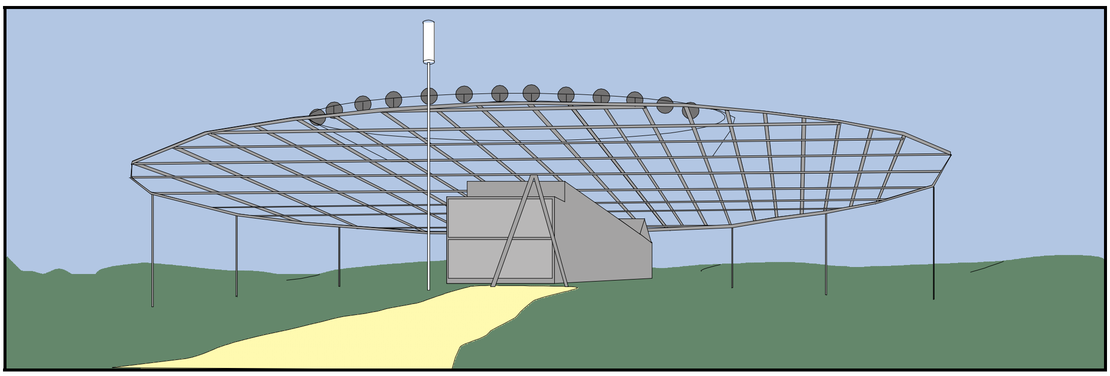


Figure 16.2 A Combined Doppler VOR/DME

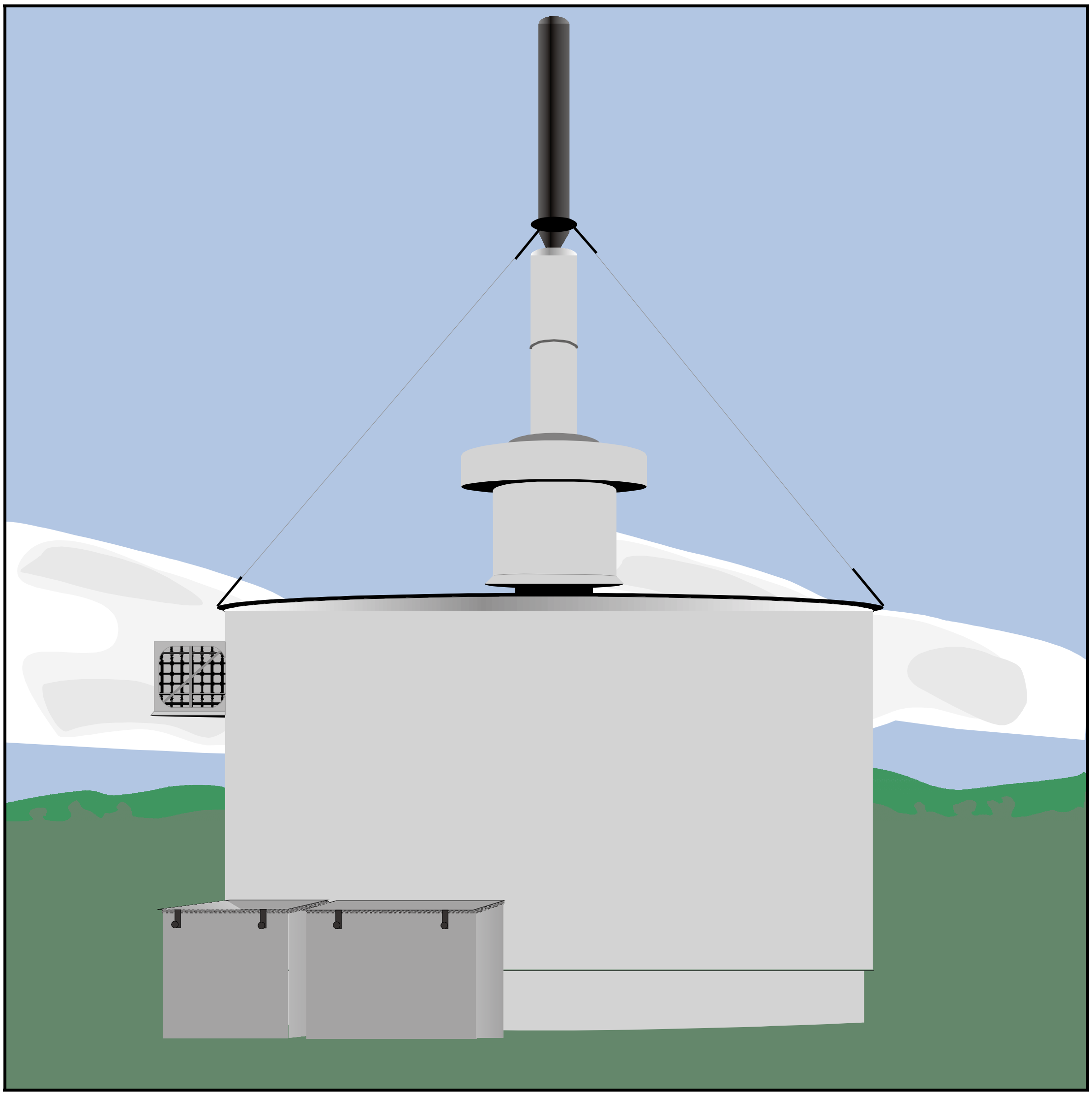


Figure 16.3 A Conventional VOR Installation Surmounted by a DME Antenna

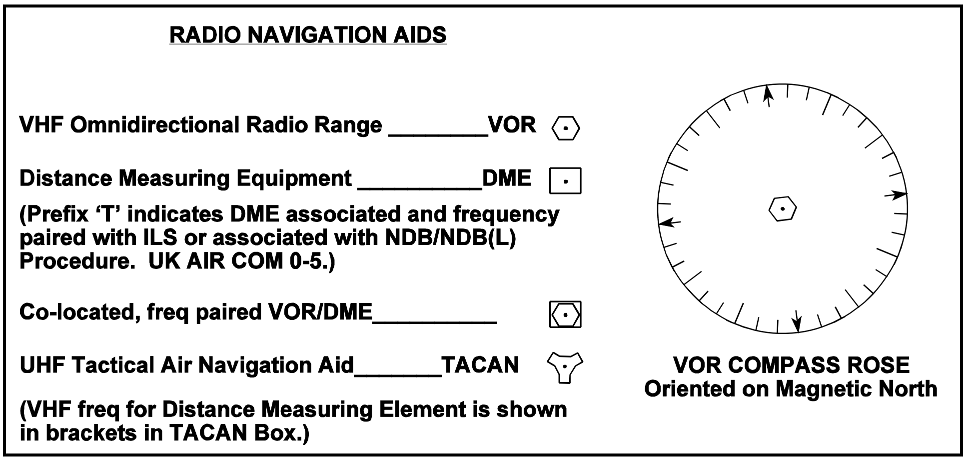


Figure 16.4 DME, VOR and Tacan Presentation - Topographical Chart

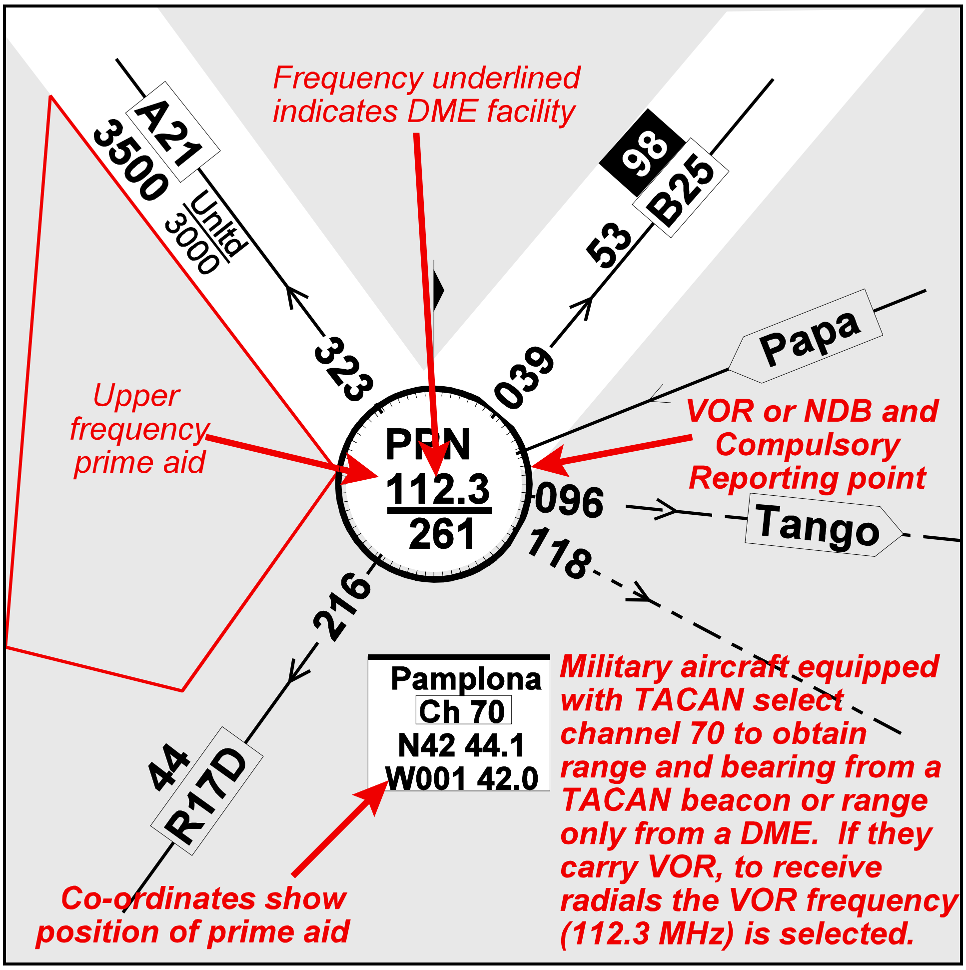


Figure 16.5 DME and VOR Presentation - AERAD Airways High Level Chart

FREQUENCIES

Channels

DME (emission code P0N) is a **secondary radar** system operating between **962 and 1213MHz** in the **UHF** band at 1MHz spacing; this provides 252 spot frequencies or channels.

There is always **a difference of +/- 63MHz** 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	1194MHz	Channel 107X	116.0MHz
OX DME	1148MHz	1211MHz	Channel 124X	117.7MHz

DME Paired With ILS Localiser Transmitter
DME is also frequency paired with the **ILS localiser** 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 computerisation is fitted.
- provides accurate range inputs into the more complex and **accurate RNAV systems**; twin, self selecting DME/DME are used.

PRINCIPLE OF OPERATION

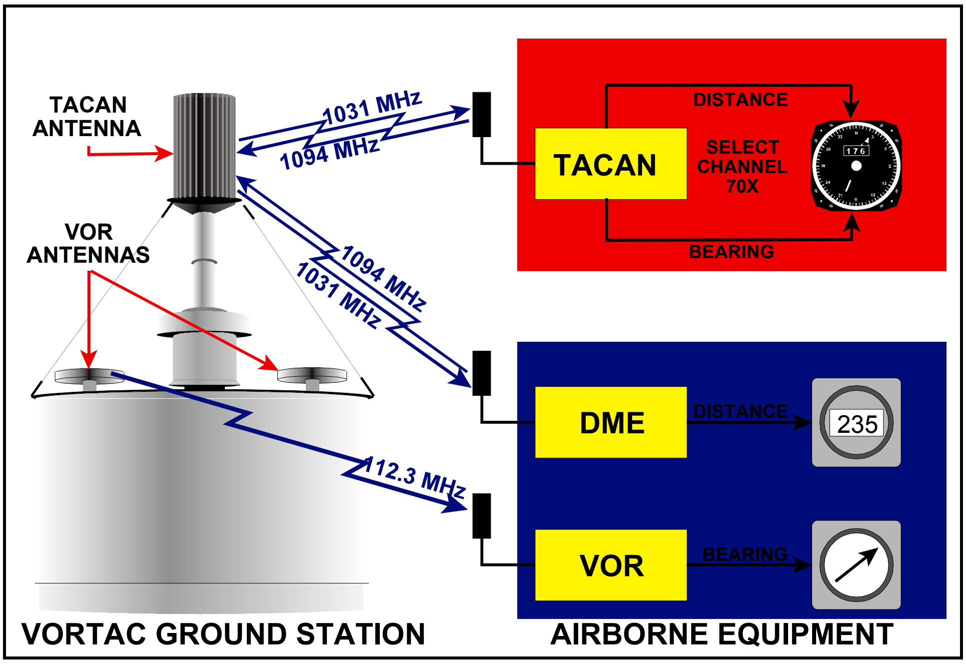


Figure 16.6 VORTAC

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. $3x10^8$ m/s. A modern DME is inherently accurate to **+/- 0.2nm**

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 3.5µ sec (1050m) 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

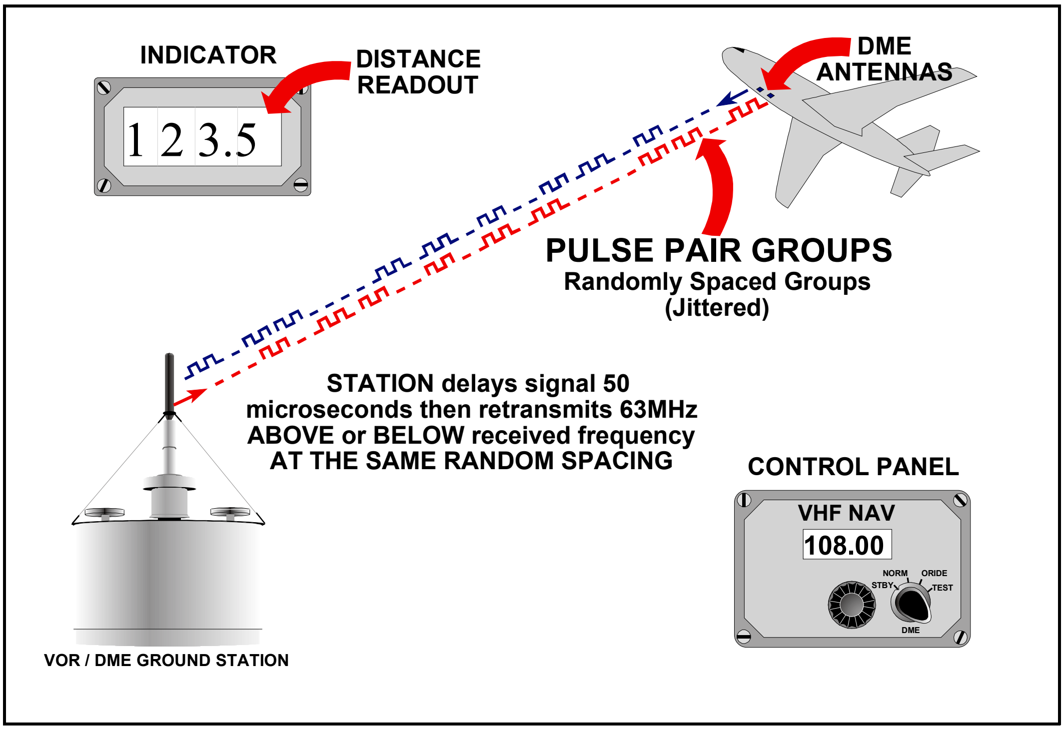


Figure 16.7 The Principle of Range Measurement

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 **randomised 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.

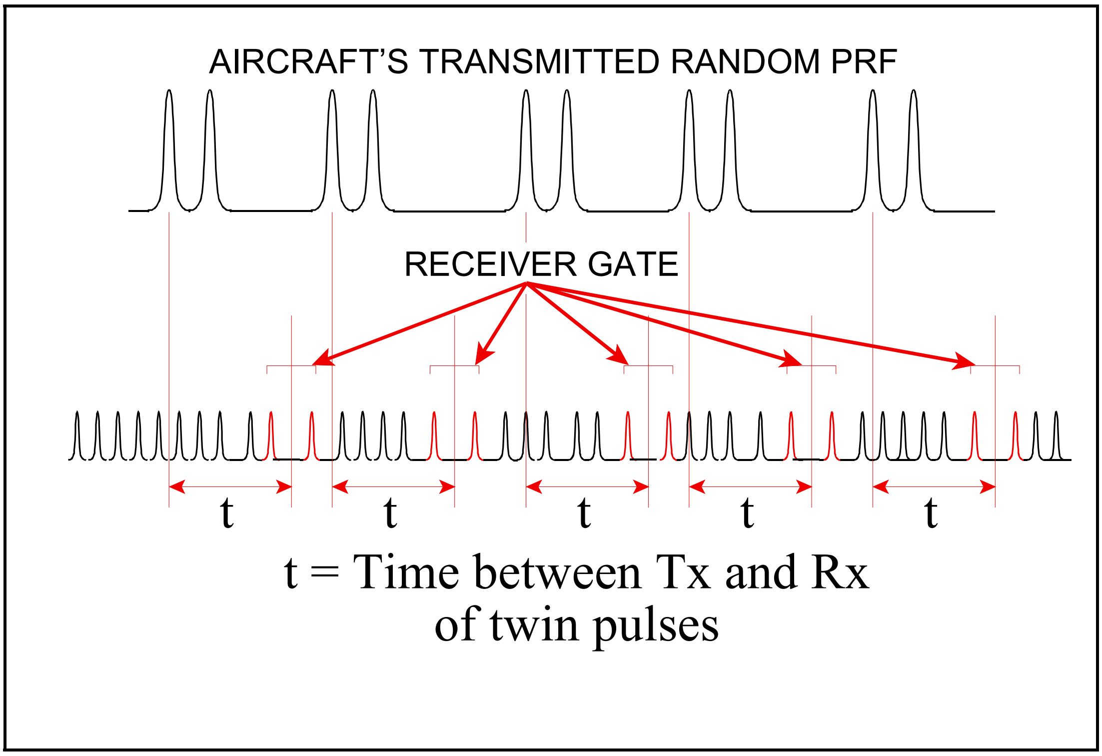


Figure 16.8 Acceptance of Own Pulses

TWIN PULSES

The use by the DME system of twin pulses ensures that the receivers never accept matching randomised 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 for 15000 pulse-pairs** (100 seconds).

If lock-on is not achieved, it will then reduce the rate to **60 pps** and maintains this rate until there is a range lock-on. At lock-on the system operates at a random PRF of **25pps.**

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

It is assumed that 95% of aircraft using a ground beacon will be in the tracking mode (i.e. indicating a slant range), not exceeding an interrogation rate of 25 pulse-pairs per second, with the remaining 5% in either of the search modes. This results in an average of 27 pulse pairs per second required for a lock-on. The search mode at the higher level runs only for a maximum of

100 seconds and the 60 PRF would not be continued in the absence of a range lock-on.

The output of a modern ground beacon is a constant **2700 pulse-pairs per second** which, in the absence of any aircraft interrogations, are being triggered by the noise generated by the receiver increasing its gain, in order to compensate for the lack of aircraft interrogations. When a ground beacon is receiving 2700 pps 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.

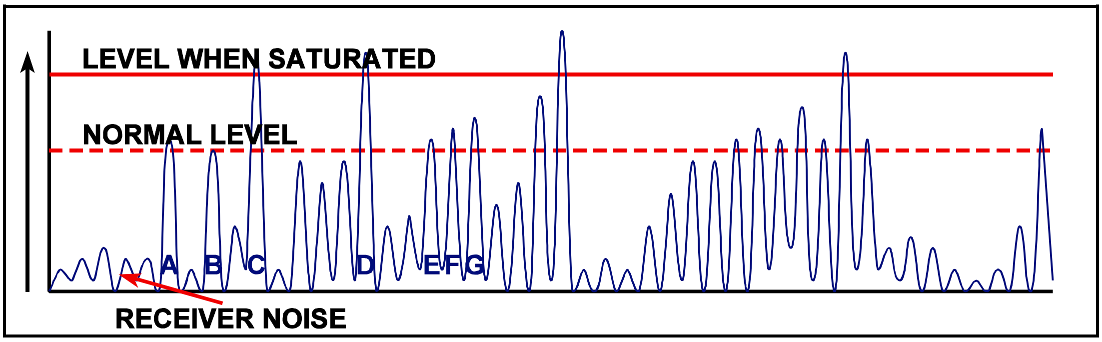


Figure 16.9 Beacon Saturation

In Figure 16.9 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 callsign 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 callsign arrangements of VOR/DME or VOR/TACAN facilities.

RELATIVE POSITIONS OF VOR/DME OR TACAN	FREQUENCIES	IDENTIFICATION
ASSOCIATED:		BOTH TRANSMIT THE SAME CALLSIGN
(i) BOTH TRANSMITTERS CO-LOCATED, or	PAIRED	THERE ARE FOUR IDENTS' EVERY 30 sec PERIOD
(ii) THE MAXIMUM DISTANCE BETWEEN BOTH TRANSMITTERS IS <u>30m/100' IN TMAs</u>, or	PAIRED	THE VOR TRANSMITS 3 OF THE FOUR
(iii) THE MAXIMUM DISTANCE BETWEEN BOTH TRANSMITTERS IS <u>600m/2000', FOR USE ELSEWHERE</u>	PAIRED	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. >6nm	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 1500m 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) should have errors not exceeding +/-0.2 nm.

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 x 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.

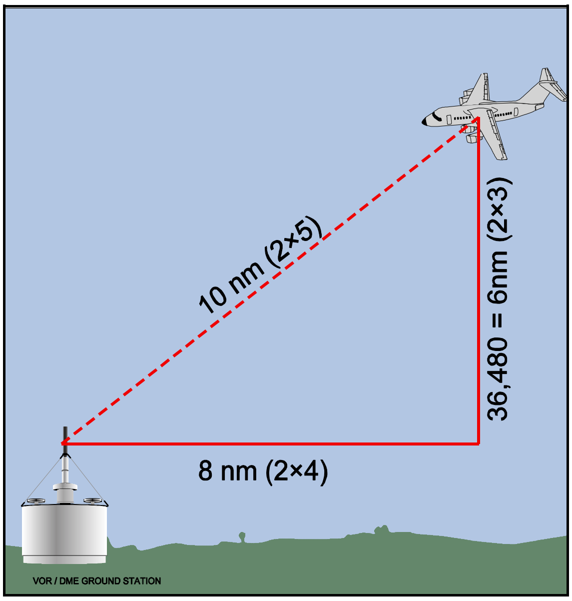


Figure 16.10

Aircraft at 36,840 ft:

$$\frac{36840}{6080} = 6\text{nm}$$

$$10^2 = 6^2 + x^2$$

$$x = \sqrt{100 - 36} = 8\text{nm ground range}$$

Applying the ICAO system accuracy limitations, the ground range is 7.625nm to 8.375nm.

Accuracy of Groundspeed Computation
The equipment's indicated groundspeed, which is computed from the rate of change of slant range, becomes more inaccurate and under-reads the actual groundspeed, 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 groundspeed of zero knots. A groundspeed 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; groundspeed 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 pps - reduced to 60 pps after 15,000 pps - further reduced to about 25 pps at lock-on
Beacon saturation	Occurs at 2,700 pps (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′ in TMA or 2000′ outside TMA - callsigns are the same; frequencies paired
Not associated	- if serving same location then callsign of DME third letter is ‘Z’ - frequencies paired
Separated	- if > 6 nm apart; callsigns 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 x height; Groundspeed 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 synchronised 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 600m 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 30m 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 synchronised 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 400ft amsl. What is the maximum range likely to be achieved?

   ab. 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 feet in a TMA or 2000 feet outside a TMA.
   c. the aerial separation not to exceed 100 metres in a TMA or 2000m 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 0.5nm, 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 feet	200 feet
c.	30m	600m
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:

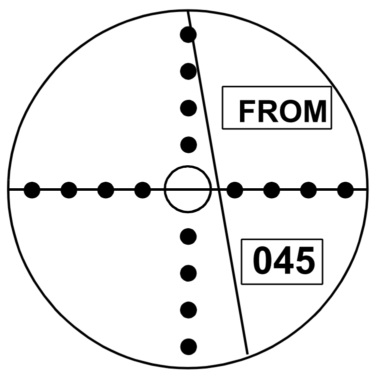
a.	primary	SHF	CW signals
b.	secondary	UHF	twin pulses
c.	secondary	SHF	"jittered pulses"
d.	primary	UHF	pulse pairs

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.

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 in the diagram alongside. At the same time the DME gave a range of 40 nm from the facility. Use the above information to answer the next two questions.

Use the 1 in 60 rule and assume 1 dot equals 2°.



16. At the time of the observation, the aircraft was on the:

a. 042° radial
b. 048° radial
c. 222° radial
d. 228° radial

17. Assuming still air conditions, on regaining the centreline, it will be necessary to make the following alteration of heading:

a. left onto 045°
b. right onto 048°
c. left onto 225°
d. right onto 225°

18. DME operates in the__frequency band, it transmits _____which give it the emission designator of __ .

a.	SHF	double size pulses	PO1
b.	UHF	twin pulses	PON
c.	EHF	twin pulses	A9F
d.	UHF	double pulses	J3E

19. 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.

20. 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.

21. 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 randomisation.
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	C	**11**	B	**21**	C
2	C	**12**	D		
3	B	**13**	C		
4	C	**14**	B		
5	C	**15**	C		
6	D	**16**	A		
7	C	**17**	A		
8	C	**18**	B		
9	D	**19**	B		
10	B	**20**	C		

CHAPTER SEVENTEEN

AREA NAVIGATION SYSTEMS (RNAV)

Contents

INTRODUCTION

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
LORAN
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 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 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 Display Unit (CDU)
- Indicator in the form of a:
  - Course Deviation Indicator (CDI) or
  - Horizontal Situation Indicator (HSI)

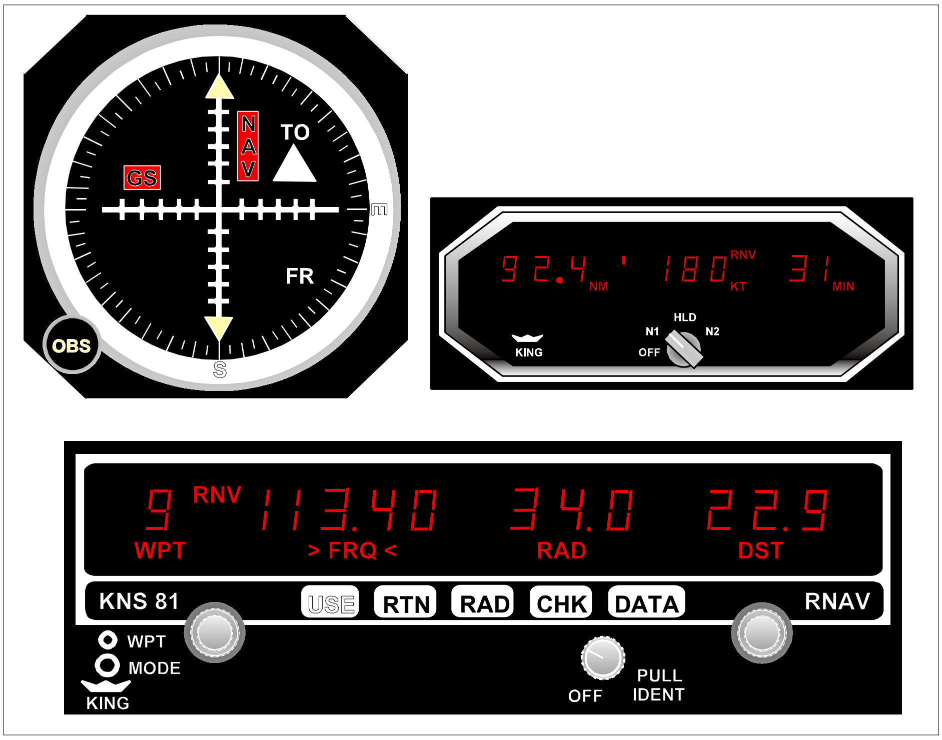


Figure 17.1 VOR/DME RNAV Integrated Nav System

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.

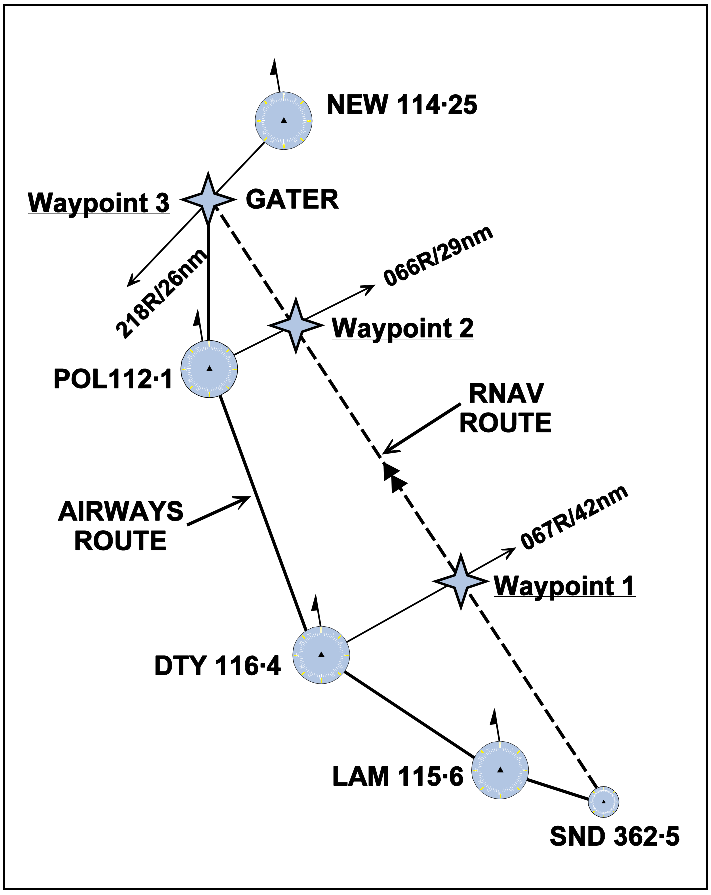


Figure 17.2 An RNAV Route and Waypoints

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 17.3. 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(R)/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 readout to WP2. It should be noted that on such a system the indications of deviation from track are in nms.

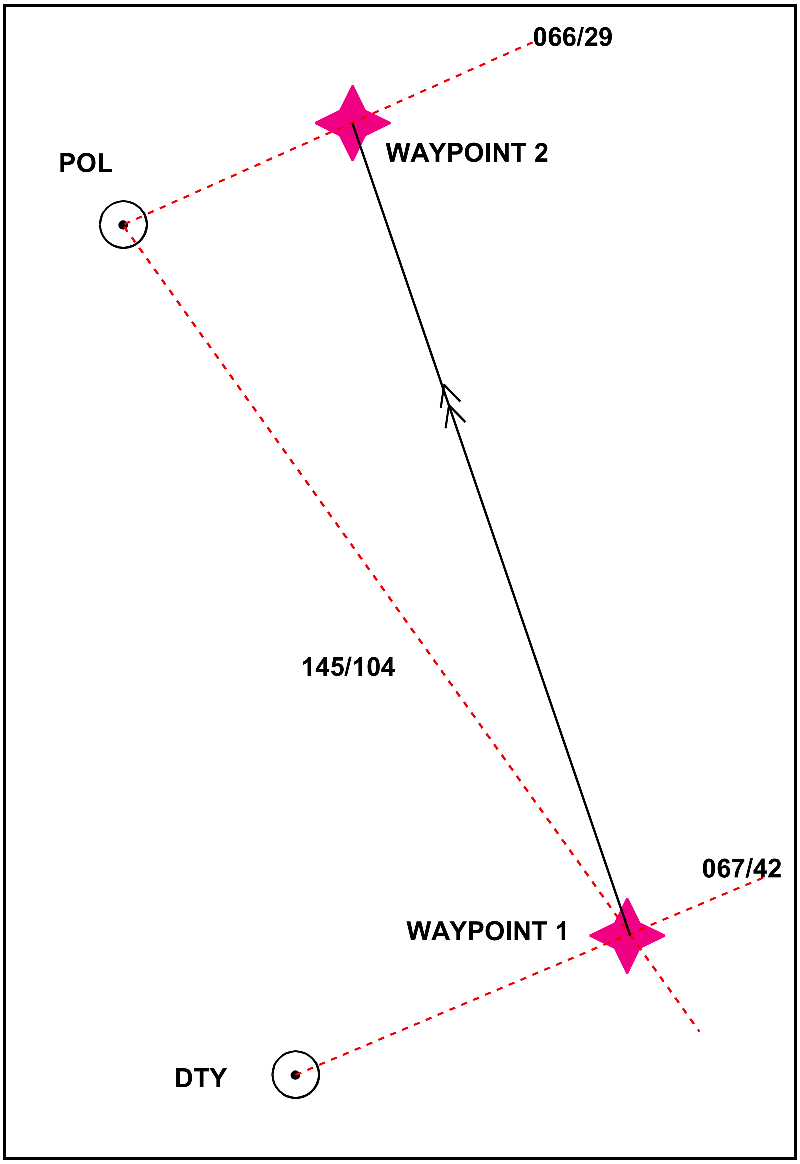


Figure 17.3

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 recognise 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.

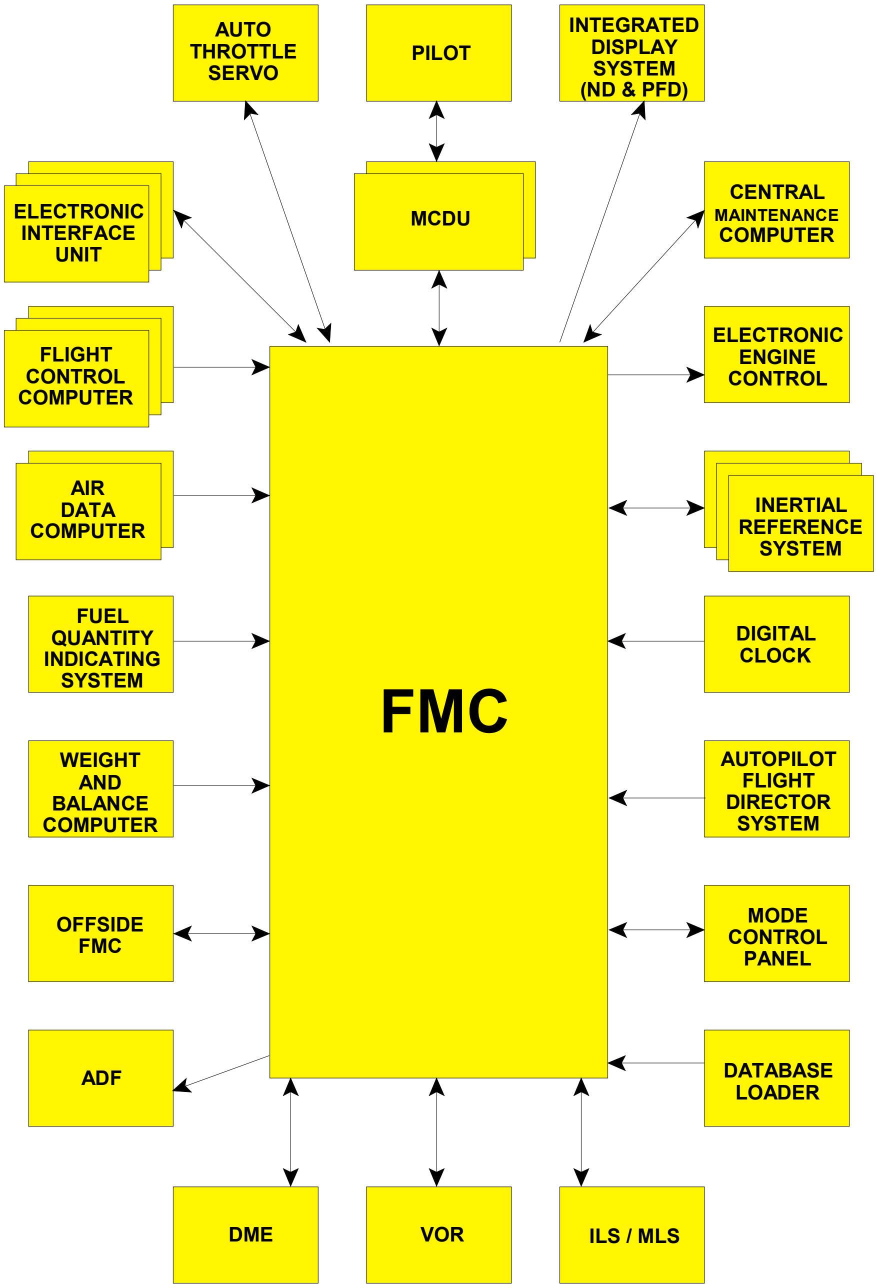


Figure 17.4 FMS Schematic

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 optimises 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 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 (see page 307) 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 (see paragraph 13.16). 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 17.5).

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.

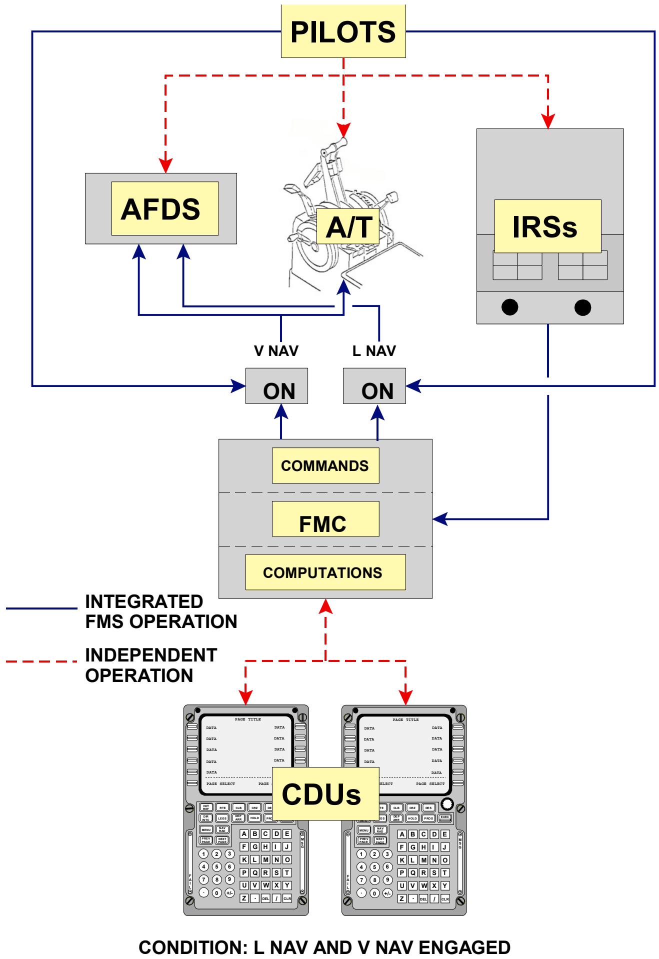


Figure 17.5 B737- 400 FMS

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 customised for the specific airline operations.

CONTROL DISPLAY UNIT (CDU)

The CDU is the means of communication with the FMC. It is used before flight to initialise the performance and navigation requirements for the flight.

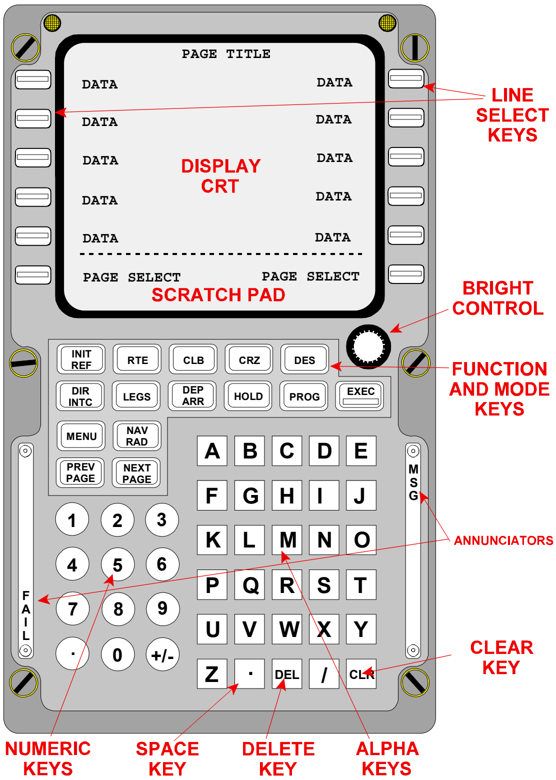


Figure 17.6 Control Display Unit

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:

- The aircraft position
- departure and destination aerodromes
- intended SID and STAR procedures
- the planned route

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

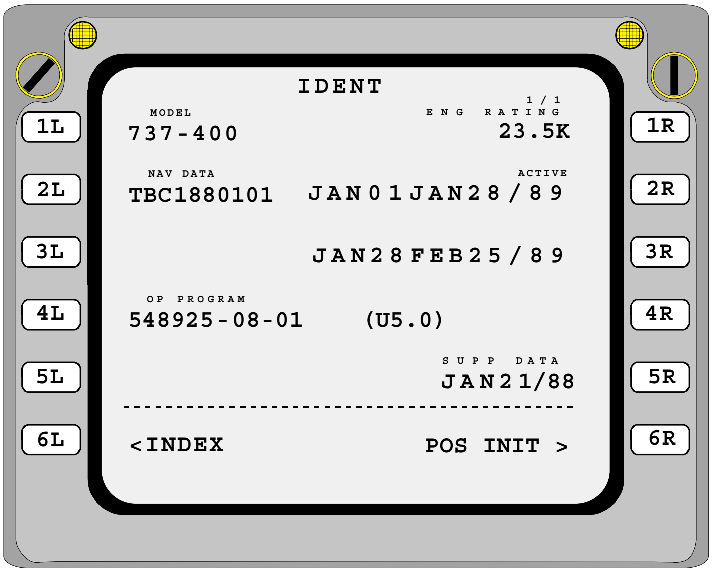


Figure 17.7

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 initialisation 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

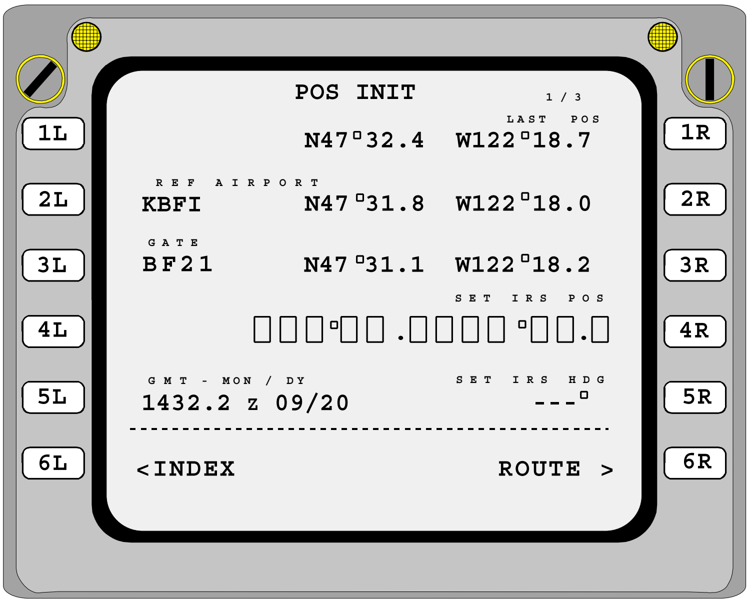


Figure 17.8

The position initialisation (POS INIT) page allows initialisation 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 initialise 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 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.

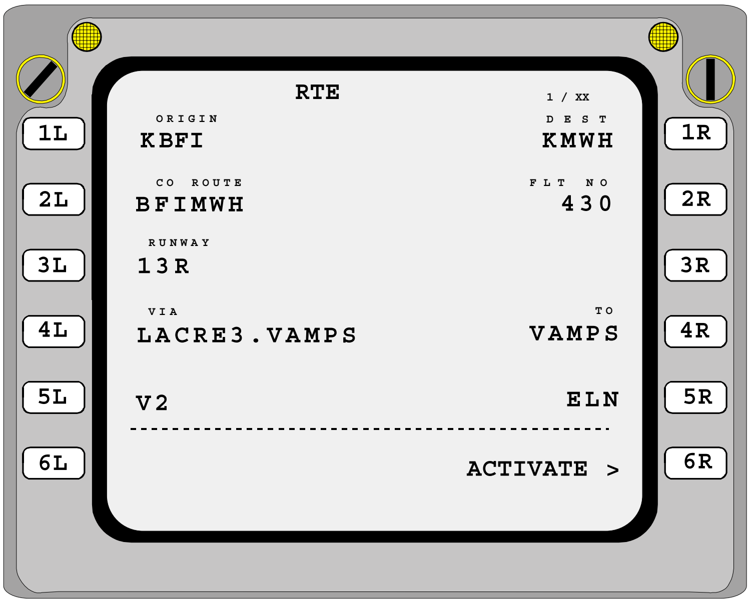


Figure 17.9

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 initialisation 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 desigantors

Up to 7 alphanumerics for SID and STAR (e.g. TURN05)

Range and bearing from a navigational aid or reporting point (eg. 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.

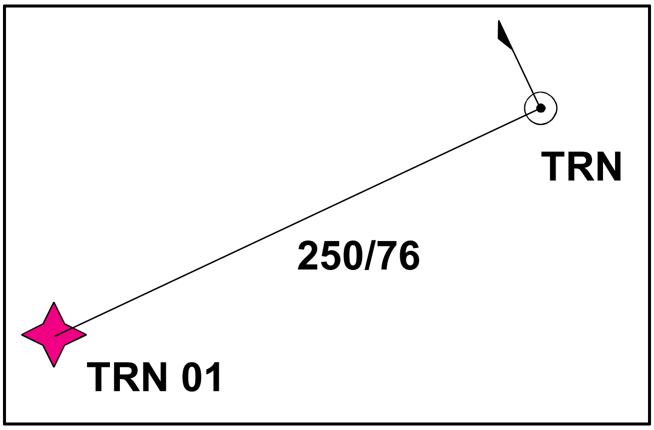


Figure 17.10 Range/Bearing Waypoint

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.

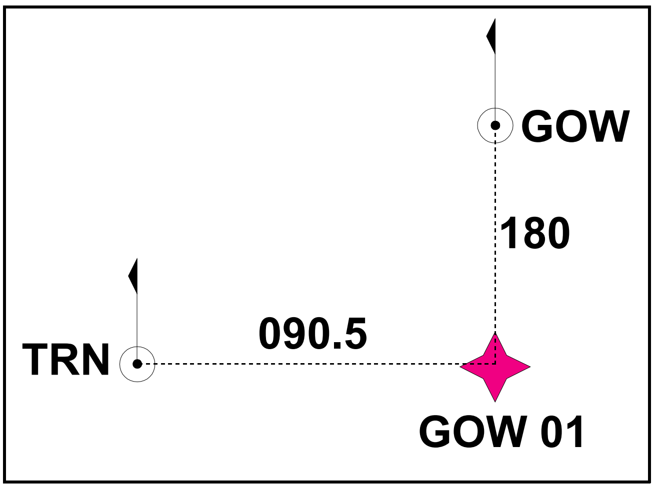


Figure 17.11 Bearing/Bearing Waypoint

CLIMB

Normally in the climb the VNAV, LNAV and timing functions will be operative.

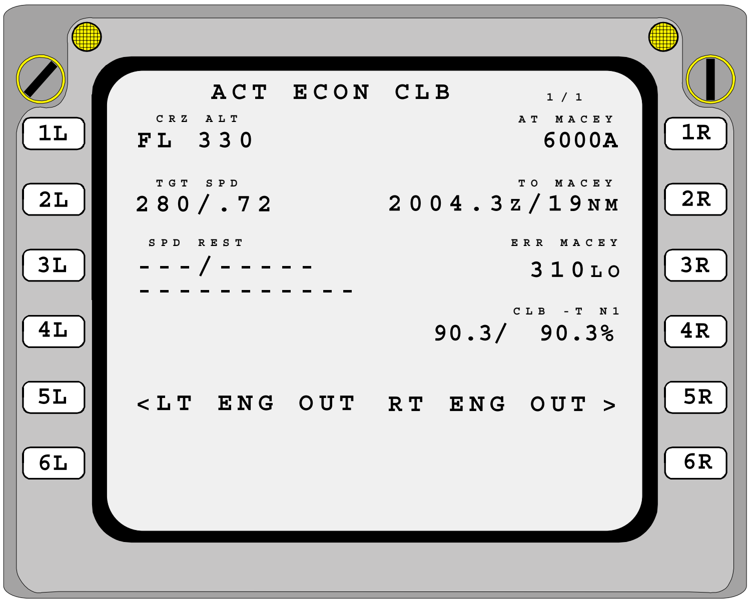


Figure 17.12

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 a RTA is specified by ATC).

CRUISE

In the cruise all three modes will normally be active.

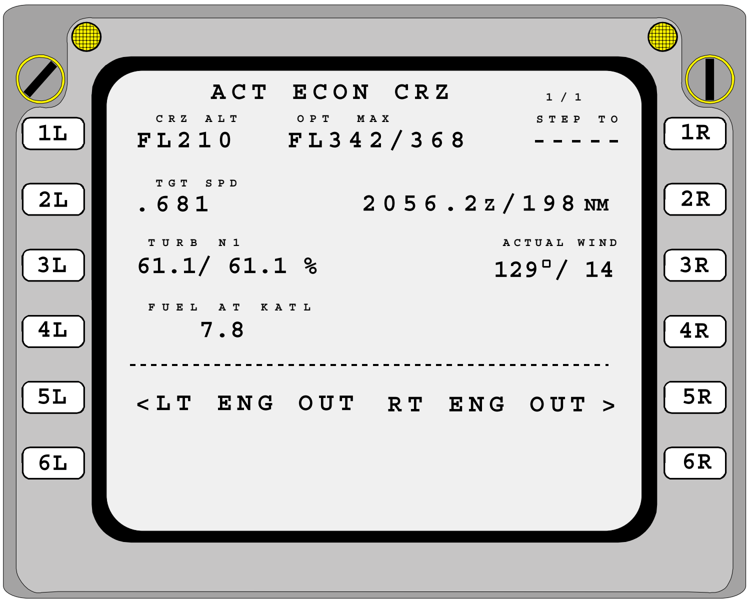


Figure 17.13

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.

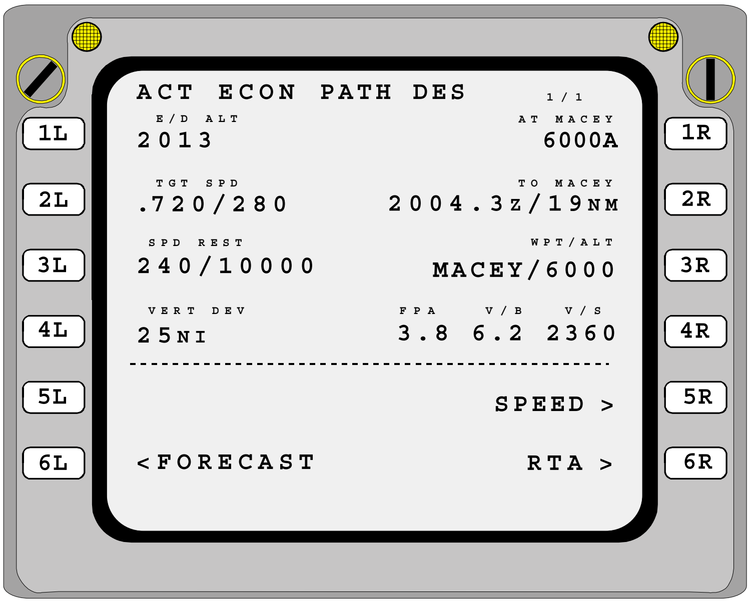


Figure 17.14

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 10kt 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 groundspeed 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 LORAN C 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 groundspeed 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/hr. 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 20nm from the phantom station, which is 270°/30 nm from the VOR/DME. The aircraft is 15nm from the VOR/DME. The range readout will show:

   a. 15 nm
   b. 20 nm
   c. 25 nm
   d. 30 nm

4. The sequence of displays accessed on initialisation 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 alpha-numerics?

 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

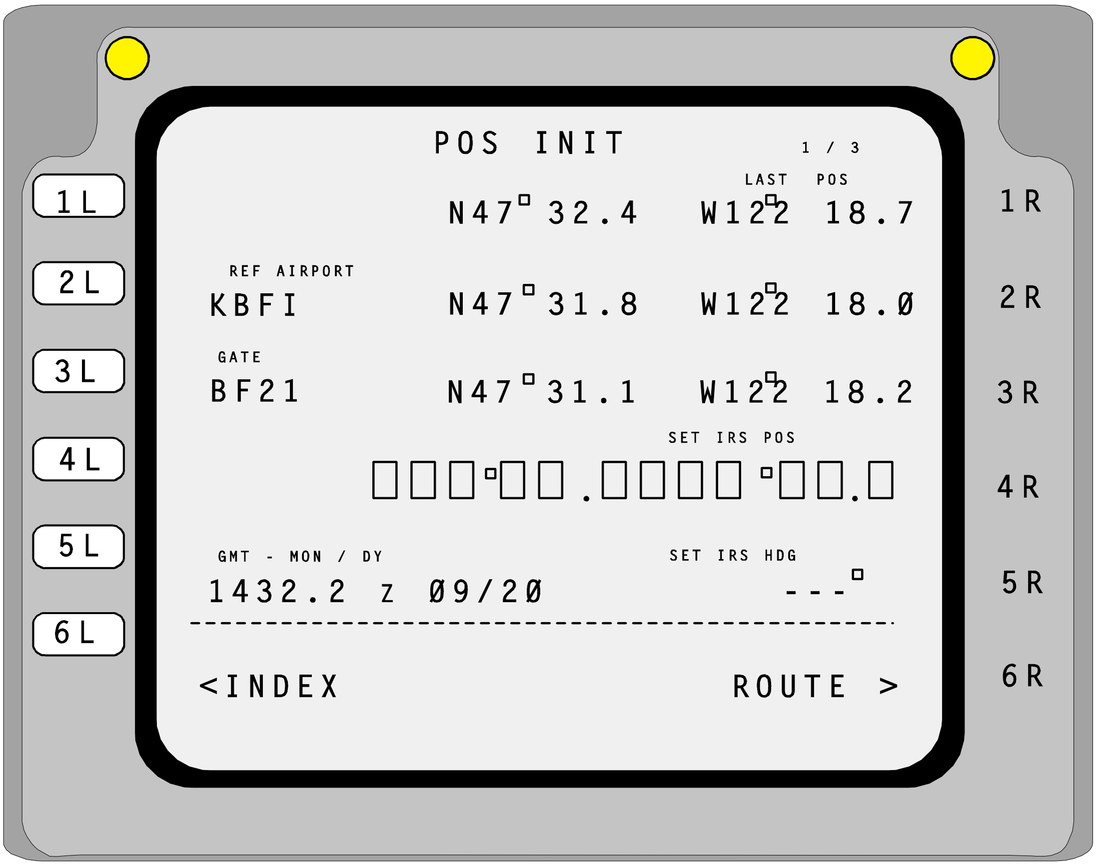
14. The correct format for the input of position 50N 00527E to the CDU is:

 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	C	11	A
2	B	12	B
3	B	13	D
4	C	14	C
5	A	15	A
6	A		
7	C		
8	C		
9	B		
10	B		

CHAPTER EIGHTEEN

ELECTRONIC HORIZONTAL SITUATION INDICATOR (EHSI)

Contents

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 (see Figure 18.12), 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.

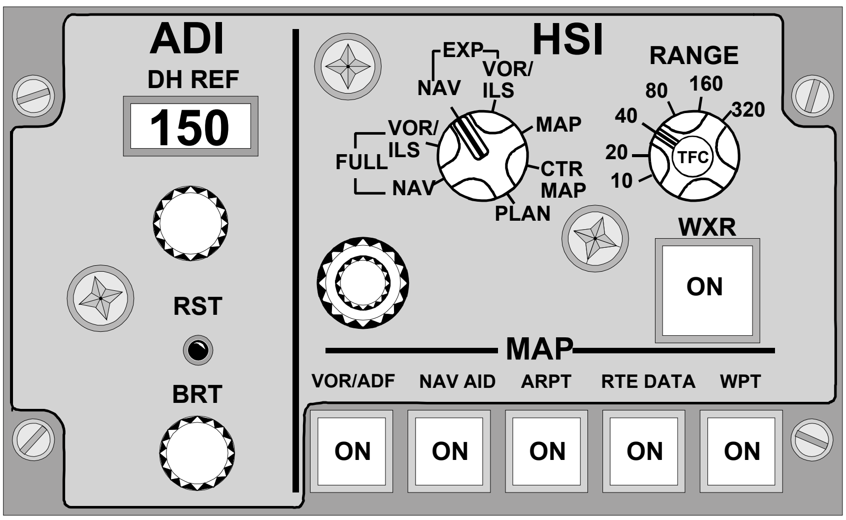


Figure 18.1

The display modes available are:

- Full rose Navigation (NAV)
- Full rose VOR/ILS
- Expanded rose Navigation (EXP NAV)
- Expanded rose VOR/ILS
- MAP
- Centre Map (CTR MAP)
- PLAN

Weather radar and TCAS information can only be displayed on the expanded NAV, expanded VOR/ILS and MAP displays. The selectable map background options are enabled in the Map, Centre 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 rose VOR, ILS and NAV modes when the WXR switch is on, and in the MAP mode at all times.

DISPLAY MODES

EXPANDED NAVIGATION MODE

The expanded navigation mode displays lateral and vertical guidance information. Weather data is displayed when the WXR switch is on.

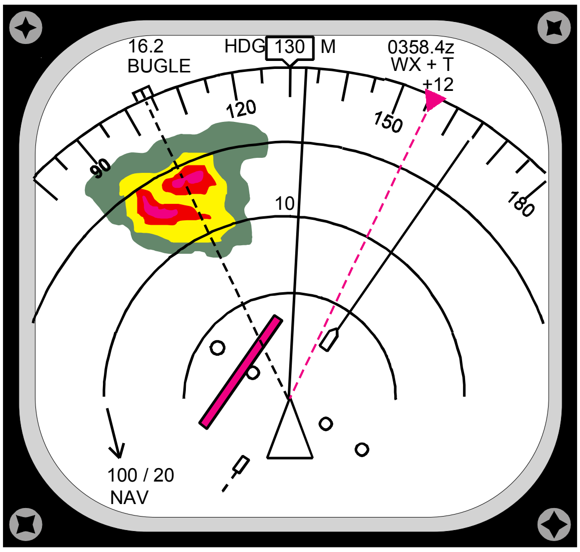


Figure 18.2 Expanded Navigation Mode

The mode of the display is shown in the bottom left hand corner. The aircraft's position is at the tip of the triangle (bottom centre) and the aircraft's present track is depicted by the straight line (133°M) and the aircraft heading is 130°M. The active waypoint and distance to go are at top left of display, with the ETA at top right. The required track shown by the deviation indicator is 165°M, and the actual bearing to the waypoint is 156°M. The aircraft is just over 2 nm right of the required track. The heading bug is selected to 104°M, the 20nm range scale is selected. WXR is selected and the radar is operating in the weather and turbulence (WX+T) mode with 12° uptilt and is showing a contouring cloud centred on 105°M at 8 to 16nm. The wind is 100°M/20 kt.

FULL NAVIGATION MODE

Figure 18.3 Full Navigation Mode

The full navigation mode is displaying the same data as the expanded navigation mode (at 14.3), except that some of the symbology is different (aircraft symbol and track) and there is no WXR facility. The vertical scale shows that the aircraft is 2380ft above the computed descent profile.

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 18.4 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 13.3nm (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 17nm. The selected scale is 20 nm and the wind is 126°M/20kt.

FULL ROSE VOR MODE

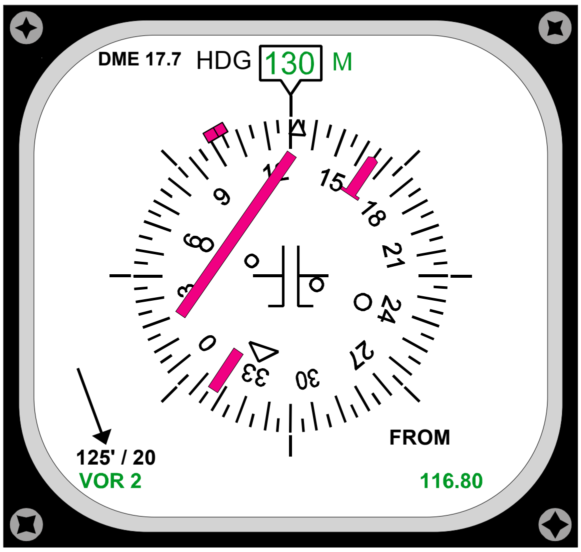


Figure 18.5 Full Rose VOR Mode

The full rose VOR mode is showing the same information as Figure 18.5, with the differences from the expanded VOR mode being the same as in the NAV modes, except that a to/from pointer is displayed (below the aircraft symbol).

EXPANDED ILS MODE

Figure 18.6 Expanded ILS Mode

The expanded ILS mode shows the appropriate ILS information when an ILS localiser frequency is selected. The glideslope indications are suppressed when the aircraft track is more than 90° removed from the ILS localiser course.

FULL ROSE ILS MODE

Figure 18.7 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 nav modes, except that the localiser deviation scale is doubled.

MAP MODE

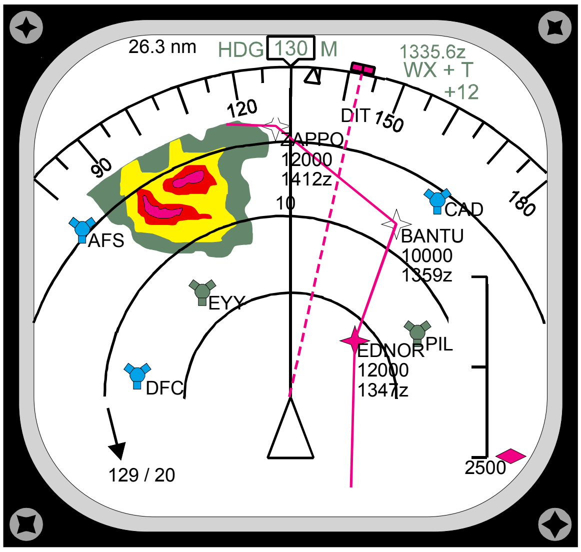


Figure 18.8 Map Mode

The MAP mode shows the navigational information selected on the control panel and is heading orientated.

CENTRE MAP MODE

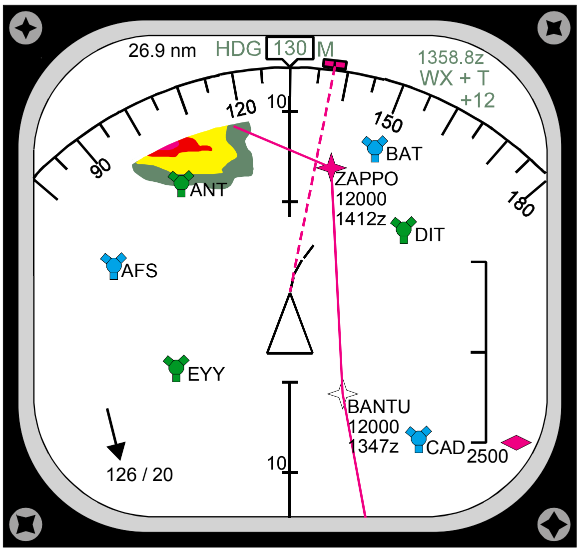


Figure 18.9 Centre Map Mode

The centre map mode displays the same information as the map mode, except the aircraft is in the centre of the screen, no range circles are displayed and the navigational information behind the aircraft is displayed.

PLAN MODE

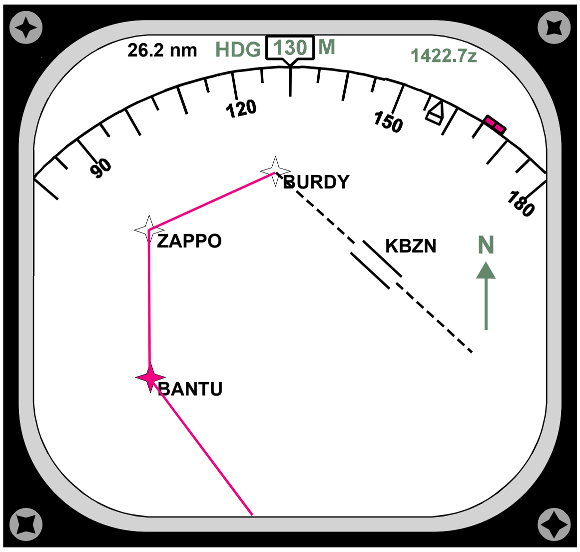


Figure 18.10 Plan Mode

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
Flight envelopes and system limits	Red
Cautions, abnormal sources	Amber/Yellow
Earth	Tan/Brown
Engaged modes	Green
Sky	Cyan/Blue
ILS deviation pointer	Magenta
Flight director bar	Magenta/Green

Specified display features should be allocated colours from one of the following colour sets:

	Colour Set 1	Colour Set 2
Fixed reference symbols	White	Yellow*
Current data, values	White	Green
Armed modes	White	Cyan
Selected data, values	Green	Cyan
Selected heading	Magenta**	Cyan
Active route/flight plan	Magenta	White

* The extensive use of yellow for other than caution or abnormal information is discouraged

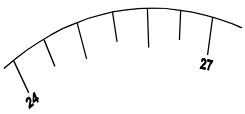
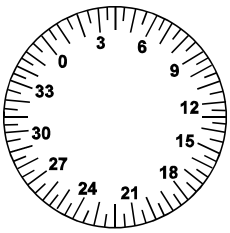
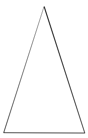
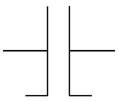
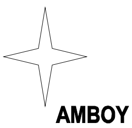
** In colour set 1, magenta is intended to be associated with those analogue parameters that constitute 'fly to' or 'keep centred' type information

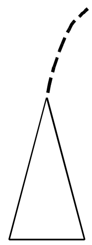
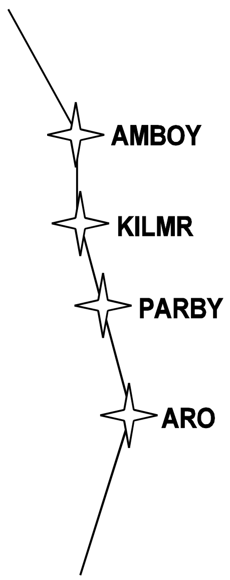
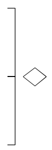
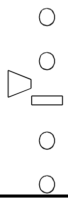
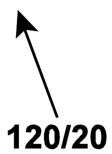
Precipitation and turbulence areas should be coded as follows:

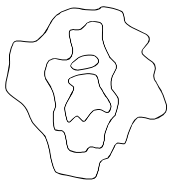
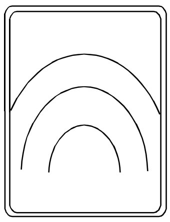
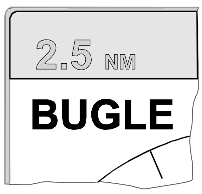
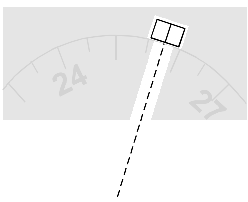
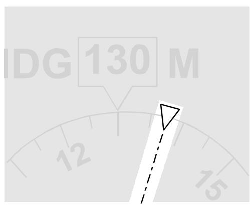
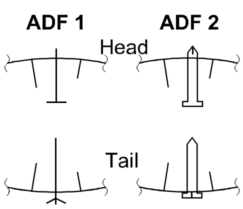
Precipitation	0 - 1	mm/hr	Black
	1 - 4	mm/hr	Green
	4 - 12	mm/hr	Amber/Yellow
	12 - 50	mm/hr	Red
	Above 50	mm/hr	Magenta
Turbulence			White or Magenta

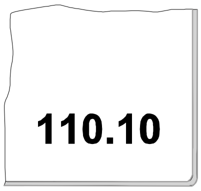
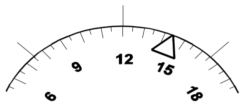
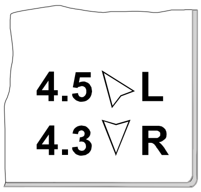
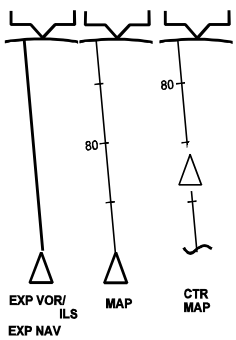
EHSI SYMBOLOGY

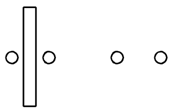
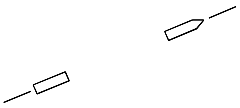
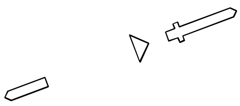
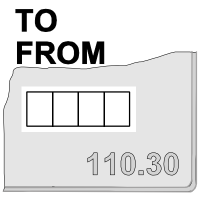
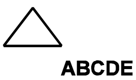
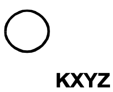
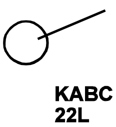
The symbology used in the B737-800 is depicted in the following table, which should be used in conjunction with the displays shown in Figures at 18.3 to 18.10:

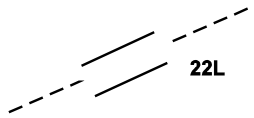
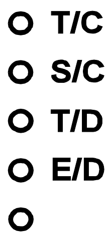
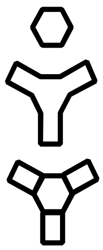
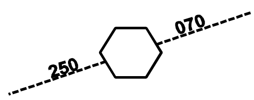
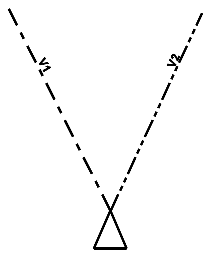
Symbol	Name	Applicable Modes	Remarks
200nm or DME 124	Distance Display (W)	ALL	Distance is displayed to next FMC Waypoint (nm) or tuned Navaid (DME). Below 100nm tenths of a nm will be displayed
HDG 263 M	HEADING Orientation (G) Indicator (W) Reference (G)	ALL	Indicates number under pointer is a heading - box indicates actual heading. Referenced to Magnetic (M) or true (TRU) North.
0835.4z	ETA Display (W)	NAV, 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 (360º available but approximately 70º are displayed except CTR MAP - 120°)
	Full Compass Rose (W)	Full NAV, Full VOR, Full ILS	Compass Data is provided by the selected IRS.
	Aeroplane Symbol (W)	EXP NAV, EXP VOR/ILS, MAP, PLAN	Represents the aeroplane and indicates its position at the apex of the triangle.
	Aeroplane Symbol (W)	Full NAV, 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.

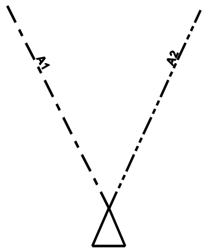
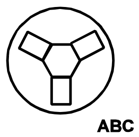
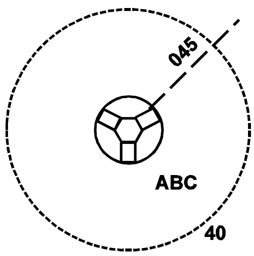
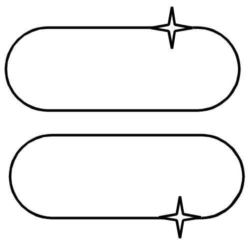
	Trend Vector	MAP	Predicts aeroplane directional trend at the end of 30, 60 and 90 second intervals. Based on bank angle and ground speed. Three segments are displayed when selected range scale is greater than 20nm, two on the 20nm and one segment when on the 10nm scale.
	Active Route (M) Active Route 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)	NAV, MAP	Displays vertical deviation from selected vertical profile (pointer) in MAP mode during descent only. Scale indicates +/- 400ft deviation.
	Glide slope Pointer (M) and Deviation Scale (W)	ILS	Displays Glide slope position and deviation in ILS mode.
	Wind Speed and Direction (W)	NAV, 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.

	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 NAV, 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, EXP NAV, MAP	Range Arcs are displayed in the expanded rose VOR/ILS and NAV modes when the Weather Radar Switch is ON. Range arcs are displayed in the MAP mode with or without the WXR Switch ON.
	Active Waypoint Name (M)	NAV	Displays the name of the active waypoint.
	Selected Heading Bug (M) and Reference Line	ALL	Indicates the heading selected on the MCP. A dashed line extends from the marker to the airplane symbol (except for PLAN mode) for ease in tracking the marker when it is out of view.
	Waypoint Bearing Pointer (M)	NAV	Displays relative bearing to active waypoint.
	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 NAV, FULL VOR/ILS	Indicates airplane'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 airplane vertical speed.
	Position Difference Display (W)	NAV, 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 NAV, EXP VOR, EXP ILS, MAP	Displays present ground track based on airplane 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)	NAV, VOR, ILS	Displays ILS, VOR, or FMC (NAV) course deviation. ILS 1 dot ≈ 1° Normal Scale ILS 1 dot ≈ 1/2° Expanded Scale VOR 1 dot ≈ 5° NAV 1 dot ≈ 2 NM
	Selected Course Pointer (W) and Line (M)	EXP NAV, EXP ILS, EXP VOR	Points to selected course as set by the respective MCP course selector (VOR / ILS) or by the FMC (NAV)
	Selected Course Pointer (W) To / From Pointer (W)	FULL NAV, FULL VOR, FULL ILS	Points to selected course as set by the respective MCP course selector (VOR / ILS) or by the FMC (NAV) 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.
	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.
	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.
	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.
	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** Tubed 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 320NM. 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 displayed for each distance entered on the FMC / 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 airplane is within 3 min. of the holding fix.

QUESTIONS

1. Refer to appendix A. Which display shows the expanded ILS mode?

   a. A
   b. B
   c. D
   d. E

2. Refer to appendix A. Which mode is display C?

   a. Centre map
   b. Map
   c. Plan
   d. Expanded nav

3. Refer to appendix A. Which mode is display A?

   a. full ILS
   b. full VOR
   c. full nav
   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 A, what is the aircraft's track?

   a. 130°
   b. 165°
   c. 146°
   d. 135°

6. The EASA CS25 colour code for ILS deviation pointer is:

   a. magenta
   b. cyan
   c. green
   d. amber

7. The EASA CS-25 colour code for selected heading is:

   a. green
   b. magenta
   c. amber
   d. white

8. The EASA CS-25 colour code for precipitation rate in excess of 50 mm/hr is:

a. red
b. amber
c. magenta
d. white or magenta

9. The EASA CS-25 colour code for the active route is:

a. yellow
b. magenta
c. green
d. cyan

10. The EASA CS-25 colour code for a downpath waypoint is:

a. white
b. magenta
c. green
d. cyan

11. The horizontal deviation on the expanded ILS display represented by one dot is approximately:

a. 1°
b. 2°
c. 0.5°
d. 5°

12. On which displays will the range markers be displayed regardless of the weather selection?

a. MAP
b. EXP ILS/VOR, MAP & CTR MAP
c. MAP & CTR MAP
d. PLAN, EXP ILS/VOR, MAP & CTR MAP

13. 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

14. Refer to Appendix A. The track direction from BANTU to ZAPPO on display F is:

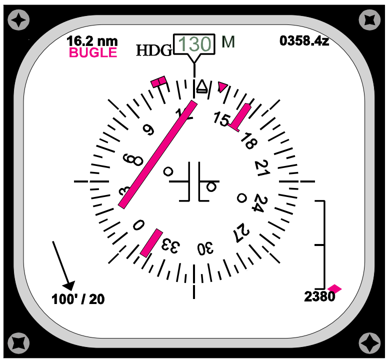
a. 360° (M)
b. 130° (M)
c. 360° (T)
d. 130° (T)

15. The EASA CS- OPS1 recommended colour code for an in-use radio navigation facility is:

    a. cyan
    b. magenta
    c. white
    d. green

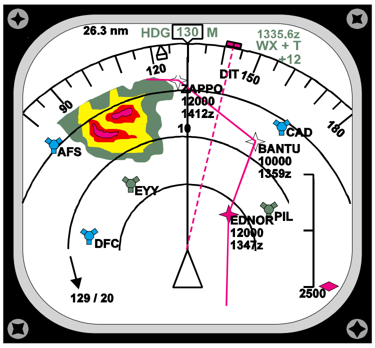
APPENDIX A

A



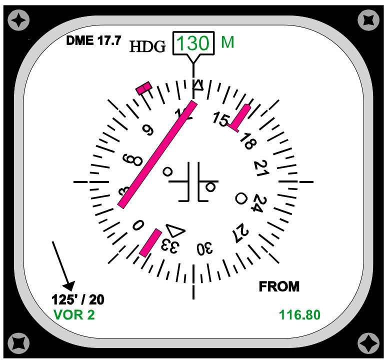
B

C

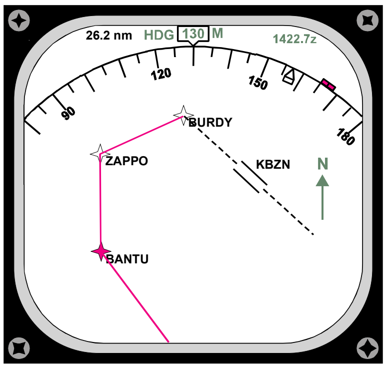


D

E



F



ANSWERS

1	C	11	C
2	B	12	A
3	C	13	C
4	B	14	C
5	D	15	D
6	A		
7	B		
8	C		
9	B		
10	A		

CHAPTER NINETEEN

GLOBAL NAVIGATION SATELLITE SYSTEMS (GNSS)

Contents

INTRODUCTION

The development of space based navigation systems commenced in the 1950's 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. There are some doubts about the long term viability of GLONASS because of the economic situation in Russia.

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) currently under development is the European contribution to a global augmentation system providing integrity and improved accuracy.

The European **Galileo**, which is under development and intended to become operational in 2008, but this will probably slip to 2010. 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. It can be anticipated that other countries or regions may develop their own systems for the same reason.

This chapter will study GPS, LADGNSS and EGNOS in detail, but it should be borne in mind that GLONASS operates on the same principles as GPS, although there are differences in implementation.

SATELLITE ORBITS

Johannes Kepler's three laws quantified the mathematics of planetry orbits which apply equally to the orbits of satellites:

First Law: a satellite's orbit describes an ellipse with the earth at one of the foci.

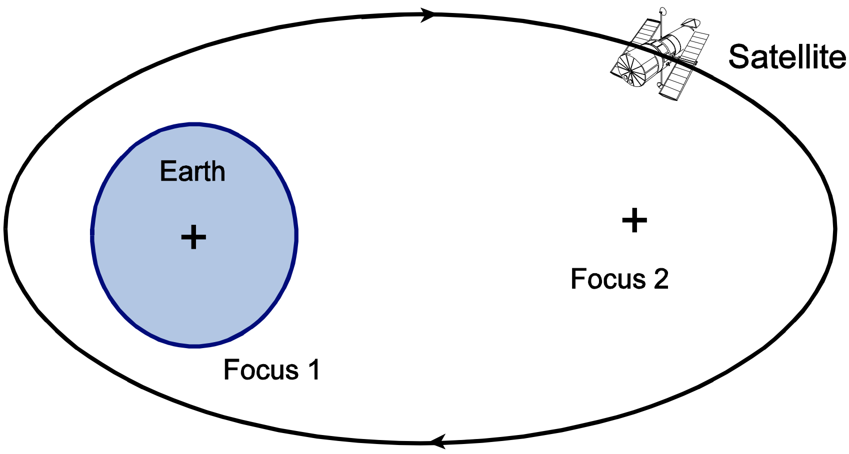


Figure 19.1

Second Law: a satellite sweeps out equal areas in equal time.

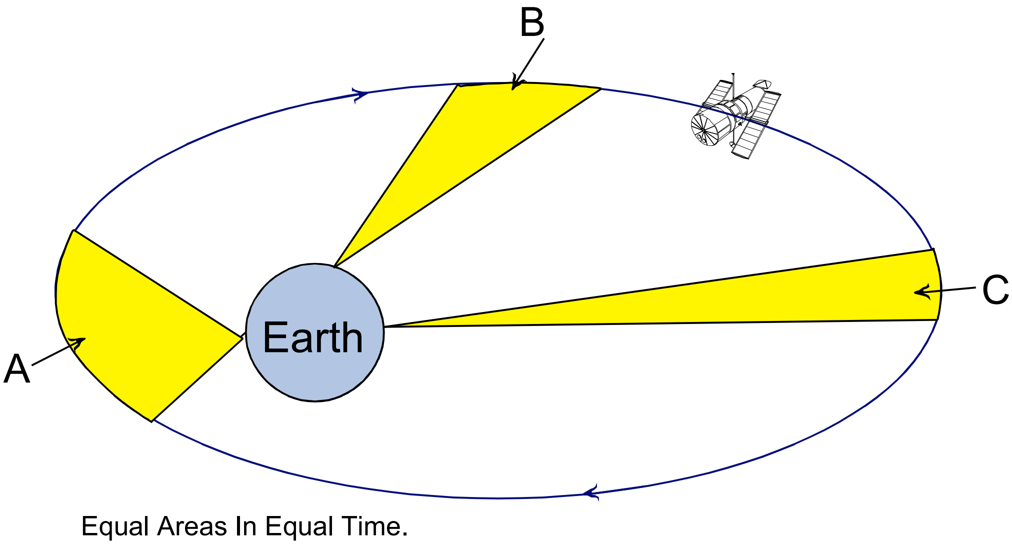


Figure 19.2

Third Law: The square of the satellite's orbital period is proportional to the cube of its average distance.

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.

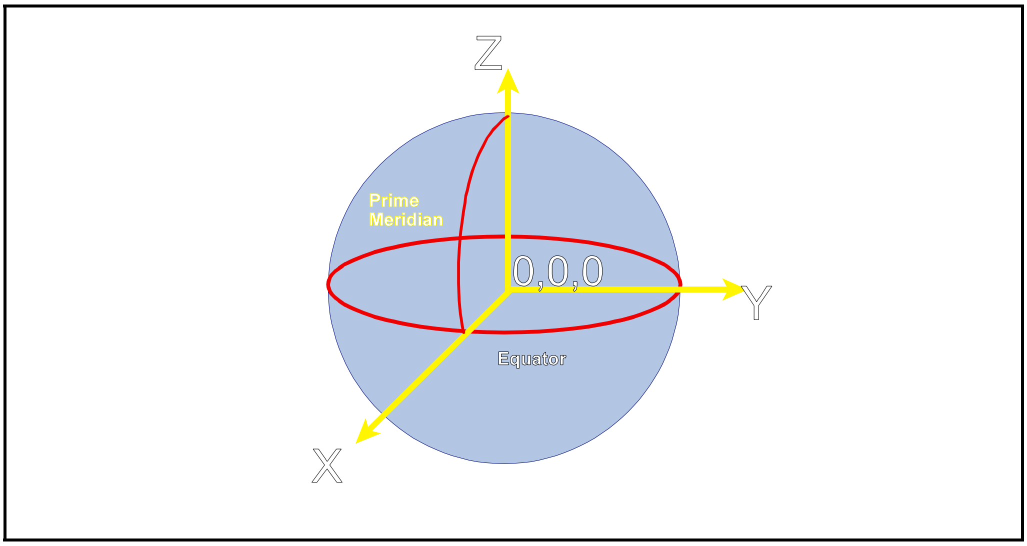


Figure 19.3

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.

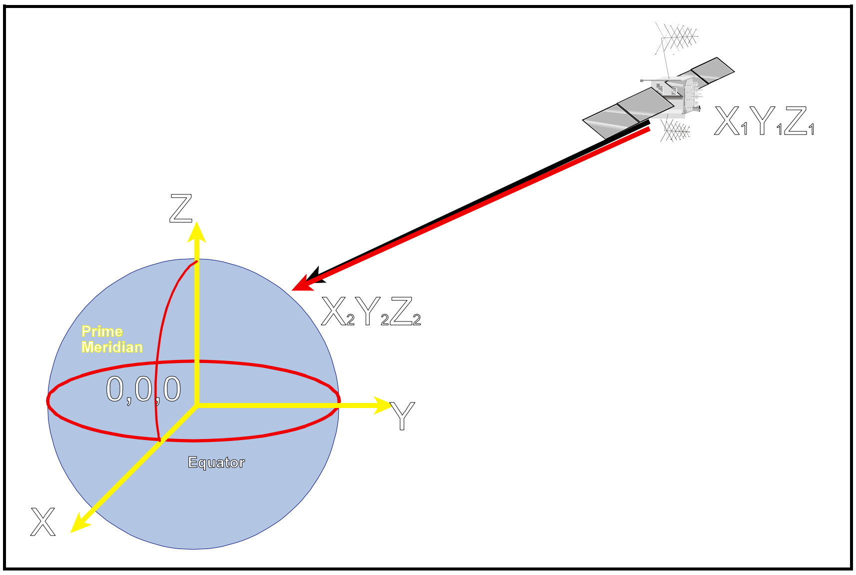


Figure 19.4

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

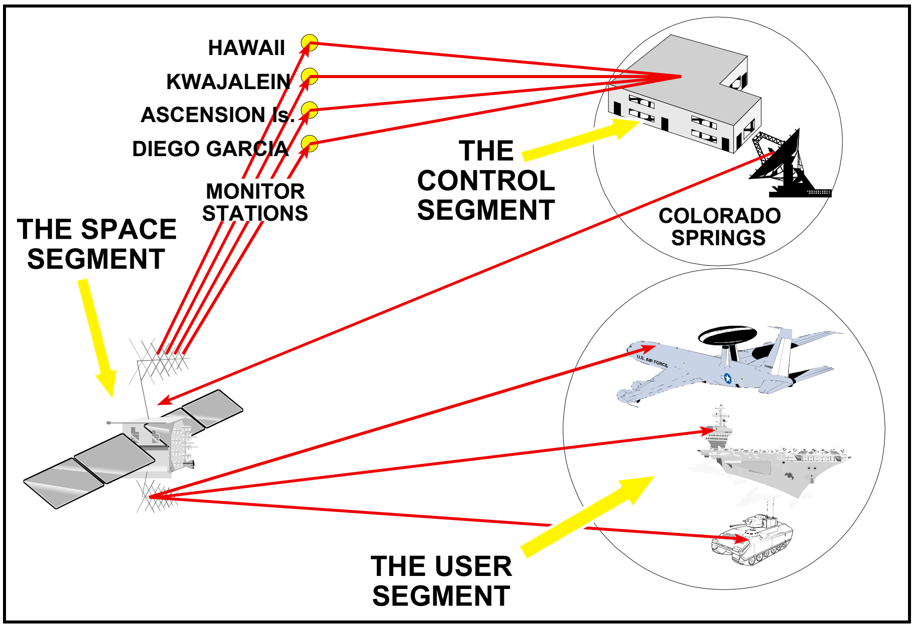


Figure 19.5 The Three Segments of the GPS Operational Control System

GPS time is measured in weeks and seconds from 00:00:00 on 06 January 1980 UTC. An epoch is 1,024 weeks after which the time restarts at zero. GPS time is referenced to UTC but does not run in direct synchronisation, so time correlation information is included in the SV broadcast (see page 343). In July 2000 the difference was about 13 seconds.

THE SPACE SEGMENT

In GPS the space segment comprises a constellation of 24 SVs in 6 orbital planes; 21 SVs are operational and the other 3 are in-space spares, to be activated to replace any failure of an operational SV. The orbits have an average height of 10,898nm (20,180km) 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.

A SV will be **masked** (that is not selected for navigation use) if its elevation is less than 5° above the horizon.

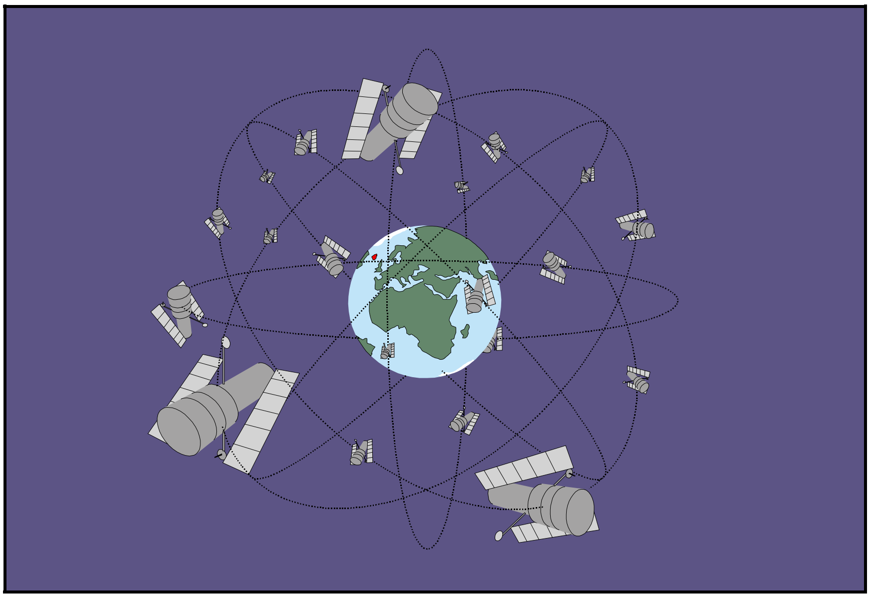


Figure 19.6. The GPS Satellite Constellation (21 active, 3 spares, in 6 orbital planes)

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: 1,575.42 MHz transmits the coarse acquisition (C/A) code repeated every millisecond with a modulation of 1.023MHz, 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-authorised users and will be available from 2007/8, its use is the same as the L2 frequency.

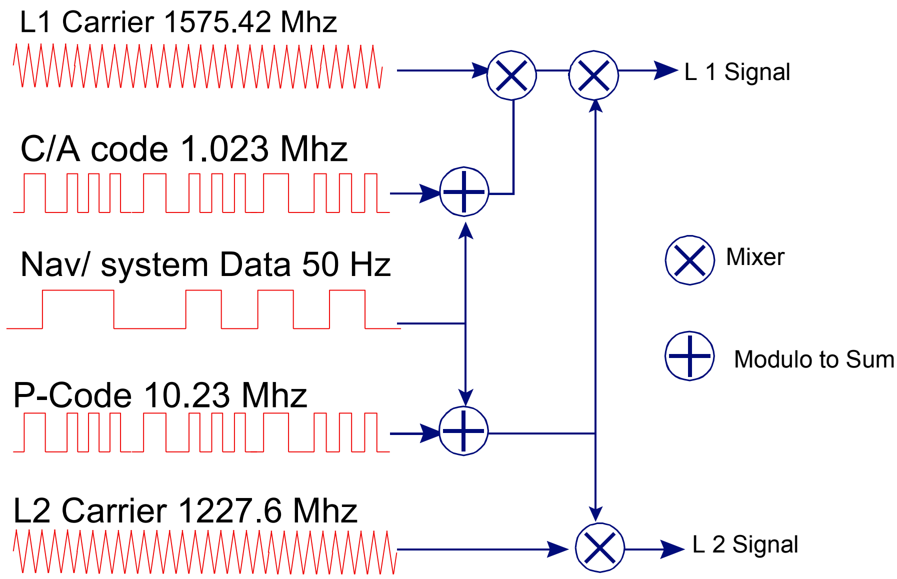


Figure 19.7

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 is intended to have 24 SVs (21 operational and 3 in-space spares) 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 1,602 MHz and the L2 frequency from 1,246 MHz.

THE CONTROL SEGMENT

The GPS control segment comprises:

- A Master Control Station
- A Back-up Control Station
- 5 Monitoring Stations

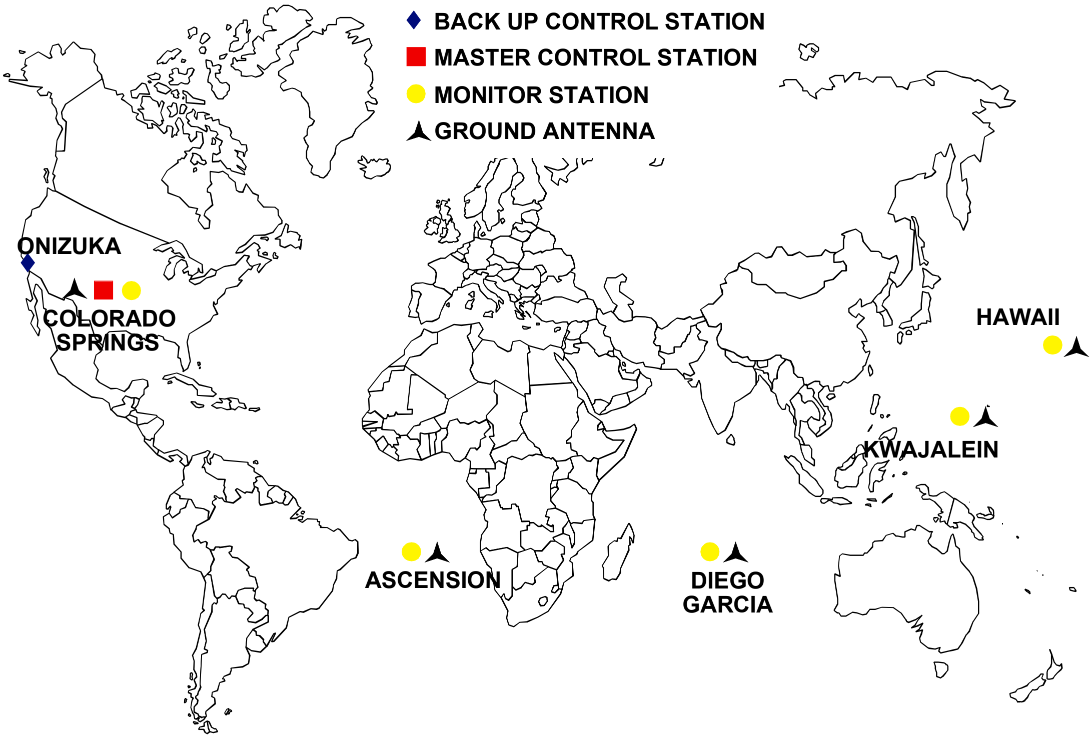


Figure 19.8 GPS Operational Control Segment

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 (see Figure 19.8).

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 19.10a GPS Receiver, Control Unit

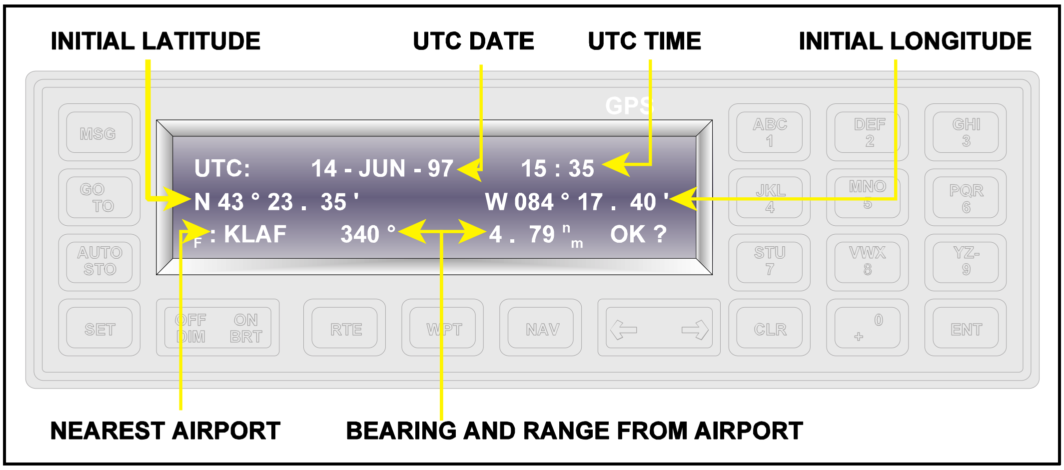


Figure 19.10b Initialisation Page

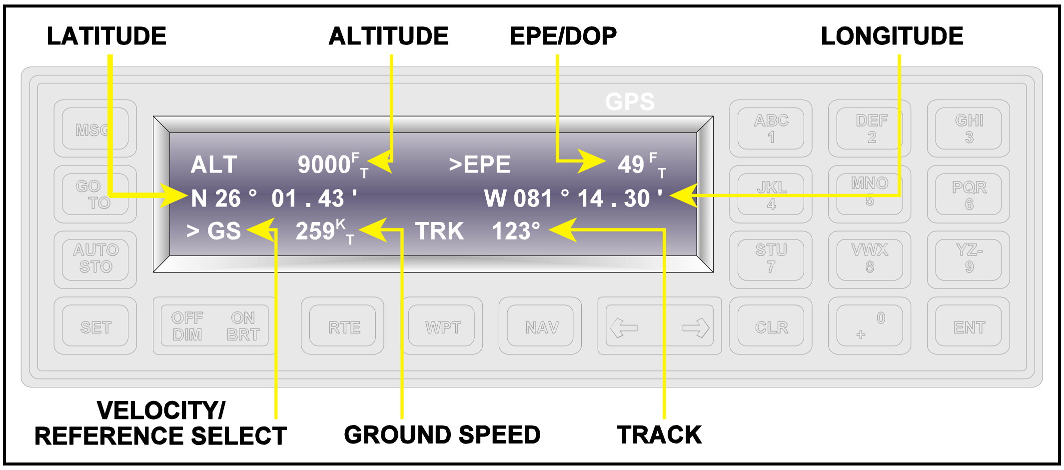


Figure 19.10c Position Page

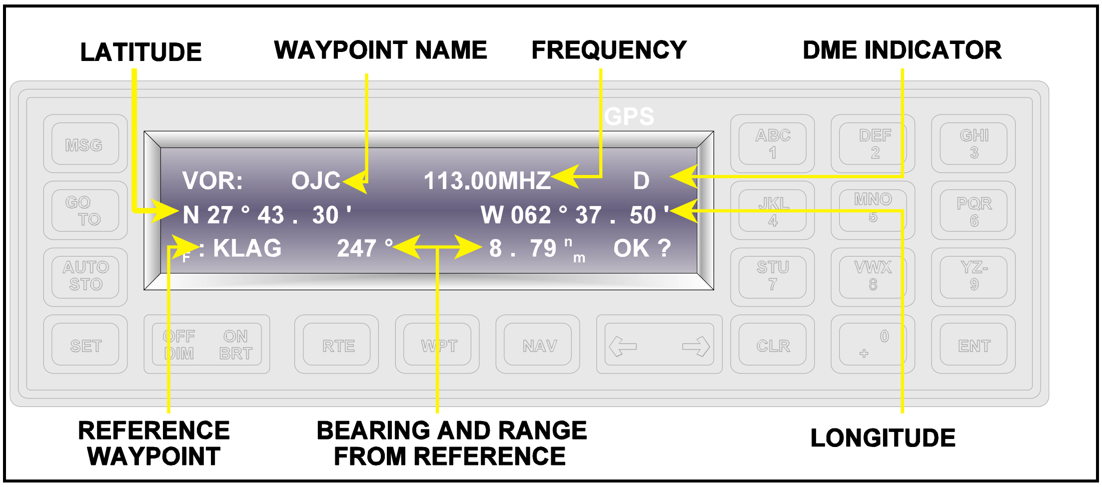


Figure 19.10d Waypoint Definitions Page

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.

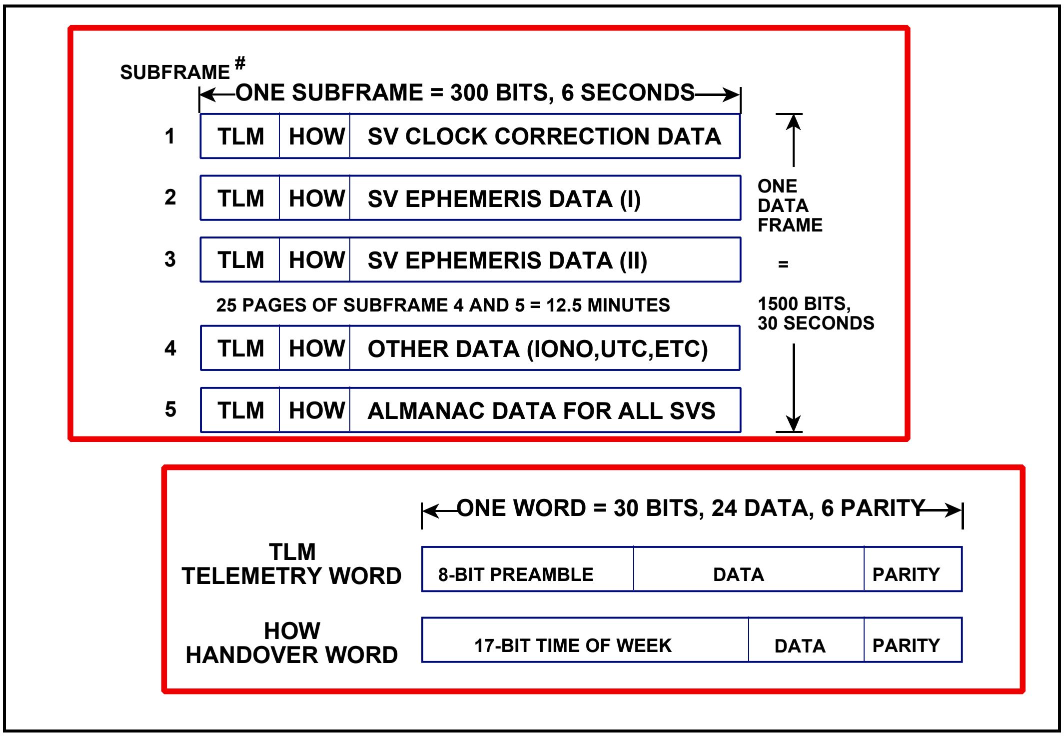


Figure 19.11 GPS Navigation Data Format

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 almanc 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 initialisation, 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.

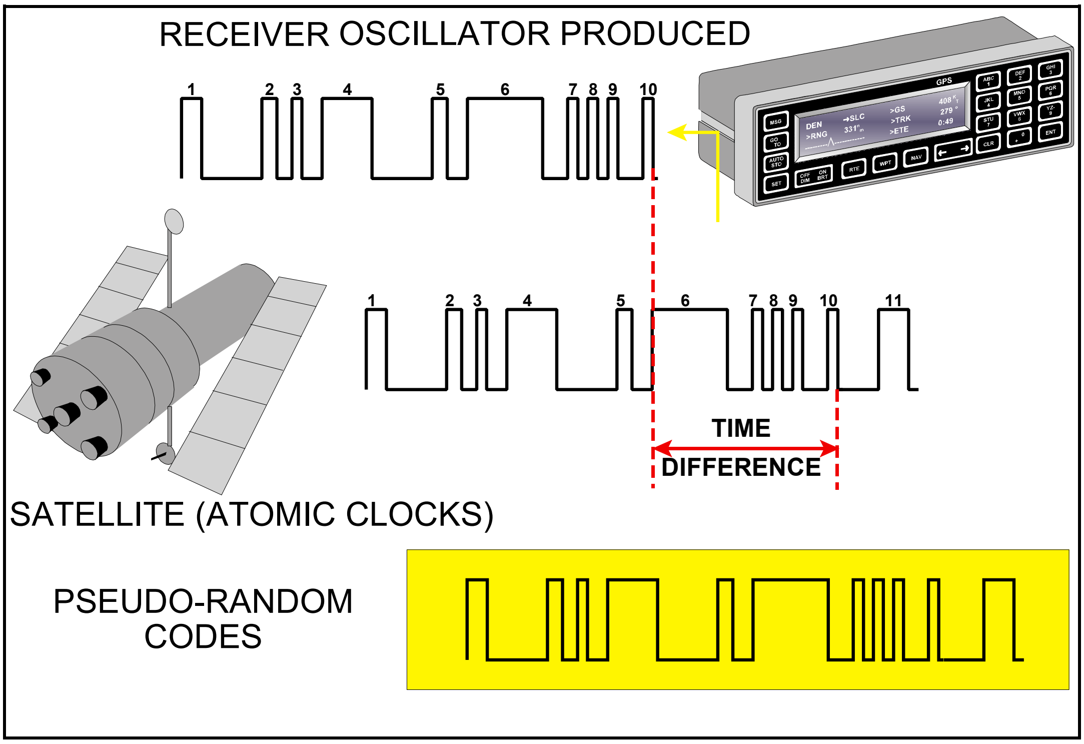


Figure 19.12 Pseudo-Random Code Time Measurement

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 10,900nm.

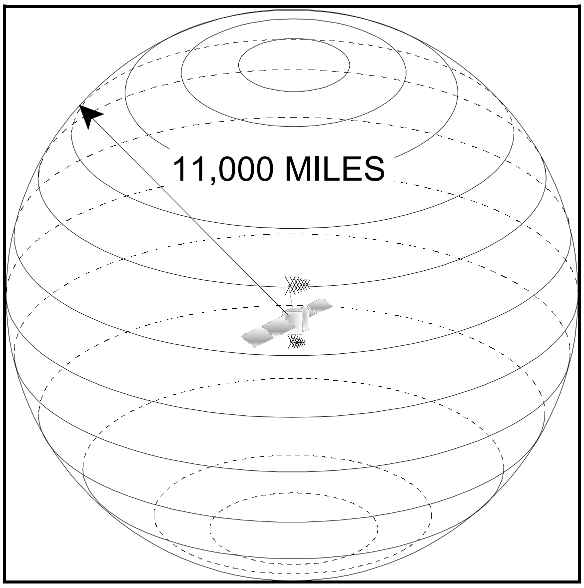


Figure 19.13

The intersection of two range spheres will give a circular position line.

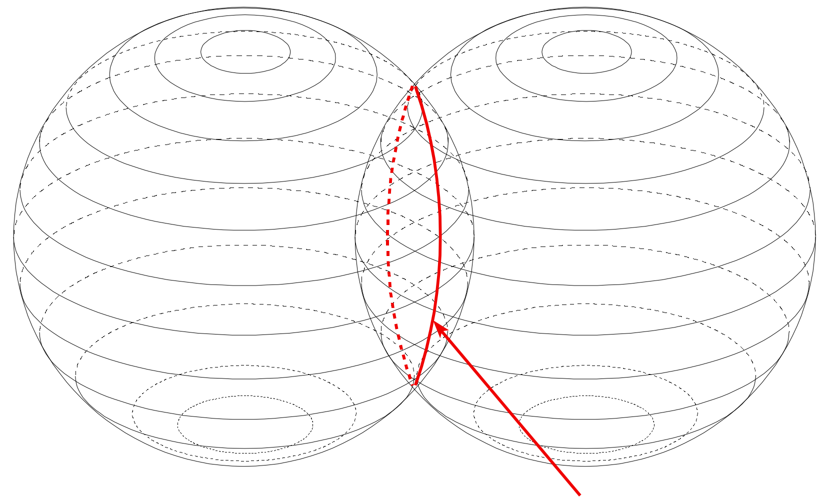


Figure 19.14

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.

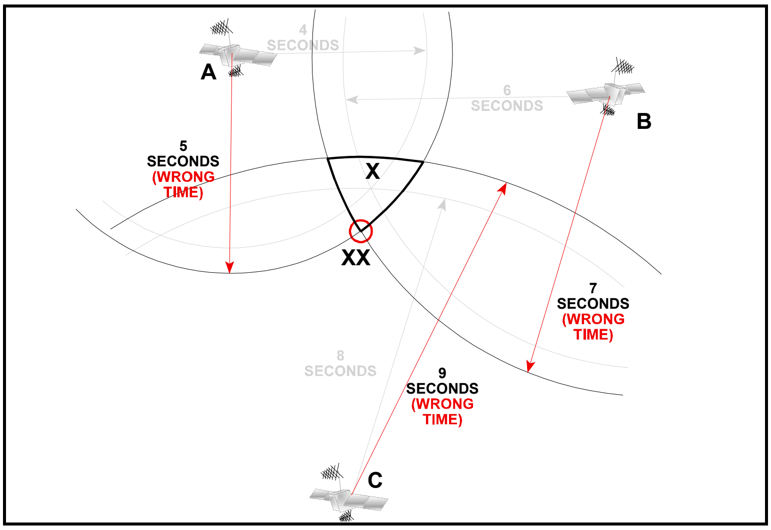


Figure 19.16a

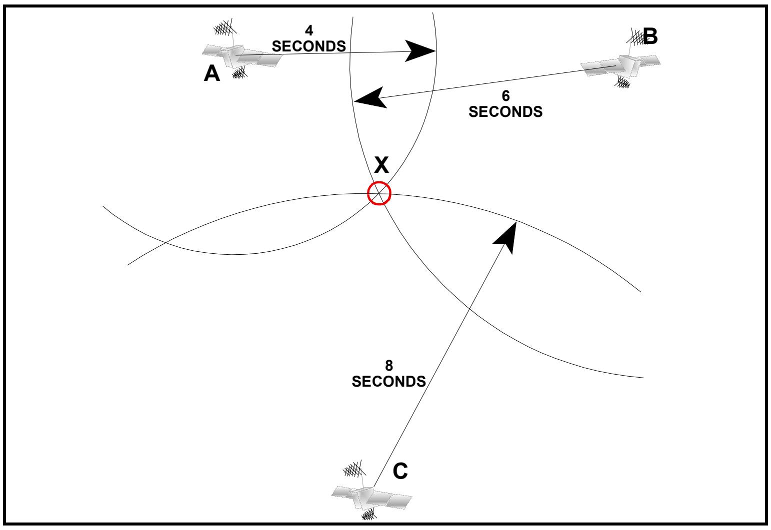


Figure 19.16b

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. As discussed on page 344 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 ionisation, 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:

$$\text{Delay} = \frac{1}{\left(\frac{L_1^2}{L_2^2}\right)}$$

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 0.3m. Maximum 0.5m. As with ionospheric propagation error this is minimised with the use of two frequencies.

Receiver noise error. All radio receivers generate internal noise, which in the case of GNSS receivers can cause errors in measurement of the time difference. Maximum 0.3m.

Multi-path reception. Reflections from the ground and parts of the aircraft result in multi-path reception. This can be minimised by careful siting of the aerial and by internal processing techniques. Maximum 0.6 m.

Geometric dilution of precision (GDOP). This is the GPS term for a poor cut between position lines. GDOP occurs when the satellites are (relatively) close to each other.

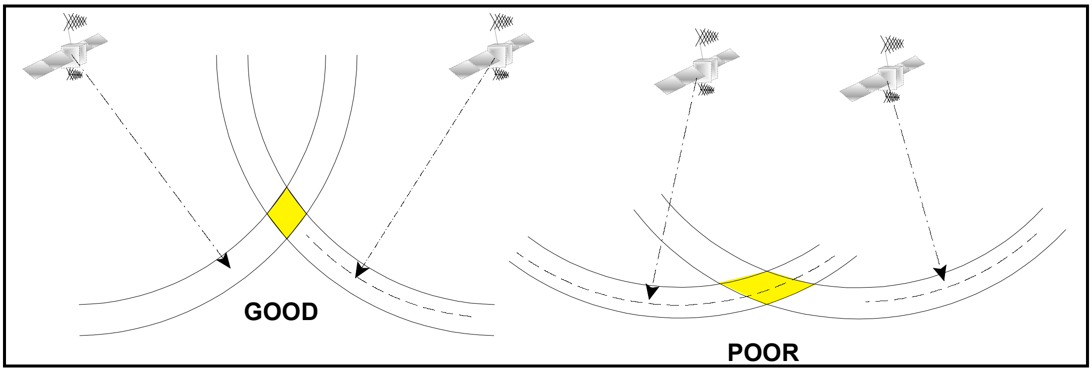


Figure 19.17 GDOP

GDOP is further divided:

Position dilution of precision (PDOP). This refers to errors in the X, Y and Z coordinates.

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.

Time dilution of precision (TDOP). This refers to timing errors.

Errors caused by GDOP are minimised 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 minimised 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:

- Vertical: +/-13 m
- Horizontal: +/-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 minimise 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 minimising ionospheric and tropospheric errors. It will not remove errors arising from receiver noise and multi-path 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 from an aerial close to the runway threshold and is formatted in such a way that the GPS receiver in the aircraft reads the transmission as being from a SV situated on the aerodrome. This pseudo-SV is known as a **pseudolite** (pseudo-satellite).

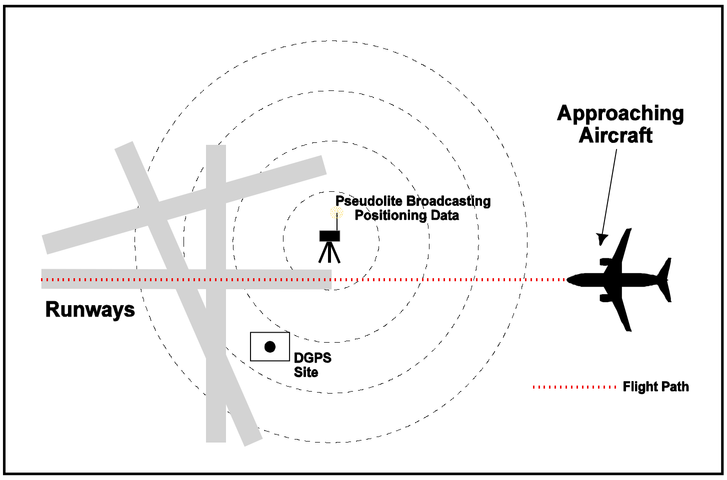


Figure 19.18 LAAS

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 3C type operations.

Satellite Based Augmentation Systems (SBAS)
SBAS utilise a **wide area DGPS (WADGPS)** implemented through a **wide area augmentation system (WAAS)**. There are three systems currently under development which will cover a large area of the northern hemisphere, these are:

The **European Geostationary Navigation Overlay System (EGNOS),** declared operational in July 2004.

The USA **WAAS,** declared operational in July 2003.

The Japanese **Multi-functional Transport Satellite Augmentation System, (MSAS)** expected to become operational in 2010.

The Indian **Geo and GPS Augmented Navigation (GAGAN),** expected to become operational in 2014.

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 compatability 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 a RCS. The RCS will be linked in turn to MCS (or NES).

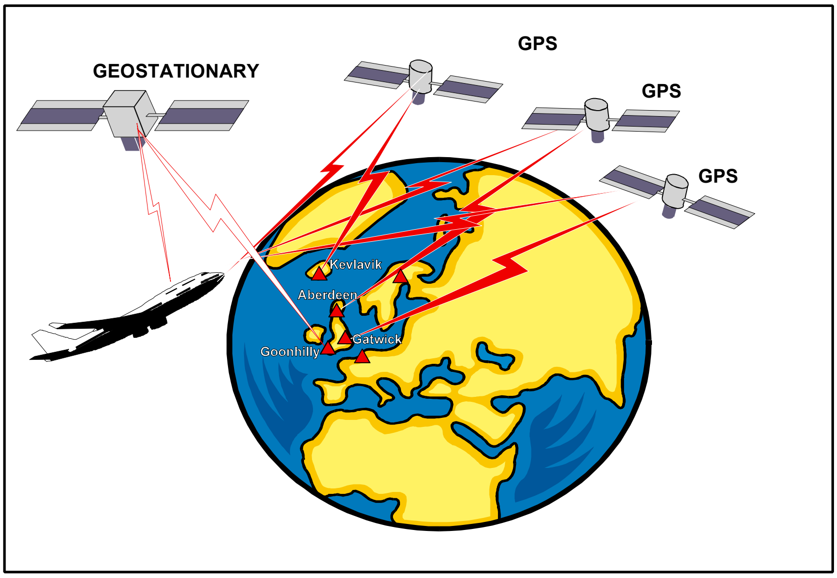


Figure 19.19 EGNOS Segments

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 geo-stationary 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 1 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. 20180 km, 65°
    b. 20180 km, 55°
    c. 19099 km, 65°
    d. 19099 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. GDOP
   b. Receiver clock
   c. Ionospheric propagation
   d. Ephemeris

9. The frequency available to non-authorised 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. elective availability, satellite ephemeris and clock
   c. GDOP, selective availability and propagation
   d. receiver clock, GDOP, 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 co-ordinates 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 co-ordinates to aircraft

16. The position derived from NAVSTAR/GPS satellites may be subject to the following errors:

    a. selective availability, skywave interference, GDOP
    b. propagation, selective availability, ephemeris
    c. GDOP, static interference, instrument
    d. ephemeris, GDOP, 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. synchronise 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 GDOP
    d. removes receiver clock errors

20. The NAVSTAR/GPS reference system is:

    a. A geo-centred 3D Cartesian co-ordinate system fixed with reference to the sun
    b. A geo-centred 3D Cartesian co-ordinate system fixed with reference to the prime meridian, equator and pole
    c. A geo-centred 3D Cartesian co-ordinate 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	A	11	C	21	A
2	C	12	B	22	A
3	B	13	B	23	B
4	C	14	A	24	A
5	B	15	D	25	B
6	C	16	B	26	C
7	D	17	C		
8	C	18	A		
9	B	19	B		
10	A	20	B		

CHAPTER TWENTY

LORAN C

Contents

INTRODUCTION

LORAN is an acronym for "long range navigation". **LORAN C** is a hyperbolic system operating at a frequency of **100 kHz**. It uses the principle of **differential range by pulse technique** to measure **the time difference** between the arrival, at an aircraft's receiver, of a series of pulses from a **Master** transmitter and a series of pulses from up to four **Slave or Secondary** transmitters; this arrangement of transmitters is known as a **chain.** Loran C is also used as a non-precision approach aid in the USA.

Loran C was planned to be shut down by the end of year 2000 but has now been extended until the end of 2008, and it is very likely that it will be extended for several more years beyond 2008.

HYPERBOLAE

Definition
A hyperbola is the **locus of** (a line joining) **all points having the same difference in distance from two fixed points** called **the foci.** A series of such hyperbolae is known as a family as shown in Figure 16.1 where the foci are called Master and Slave.

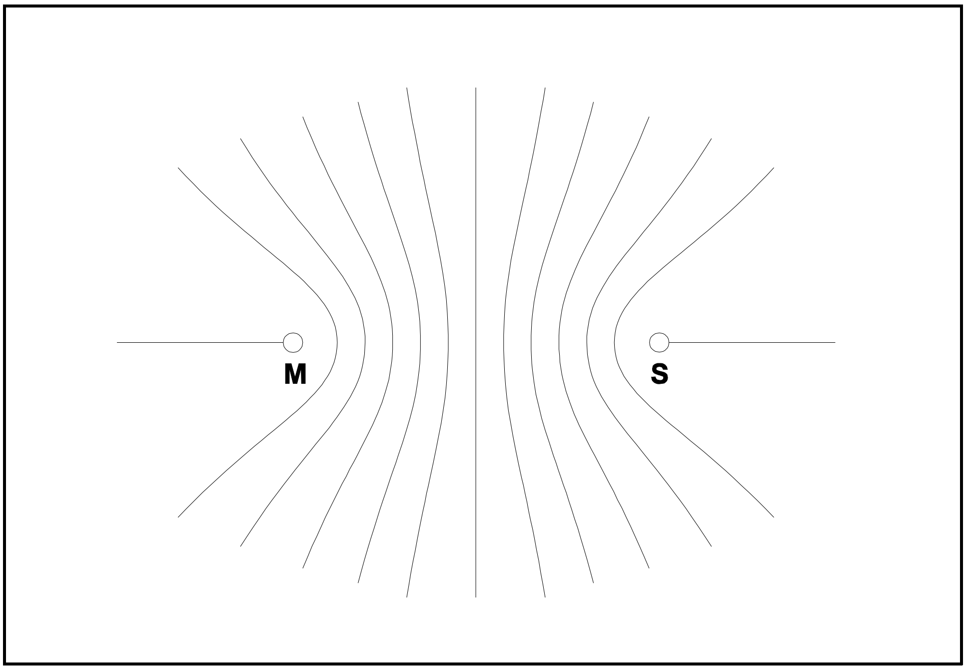


Figure 20.1 Family of Hyperbolae

Baseline and Right Bisector
The two fixed points used to create a family of hyperbolae, for either a Decca or Loran C chain, are the Master and Slave transmitters, **M** and **S**; the Master controls the Slave and the great circle distance between them is the **baseline**. See Figure 20.2.

The line joining C, B, A, B1, C1 is a hyperbola called the **the right bisector** or **bisector line,** as all points on it have a constant difference in range of 0 units from M and S.

Baseline Extensions
The baseline extensions, from M or S, shown in Figure 20.3 are also a hyperbolae as the difference in distance along those lines is a constant M to S or baseline distance.

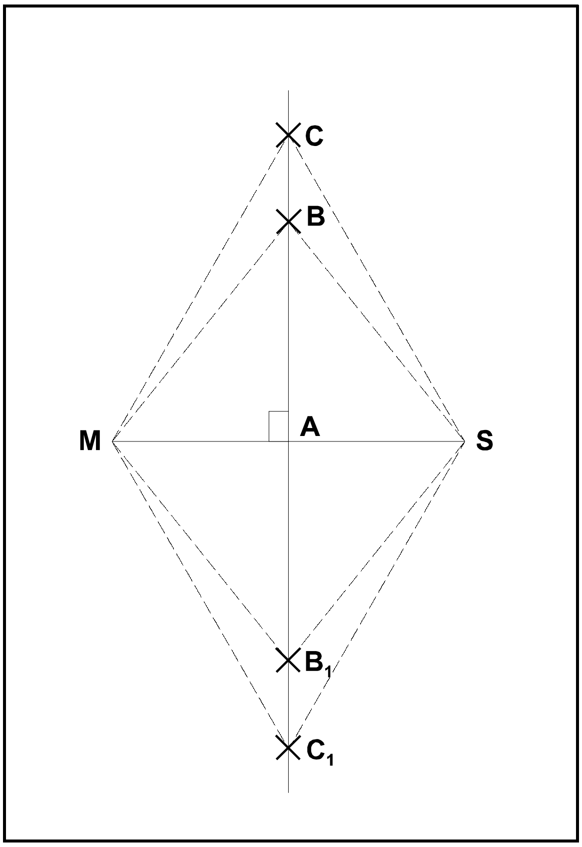


Figure 20.2 Baseline Right Bisector

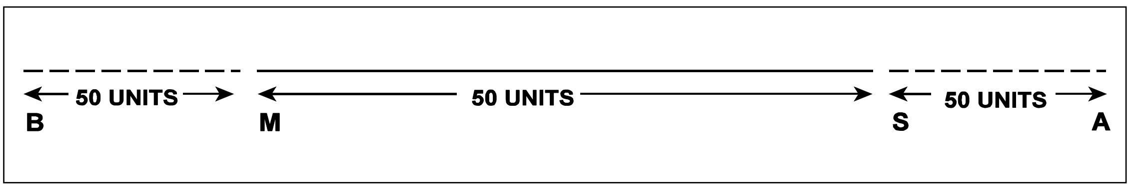


Figure 20.3 Baseline Extensions

Curved Hyperbola
Any hyperbola constructed in the areas between the right bisector and the extended baseline will be curved. See Figure 20.4. Thus any point on a curved hyperbola has a constant range difference from M and S.

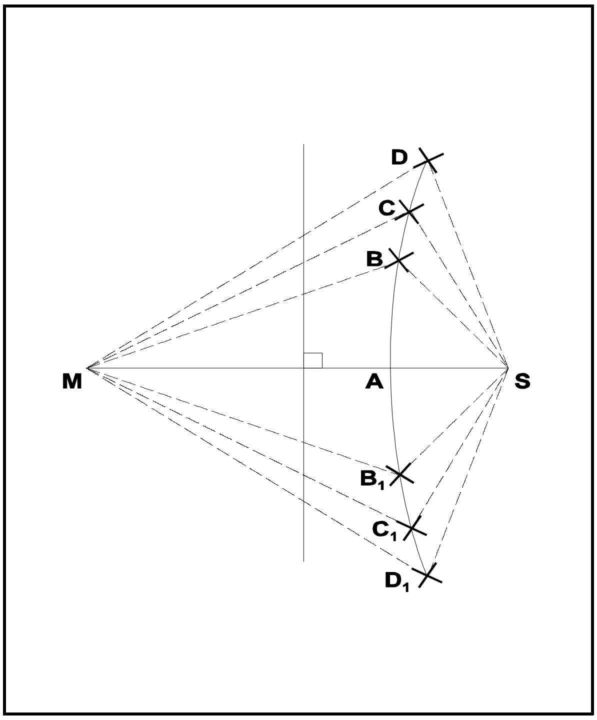


Figure 20.4 Curved Hyperbola

LORAN COVERAGE

Figures 20.5 and 20.6 show the coverage of LORAN C extending from South-east Asia, over the North Pacific, across the United States, the North Atlantic and over Europe.

An example of the composition of an individual chain is as follows:

STATION	POSITION	DESIG	LOCATION
Eidhi Faroes	(Master)N62 18 W007 04	7970	Faroes
Bo	(Slave) N63 38 E014 28	7970X	Norway
Sylt	(Slave) N54 48 E008 18	7970W	Germany
Jan Mayen	(Slave) N70 55 W008 44	7970Z	Arctic Ocean
Sandur	(Slave) N64 54 W023 55	7970Y	Iceland

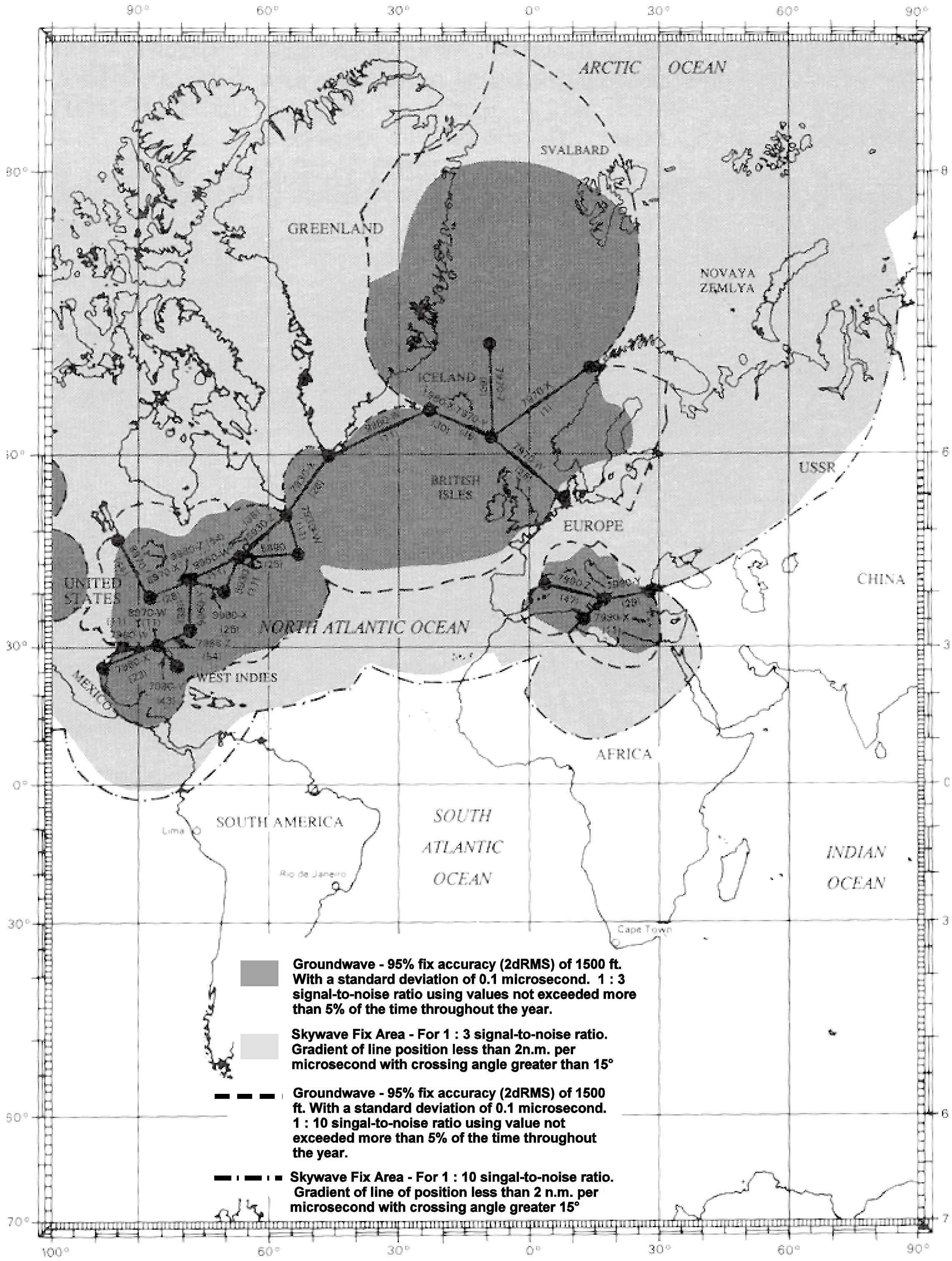


Figure 20.5 Atlantic Coverage

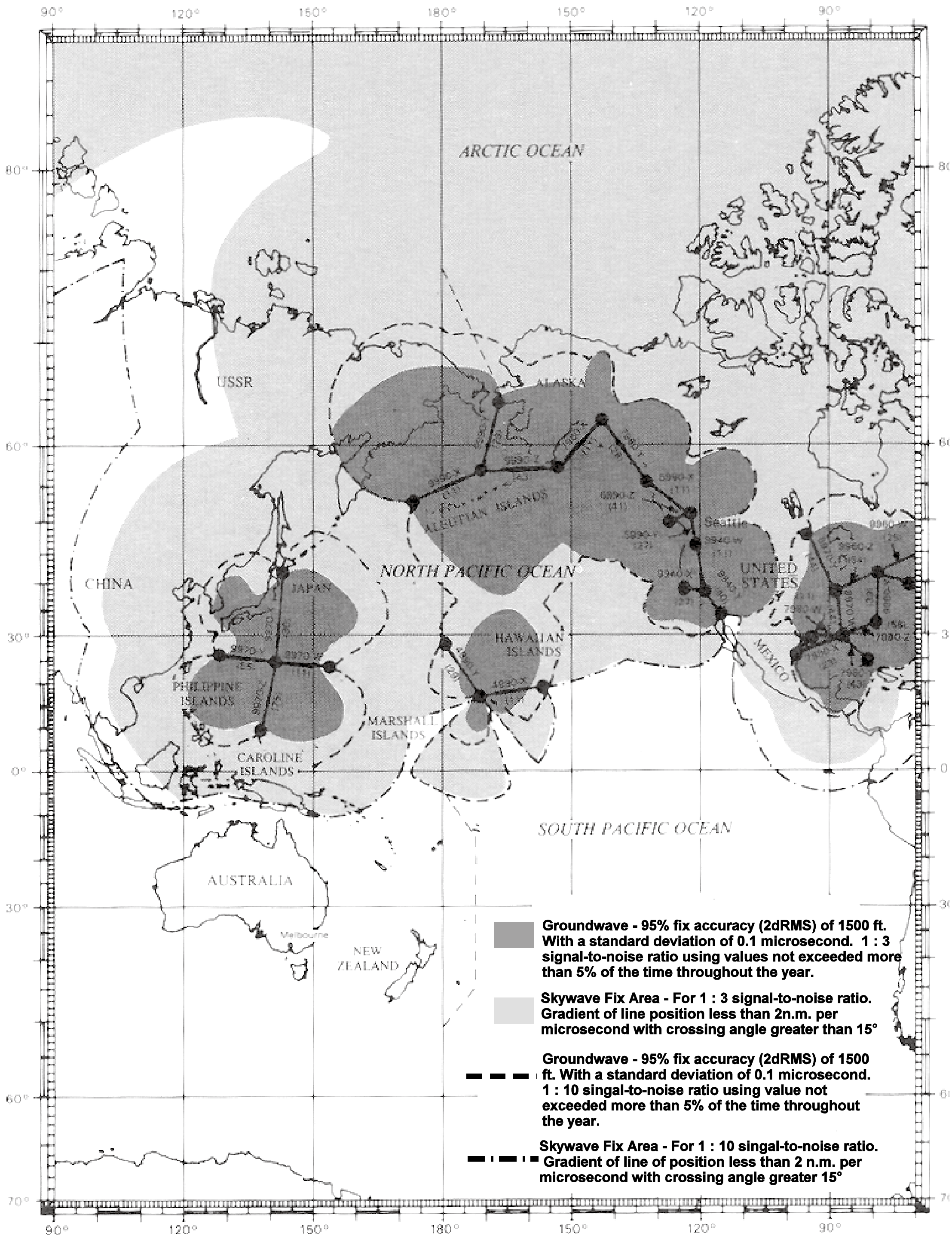


Figure 20.6 Pacific Coverage

LORAN EQUIPMENT

Prior to modern electronics, computer technology and pilot operated systems, the pulses from the transmitters were displayed on a cathode ray tube (CRT) with the time differences between the master and slave transmitters being displayed, alternately, on a readout unit once every second.

Figure 20.7 shows a Loran C Readout Unit and Receiver/CRT. The CRT displays the nine "gated" pulses of the master transmission and the eight pulses of the four slave transmissions, two of which have been selected and "gated". The operator selected the two slaves that gave the best position line cut to produce the most accurate navigational fix. The microsecond time difference values displayed on the readout unit were plotted on the appropriate LORAN C plotting chart.

The latest equipments have receivers that can evaluate, simultaneously, up to eight slaves from four chains. The computerised results are presented as latitude and longitude or along and across track co-ordinates. The chains and stations are acquired and deselected as required as the aircraft progresses through its waypoints. These systems also possess powerful computers which store and display useful navigation and performance data and can interface with GPS or INS to provide FMS/RNAV systems.

PRINCIPLE OF OPERATION

LORAN C uses the principle of **differential range by pulse technique.** In order to understand the principle it is useful to consider how the LORAN C pulses and time difference readings appear on the operator's CRT/Readout unit (Figure 20.7). Figure 20.8 shows part of a Loran C chart. Consider master-slave time differences of 50000 μs and 64600 μs as shown in Figure 20.6.

Timebase 1 (Figure 20.9a.) shows the nine Master pulses "gated" at the extreme left of the timebase and the four Slave groups of eight pulses appearing at their correct μs time intervals. The operator has also "gated" Slaves Y and Z as these hyperbolae provide the most accurate fix. The distances between the Master pulses and the two selected Slave pulses represent their coarse time differences in μs, displayed at the readout unit.

Timebase 2 (Figure 20.9b.) shows the master pulse expanded and more accurately aligned with its "gate". This timebase is then selected in turn for each chosen slave which is then "gated" more accurately in order to refine the differential timing.

Timebase 3 is finally selected for the Master and each chosen Slave. It is at this stage in the manually operated set and the automated systems that the eight pulses of the master and slaves are combined to produce the separate composite, strong pulses of 250-300μs width as shown in Figure 20.9c.

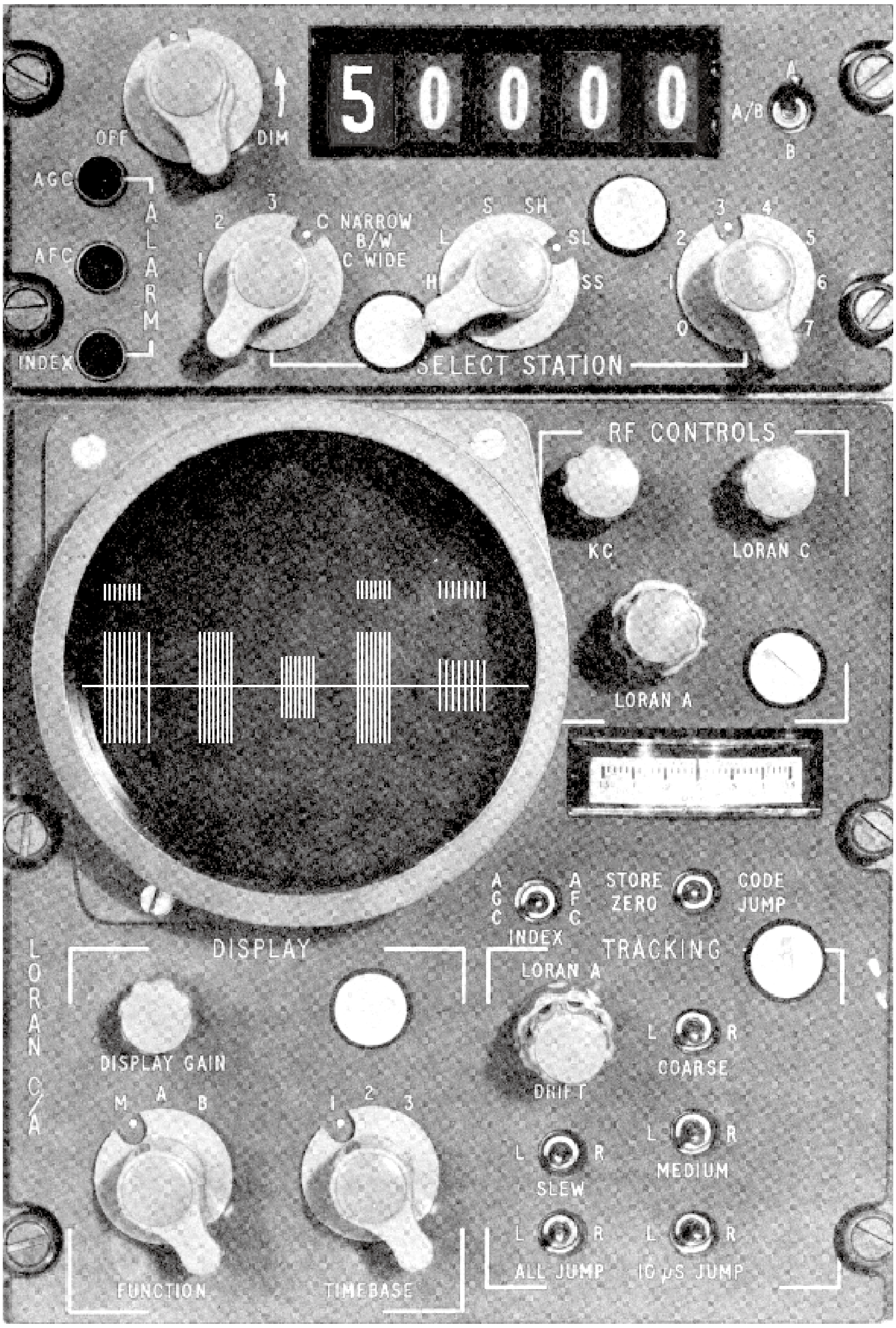


Figure 20.7 Readout unit & Receiver/CRT presentation

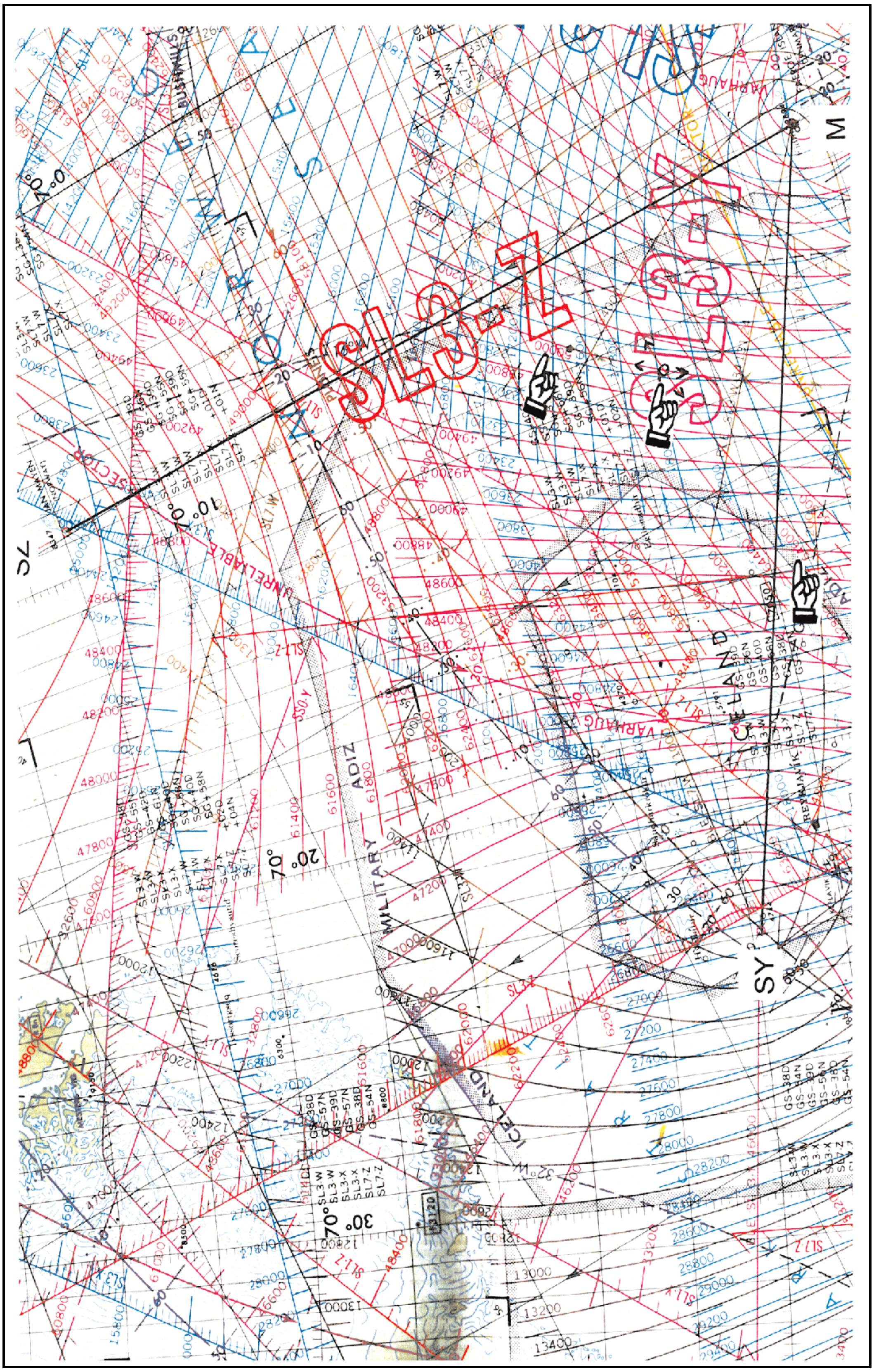


Figure 20.8 Portion of Loran C Hyperbolic Chart

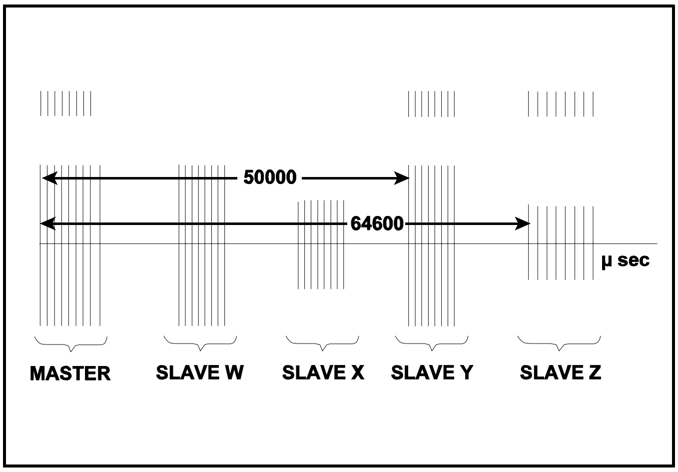


Figure 20.9a Master and Slaves Gated

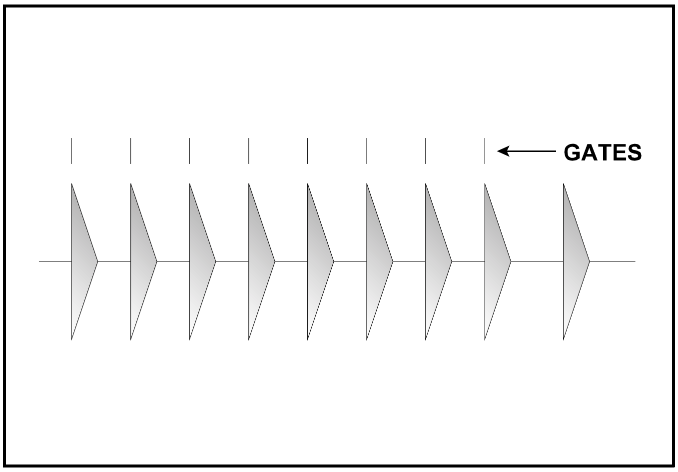


Figure 20.9b Master more accurately Gated

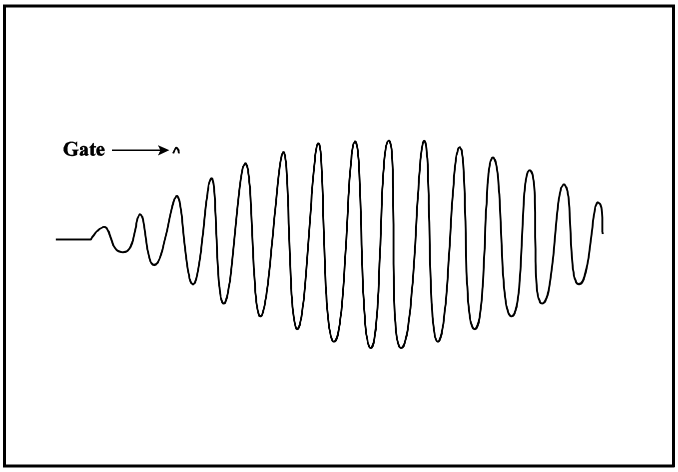


Figure16.9c Combined Pulses and 3rd. Cycle gated

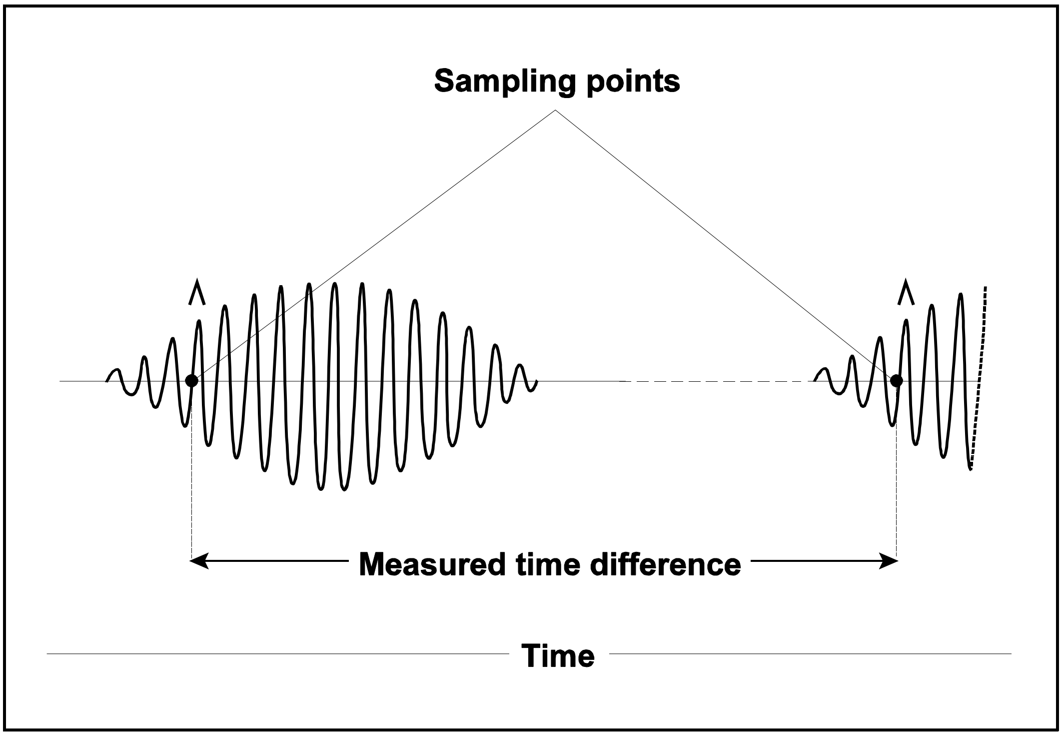


Figure 20.9d Cycle matching or Indexing

Figure 20.9d shows **cycle matching** where the accurately measured time difference (µs) between the same cycle in the master and slave pulses is obtained. **The third cycle** is used as this **is never contaminated by a skywave** pulse and once it has been acquired, in either the manually operated or the modern automated equipments, tracking and timing measurement is automatic and positive throughout flight in groundwave cover. As the period for 100 kHz carrier wave is 10 µs then, by phase matching the corresponding cycles of the master and slave transmissions, the **accuracy obtained is in the order of 10 µs.**

CHAIN IDENTIFICATION

All the master and slave stations transmit at a single basic frequency of **100 kHz.** To overcome the consequent problem of **chain identification** a chain is allocated a **Specific PRI, or Group PRI** which itself is based upon a **Basic PRI** in accordance with the following tables:

Basic PRI	**Chain's Specific PRI or Group PRI**
50000µs	Basic PRI minus 100µs
60000µs	" " 200µs
80000µs	" " 300µs
100000µs	" " 400µs
	" " 500µs
	" " 600µs
	" " 700µs

The production of chain identification is shown in the following examples:

- The Faroes chain, which has four slaves (W at Sylt, X at BO, Y at Sandur and Z at Jan Mayen Island) has a basic PRI of 80000µs and a specific PRI (GRI) of 79700µs (80000 -300µs). The code for this chain is 7970.

- The Johnston Island chain in the South Pacific, which has two slaves (X at Hawaii and Y at Midway) has a basic PRI of 50000µs and a specific PRI(GRI) of 49900µs (50000-100µs). The code for this chain is 4990.

SLAVE STATION - TIME DELAYS

It can be seen from the diagram of the pulses displayed on the CRT, Figures 20.7/20.9a, that the master must arrive at a receiver, positioned at any location on a particular chain, before the slave pulses and that their transmissions must arrive also in the **correct time/distance sequence**. This is achieved by building in **µs time delays at the slave transmitters**. (Figure 20.10). Each slave or secondary transmitter has a different delay such that the secondary transmissions always arrive at a receiver in the sequence W, X, Y, Z. These time delays at the slave stations are also known as **secondary specific delays** or emission or coding delays.

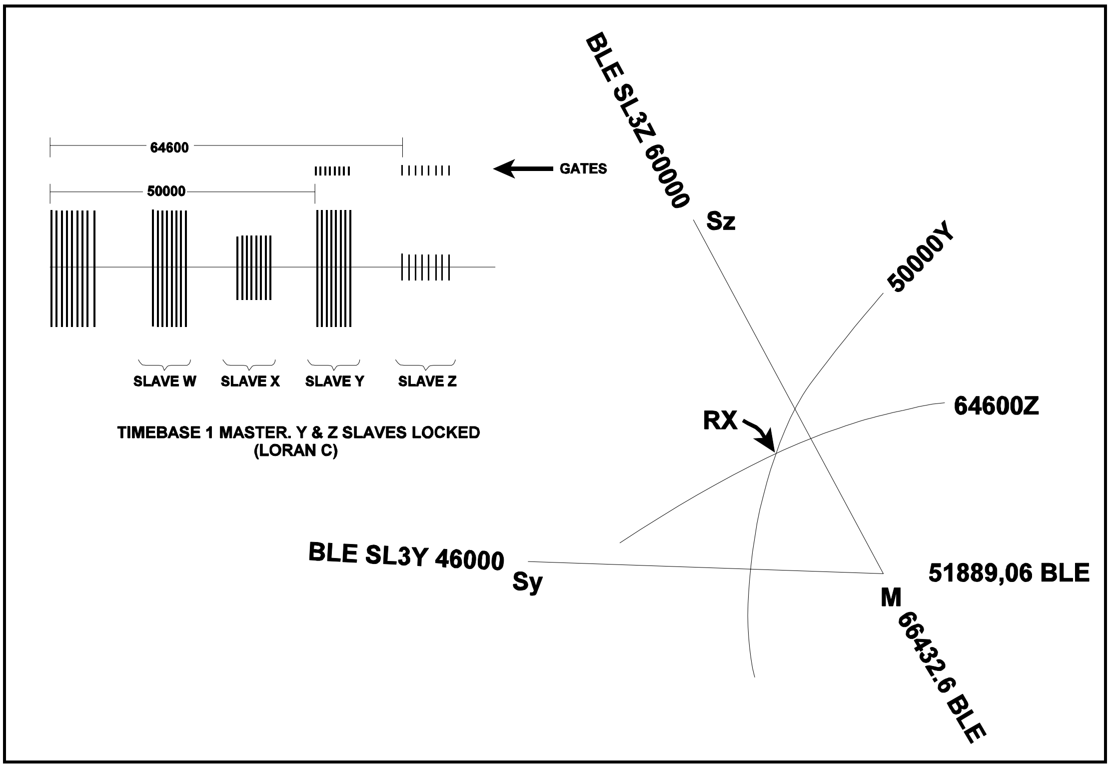


Figure 20.10 Baseline Extension Time Delays

DIFFERENTIAL RANGE BY TIMING

Consider master (M) and slave (S) stations at a certain distance apart (the baseline distance). Let **T µs** be the time for a pulse to travel from M to S or vice versa **(master/slave propagation delay)** and **D µs** the delay at S **(the secondary specific delay)**.
The difference in distance to the two stations is then obtained simply by multiplying the time difference with the speed of light.

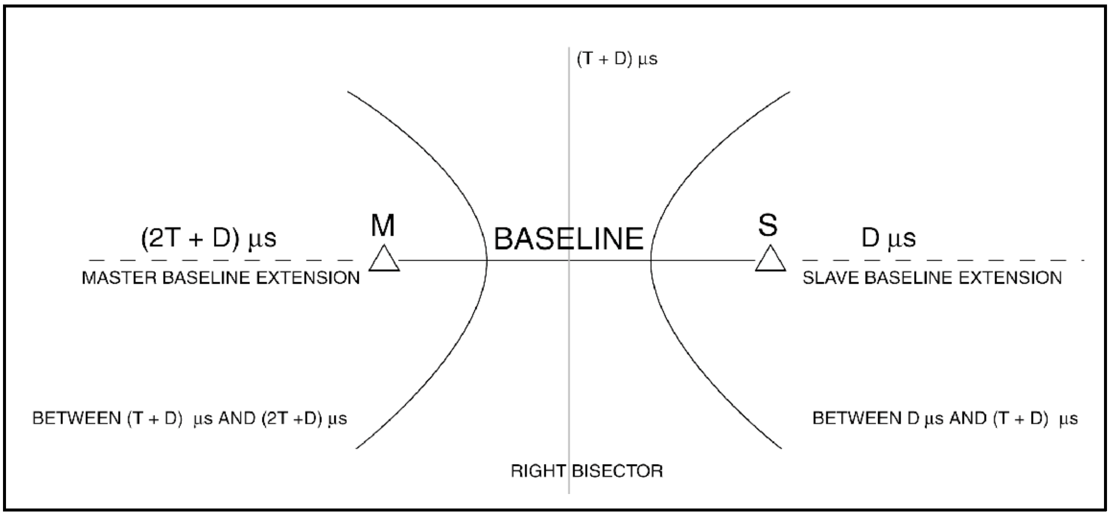


Figure 20.11 Propagation Delay

The **propagation delay** or the time delay between the pulses from M and S at every chain will be as follows:

- Baseline extension from S: Dµs
- Right bisection: (T + D)µs
- Baseline extension from M: (2T + D)µs
- Values of propagation delays on other hyperbolic will vary between Dµs and (2T + D)µs

RANGES AND FACTORS AFFECTING RANGE

Ground Wave Range
Long range surface waves, which are affected by the earth's conductivity, give the following approximate **daytime ranges:**

- **1200 nm** over **water**
- **900 nm** over **land**

Skywave Range
Skywaves of varying strength can be used **up to about 2500nm by night and also by day** when propagation conditions permit. For frequencies near 100 khz the base of the E and F layer acts as a reflector. In general the timings obtained from skywave pulses will be different from those obtained from ground wave pulses at the same location. The standard method of allowing for these differences is to provide **tabulated corrections on the Loran charts.**

Factors affecting Range
Transmissions are adversely affected by weather, static build-up on an aircraft in precipitation (hence static-wick dischargers), natural and man-made “noise”, and require large aerial arrays with considerable power to transmit long range. These disadvantages are minimised by using a **‘multi-pulse’ system**. The master and slave pulses are transmitted in groups of eight, the individual pulses in each group separated by 1000μs with the master group distinguishable by a ninth pulse at a 2000μs interval; the duration of a pulse is 250-350μs. These pulses are then **amalgamated at the receiver to produce a single strong pulse** with a good signal/noise ratio. Any phase coding present in the pulses is removed before this process of amalgamation.

PHASE CODING

In order to provide an **automatic search capability** and some measure of **multi-hop skywave rejection, the pulses are phase coded**. The phase of a pulse would be positive if the first half of the carrier wave is positive as shown in Figure 20.12a. The phases of the pulses in a group would be coded in a predetermined sequence as shown in Figure 20.12b. The master sequence M1 would be followed by the slave sequences S1(X), S1(Y) and S1(Z) which would be identical. This is then followed by M2, S2(X), S2(Y) and S2(Z) etc. The received pulses are compared with reference pulses stored in the receiver to ensure that individual chains are identified and also that Master and Slave pulses cannot be mismatched at the receiver or contaminated by skywaves.

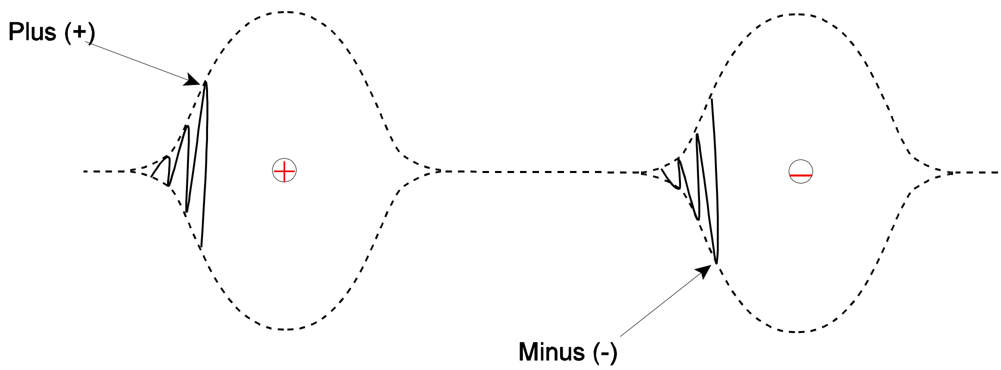


Figure 20.12a Carrier Wave Phase

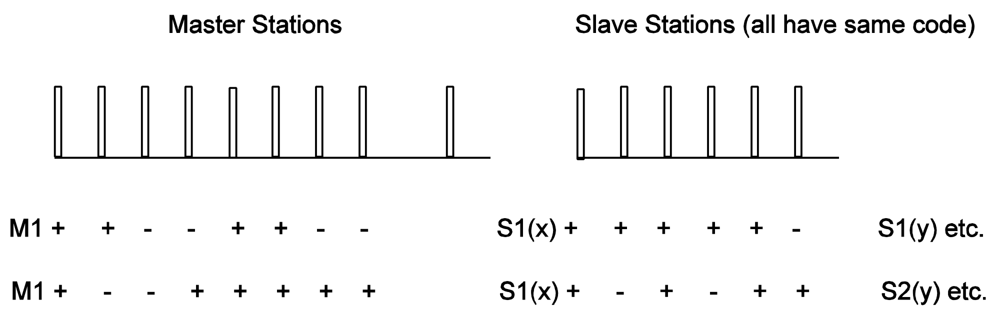


Figure 20.12b Phase Coding

FIX ACCURACY

The accuracy of the fix obtained depends upon the range and the type of radio wave arriving at the receiver.

- In good groundwave cover the accuracy is better than **0.2 nm** decreasing to **1nm** at **1,000 nm** range.

- Skywave accuracy up to about **2,500 nm** is **10-20 nm** depending upon conditions and the accurate application of predicted corrections.

- At ranges of 1000 to 1200nm and more, accuracy is diminished because the surface wave pulses are contaminated by skywave pulses.

- Best results are achieved in clear weather by day over water in the region of the baseline between a master and a slave. These baseline distances are between 500 and 1000nm.

APPENDIX 16 A
[NOT REQUIRED FOR JAA EXAMS]

Calculation of Baseline Distance (Figure 20.10)

Delays at SY and M are 46000μsec and 51889.06μsec

$$\text{Baseline, SY to M} = \frac{51889.06 - 46000\mu sec \times 300m}{1852 \times 2} = 477nm$$

Delays at SZ and M are 60000μsec and 66432.6μsec

$$\text{Baseline, SZ to M} = \frac{66432.6 - 60000\mu sec \times 300m}{1852 \times 2} = 521nm$$

Calculation of Line of Constant Time Range Difference, i.e. A Hyperbola
Consider the hyperbola with a constant difference, measured at a LORAN C receiver, of 50000μsec between the master and Y slave's transmissions:

$$\text{Time M to SY} = \frac{51889.06 - 46000\mu sec}{2}$$

= 2944.53μsec

Delay at SY = 46000μsec

SY to receiver = 50000 - (46000 + 2944.53)μsec

= 1055.47μsec, 171nm

Therefore, any point on the 50000μsec hyperbola equates to a constant time difference of 1055.47μsec, or, constant difference in distance of 171nm in relation to the fixed points M and SY .

The actual great circle distances from the master and Y slave to the point RX on figure 8. are 202nm and 373nm, a constant difference of 171nm. The same process could be used to calculate the baseline distance master to Z slave and the 64600μsec hyperbola time/range difference.

Chain Malfunctions and Abnormalities
All transmissions are monitored at the masters, slaves and special out stations. The ninth master pulse and the first two pulses of a slave can be coded to "blink" to indicate a specific fault. Modern Loran C CDUs have some form of status warning system which gives the pilot an indication of a malfunction and the possible course of action to adopt. Common irregularities are:

- Station not transmitting
- Incorrect number of pulses
- Incorrect pulse spacing
- Incorrect pulse shape

The CDU is also provided, usually, with a Built In Test Equipment (BITE) which monitors overall system performance whilst on the ground or in flight, whether or not signals are available.

LORAN SUMMARY

Features	Long range hyperbolic navigation using pulse technique in LF band Master and four Slave or Secondary stations (W, X, Y and Z) Older equipment used CRT and charts. Newer systems computerised.
Principle of	Differential range by pulse technique or timing
Operation	Master station transmits 9 pulses, Slave stations 8 pulses Selection of Time-bases and Gating of pulses enables time difference measurement between master and slave pulses to within 10 μs Third cycle used for cycle matching - no skywave interference
Chain Ident.	Basic PRI minus 100 - 900 μs gives Specific PRI for chain
Time Delays	Specific time delay at each slave or secondary station ensures pulses arrive at receiver always in sequence W, X, Y, Z.
Differential	From propagation delay between pulses from master and slave stations.

Range	Propagation delay is:	D μs	on baseline extension from S
		(T + D) μs	on right bisector
		(2T + D) μs	on baseline extension from M
		Between D μs and (2T +D) μs.	on other hyperbolae
		[T μs = M to S time	D μs = time delay at slave]
Range	Ground wave	1200 nm over water	900 nm over land
	Skywave	up to 2500 nm	Tabulated corrections on chart
	Signal improved by multi-pulse system (amalgamated pulses).		
Automatic Search	Pulses phase coded plus (+) or minus (-). Master and slaves have different sequences Chain identified by comparing with reference pulses in receiver.		
Accuracy	Ground wave	- 0.2 nm to 1 nm	at 1,000 nm range
	Skywave	- 10 to 20 nm	at 2,500 nm range.

QUESTIONS

1. The principle of operation of Loran C is:

a. timing the interval between transmitted and received pulses.
b. differential range by frequency comparison.
c. differential range by pulse transmissions.
d. differential range by phase comparison.

2. The frequency and waveband of LORAN C are:

a. 100 kHz, hectometric
b. 100 MHz, kilometric
c. 100 MHz, hectometric
d. 100 kHz, kilometric

3. The coverage of LORAN C is:

a. Specified areas only
b. Northern hemisphere only
c. Oceanic areas
d. Northern hemisphere oceanic areas

ANSWERS

1	C
2	D
3	A

CHAPTER TWENTY ONE

REVISION QUESTIONS

Contents

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 a 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 letdown?

    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. A 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 NDB's, 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 bearing 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 NDB's particularly by day
b. interference between aircraft aerials
c. interference from other NDB's, 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 NDB's 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 centreline 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. On a CVOR the phase difference between the AM and FM signals is 30°. The VOR radial is:

a. 210
b. 030
c. 330
d. 150

27. 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

28. 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

29. 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

30. 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

31. Which of the following is a valid frequency (MHz) for a VOR?

    a. 107.75
    b. 109.90
    c. 118.35
    d. 112.20

32. 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 VOR's operating on the same frequency
    c. skywave contamination of the VOR signal
    d. scalloping errors

33. 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

34. 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

35. 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

36. 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

37. 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

38. The frequency band of VOR is:

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

39. 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

40. 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. 26000 ft
b. 16000 ft
c. 24000 ft
d. 20000 ft

41. 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

42. At a range of 200 nm from a VOR, if there is an error of 1°, how far off the centreline is the aircraft?

a. 3.5 nm
b. 1.75 nm
c. 7 nm
d. 1 nm

43. 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

44. Which of the following provides distance information?

    a. DME
    b. VOR
    c. ADF
    d. VDF

45. 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

46. 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 15000 pulse pairs
    c. it stays in the search mode at 150 ppps
    d. it alternates between search and memory modes every 10 seconds

47. The most accurate measurement of speed by DME for an aircraft at 30000 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

48. A DME beacon will become saturated when more than about …… aircraft are interrogating the transponder.

    a. 10
    b. 50
    c. 100
    d. 200

49. A typical DME frequency is:

    a. 1000 MHz
    b. 1300 MHz
    c. 1000 kHz
    d. 1575 MHz

50. 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

51. 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

52. 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

53. A DME frequency could be:

a. 10 MHz
b. 100 MHz
c. 1000 MHz
d. 10000 MHz

54. 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

55. 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

56. What information does military TACAN provide for civil aviation users?

a. magnetic bearing
b. DME
c. Nothing
d. DME and magnetic bearing

57. 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

58. What are the DME frequencies?

a. 1030 & 1090 MHz
b. 1030 – 1090 MHz
c. 960 &1215 MHz
d. 960 – 1215 MHz

59. 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

60. 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

61. 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

62. 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

63. 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

64. The errors of an ILS localiser (LLZ) beam are due to:

    a. emission sidelobes
    b. ground reflections
    c. spurious signals from objects near the runway
    d. interference from other systems operating on the same frequency

65. 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

66. The principle of operation of the ILS localiser 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

67. The ILS glideslope transmitter generates false glidepaths 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

68. 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

69. A HSI compass rose is stuck on 200°. When the aircraft is lined up on the centreline of the ILS localiser for runway 25, the localiser needle will be:

    a. left of the centre
    b. centred
    c. right of the centre
    d. centred with the fail flag showing

70. The coverage of the ILS glideslope with respect to the localiser centreline is:

    a. +/-10° to 8 nm
    b. +/-10° to 25 nm
    c. +/-8° to 10 nm
    d. +/-35° to 17 nm

71. 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

72. 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

73. The sensitive area of an ILS is the area aircraft may not enter when:

    a. ILS operations are in progress
    b. category 1 ILS operations are in progress
    c. category II/III ILS operations are in progress
    d. the ILS is undergoing calibration

74. The ILS localiser 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

75. The audio frequency of the outer marker is:

    a. 3000 Hz
    b. 400 Hz
    c. 1300 Hz
    d. 1000 Hz

76. 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

77. The frequency band of the ILS glidepath is:

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

78. In which band does the ILS glidepath operate?

a. metric
b. centimetric
c. decimetric
d. hectometric

79. The coverage of MLS is …… either side of the centreline to a distance of ……

a. 40°, 40 nm
b. 40° 20 nm
c. 20°, 20 nm
d. 20°, 40 nm

80. 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

81. 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

82. The frequency band of MLS is:

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

83. Primary radar operates on the principle of:

a. transponder interrogation
b. pulse technique
c. phase comparison
d. continuous wave emission

84. 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

85. 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

86. 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

87. 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

88. 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

89. The maximum range of a ground radar is limited by:

a. pulse width
b. peak power
c. average power
d. pulse recurrence rate

90. 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

91. 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

92. 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

93. Which is the most suitable radar for measuring short ranges?

a. millimetric pulse
b. continuous wave primary
c. centimetric pulse
d. continuous wave secondary

94. The main advantage of a slotted scanner is:

a. reduces sidelobes and directs more energy into the main beam
b. removes the need for azimuth slaving
c. sidelobe suppression
d. can produce simultaneous map and weather information

95. The maximum unambiguous (theoretical) range for a PRF of 1200 pps is:

a. 134 nm
b. 180 nm
c. 67 nm
d. 360 nm

96. The PRF of a radar is 450 pps. If the speed of light is 300000 kps, what is the maximum range of the radar?

a. 150 km
b. 333 km
c. 666 km
d. 1326 km

97. 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

98. Which of the following is a primary radar system?

a. SSR
b. DME
c. GPS
d. AWR

99. On what principle does primary ATC radar work?

a. pulse technique
b. pulse comparison
c. continuous wave
d. transponder interrogation

100. ATC area surveillance radars will normally operate to a maximum range of:

a. 100 nm
b. 200 nm
c. 300 nm
d. 400 nm

101. An area surveillance radar is most likely to use a frequency of:

a. 330 MHz
b. 600 MHz
c. 10 GHz
d. 15 GHz

102. Short range aerodrome radars will have …… wavelengths.

a. millimetric
b. centimetric
c. decimetric
d. metric

103. The ASMR operates in the …… band, the antenna rotates at …… rpm can …… distinguish between aircraft types.

a. UHF, 120, sometimes
b. SHF, 60, always
c. UHF, 120, never
d. SHF, 60, sometimes

104. The frequency band of most ATC radars and weather radars is:

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

105. The airborne weather radar (AWR) cannot detect:

a. snow
b. moderate rain
c. dry hail
d. wet hail

106. The frequency of AWR is:

a. 9375 MHz
b. 937.5 MHz
c. 93.75 GHz
d. 9375 GHz

107. The use of the AWR on the ground is:

a. not permitted
b. permitted provided reduced power is reduced
c. permitted provided special precautions are taken to safeguard personnel and equipment
d. only permitted to assist movement in low visibility conditions

108. Which type of cloud does the AWR detect?

a. Cirro-cumulus
b. Alto-stratus
c. Cumulus
d. Stratus

109. The AWR uses the cosecant squared beam in the …… mode.

a. WEA
b. CONT
c. MAP
d. MAN

110. 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

111. 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

112. 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

113. 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

114. 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

115. 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

116. With the AWR set at 100 nm range a large cloud appears at 50 nm. If the range is reduced to 50 nm:

a. the image will decrease in area and remain where it is
b. the image will increase in area and move to the top of the screen
c. the image will increase in area and move to the bottom of the screen
d. the image will decrease in area and move to the top of the screen

117. 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

118. 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

119. On switching on the AWR a single line appears on the display. This means that:

a. the transmitter is unserviceable
b. the receiver is unserviceable
c. the CRT is not scanning
d. the antenna is not scanning

120. The AWR can be used on the ground provided:
    i. the aircraft is clear of personnel, buildings and vehicles
    ii. conical beam is selected
    iii. maximum uptilt is selected
    iv. the AWR must never be operated on the ground

a. iv
b. i and iii
c. i, ii and iii
d. ii and iii

121. Doppler navigation systems use …… to determine the aircraft groundspeed 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

122. Which axes is the AWR stabilised in?

a. Pitch, roll and yaw
b. Roll and yaw
c. Pitch and roll
d. Pitch only

123. 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

124. 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

125. 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

126. Which SSR mode A code should be selected when entering European airspace from an area where no code has been allocated?

a. 7000
b. 7500
c. 2000
d. 0000

127. 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

128. 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

129. 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

130. 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

131. The availability of 4096 codes in SSR is applicable to mode:

a. A
b. C
c. S
d. All

132. With reference to SSR, what code is used to indicate transponder altitude failure?

a. 9999
b. 0000
c. 4096
d. 7600

133. LORAN C is available:

a. globally
b. in oceanic areas
c. in continental areas
d. in specified areas

134. The frequencies used by LORAN C are:

a. 70 – 130 kHz
b. 90 – 110 kHz
c. 108 – 112 MHz
d. 190 – 1750 kHz

135. The principle of operation of LORAN C is:

a. differential range by phase comparison
b. differential range by pulse technique
c. range by pulse technique
d. range by phase comparison

136. 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

137. 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

138. 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

139. 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

140. The effect of the ionosphere on NAVSTAR/GPS accuracy is:

a. only significant for satellites close to the horizon
b. minimised by averaging the signals
c. minimised by the receivers using a model of the ionosphere to correct the signals
d. negligible

141. 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

142. 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

143. 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 co-ordinates
d. introducing an offset in the broadcast satellites X, Y & Z co-ordinates

144. 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

145. The NAVSTAR/GPS space segment:

a. provides X, Y & Z co-ordinates and monitoring of the accuracy of the satellite data
b. provides X, Y, Z & T co-ordinates and the constellation data
c. monitors the accuracy of the satellite data and provides system time
d. provides geographic position and UTC

146. 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

147. NAVSTAR GPS receiver clock error is removed by:

a. regular auto-synchronisation with the satellite clocks
b. adjusting the pseudo-ranges to determine the error
c. synchronisation with the satellite clocks on initialisation
d. having an appropriate atomic time standard within the receiver.

148. 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 co-ordinates and corrections, satellite clock time and error

149. The NAVSTAR/GPS segments are:

a. space, control, user
b. space, control, ground
c. space, control, air
d. space, ground, air

150. The preferred GNSS receiver for airborne application is:

a. multiplex
b. multi-channel
c. sequential
d. fast multiplex

151. The orbital height of geostationary satellites is:

a. 19330 km
b. 35800 km
c. 10898 nm
d. 10313 nm

152. 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

153. 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

154. 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

155. 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

156. The WGS84 model of the earth is:

a. a geoid
b. a sphere
c. an exact model of the earth
d. an ellipse

157. The frequency band of the NAVSTAR/GPS L1 and L2 frequencies is:

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

158. The number of satellites required to produce a 4D fix is:

a. 3
b. 4
c. 5
d. 6

159. How many satellites are needed for a 2D fix?

a. 4
b. 2
c. 3
d. 5

160. 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

161. Using differential GNSS for a non-precision approach, the height reference is:

a. barometric
b. GNSS
c. radio
d. radio or GNSS

162. The number of satellites required to provide a 3D fix without RAIM is:

a. 4
b. 5
c. 6
d. 3

163. The number of satellites required for a fully operational NAVSTAR/GPS is:

a. 21
b. 18
c. 24
d. 30

164. 'Unauthorised' 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

165. 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

166. The nav/system message from GLONASS and NAVSTAR/GPS is found in the …… band.

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

167. Which GNSS system can be used for IFR flights in Europe?

a. NAVSTAR/GPS
b. GLONASS
c. COSPAS/SARSAT
d. TNSS transit

168. 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

169. 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

170. What are the basic elements transmitted by NAVSTAR/GPS satellites?
    i. offset of the satellite clock from GMT
    ii. ephemeris data
    iii. health data
    iv. ionospheric delays
    v. solar activity

a. i, ii, iii, iv and v
b. i, i and iii
c. i, i and iv
d. ii, iii and iv

171. What is the purpose of the GPS control segment?

a. to control the use of the satellites by unauthorised users
b. to monitor the satellites in orbit
c. to maintain the satellites in orbit
d. degrade the accuracy of satellites for unauthorised users

172. 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

173. 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

174. 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 synchronising 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

175. 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 idealised Keplerian orbits

176. 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

177. To provide 3D fixing with RAIM and allowing for the loss of one satellite requires …… SVs:

a. 4
b. 5
c. 6
d. 7

178. 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

179. 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

180. 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

181. Which GNSS is authorised for use on European airways?

a. GLONASS
b. NAVSTAR/GPS
c. Galileo
d. COSPAS/SARSAT

182. 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

183. 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

184. 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

185. 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

186. In which frequency band are the L1 and L2 frequencies of GNSS?

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

187. 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

188. 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

189. In the 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°

190. 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

191. 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 groundspeed and position are accurate.
   c. If the forecast W/V at take-off is entered.
   d. If the groundspeed is correct and the take-off time has been entered.

192. When is the FMS position likely to be least accurate?

   a. TOD
   b. TOC
   c. Just after take-off.
   d. On final approach.

193. 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

194. When using a two dot HSI, a deviation of one dot from the computed track represents:

   a. 2°
   b. 5°
   c. 5 nm
   d. 2 nm

195. 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

196. 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

197. The JAR25 recommended colour for a downpath waypoint is:

   a. white
   b. green
   c. magenta
   d. cyan

198. The JAR25 recommended colour for the present track line in the expanded modes is:

a. white
b. green
c. magenta
d. cyan

199. The range arcs in the expanded and map modes are recommended by JAR25 to be coloured:

a. white
b. green
c. magenta
d. cyan

200. The JAR25 recommendation for the colour of a VORTAC which is not in use by the FMC is:

a. white
b. green
c. magenta
d. cyan

201. 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

202. 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

203. 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

204. The inputs the pilot will make to the FMC during the pre-flight initialisation 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.

205. The JAR25 recommended colour for an active waypoint is:

a. amber
b. magenta
c. green
d. cyan

206. The JAR25 recommended colour for an off-route waypoint is:

a. white
b. magenta
c. green
d. cyan

207. The JAR25 recommended colour for the aircraft symbol is:

a. white
b. magenta
c. green
d. cyan

208. The JAR25 recommended colour for the active route is:

a. white
b. magenta
c. green
d. cyan

209. In the NAV and EXP NAV modes one dot on the EHSI represents:

a. 2 nm
b. 2°
c. 5 nm
d. 5°

210. 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

211. 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

212. The colour recommended in JAR25 for engaged modes is:

a. green
b. magenta
c. cyan
d. white

213. The colour recommended in JAR25 for armed modes is:

a. green
b. yellow
c. white
d. magenta

214. The colour recommended in JAR25 for the display of turbulence is:

a. red
b. black
c. white or magenta
d. amber

215. The colour recommended in JAR25 for the active route is:

a. green
b. magenta
c. cyan
d. amber

216. 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

217. The JAR25 colour for selected heading is:

a. green
b. magenta
c. red
d. white

218. Refer to Appendix A diagram C. What is the current drift?

a. 4° left
b. 12° left
c. 4° right
d. 12° right

219. According to JAR25, for what type of message is the colour red used?

a. warnings, cautions, abnormal sources
b. flight envelope, system limits, engaged mode
c. cautions, abnormal sources, engaged mode
d. warnings, flight envelope, system limits

220. In the B737-400 EFIS which component generates the visual display?

a. flight control computer (FCC)
b. FMC
c. symbol generator
d. navigation database

221. 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

222. Refer to Appendix A. Which diagram is the MAP mode?

a. D
b. F
c. E
d. C

223. 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)

224. Refer to diagram B of Appendix A. The aircraft is:

a. right of the centreline and above the glidepath
b. left of the centreline and below the glidepath
c. right of the centreline and below the glidepath
d. left of the centreline and above the glidepath

225. Refer to Appendix A. Diagram F represents:

a. NAV
b. EXP VOR
c. VOR
d. ILS

226. 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

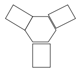
227. In accordance with JAR25, which features on an EFIS display are coloured cyan?

a. engaged modes
b. the sky
c. the flight director bar(s)
d. system limits and flight envelope

228. 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

229. On an EFIS display the pictured symbol represents:



a. DME
b. VOR/DME
c. VORTAC
d. aerodrome

230. 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.

231. Which of the following is independent of external inputs?

a. INS
b. Direct reading magnetic compass
c. VOR/DME
d. ADF

232. 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

233. The JAR25 colour recommended for the display of current data is:

a. yellow
b. red
c. magenta
d. white

234. 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

235. 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

236. 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

237. 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

238. 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

239. Refer to diagram D of Appendix A. The current aircraft track is:

a. 130°
b. 133°
c. 156°
d. 165°

240. Refer to appendix A diagram C. The wind velocity is:

a. 129°(M)/20 ms^{-1}
b. 129°(T)/20 kt
c. 129°(M)/20kt
d. 129°(T)/20 ms^{-1}

241. 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

242. Which EHSI modes cannot show AWR information?

a. FULL VOR/ILS/NAV and MAP
b. PLAN, CTR MAP and EXP VOR/ILS/NAV
c. CTR MAP and PLAN
d. PLAN and FULL VOR/ILS/NAV

243. 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

244. Refer to Appendix B. The distance displayed on the EHSI will be:

a. 10 nm
b. 11 nm
c. 12 nm
d. 21 nm

245. 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

246. 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

247. The normal maximum range for an ATC surveillance radar is:

a. 50 nm
b. 150 nm
c. 250 nm
d. 350 nm

248. 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

249. Flying an ILS approach with a 3° glideslope 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

250. The height of the GPS constellation is:

a. 19300 km
b. 20200 km
c. 10900 km
d. 35800 km

251. Which type of radar could give an indication of the shape and sometimes the type of the aircraft?

a. area surveillance radar
b. SSR
c. AWR
d. Aerodrome surface movement radar

252. 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

253. 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

254. 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

255. 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)

256. How does night effect affect ADF?

a. Causes false bearings as the goniometer locks onto the skywave
b. Skywave interference which affects the null and is worst at dawn and dusk
c. Interference from other NDB's which is worst at dusk and when due east of the station
d. Phase shift in the received signal giving random bearing errors

257. What is an ADC input to the FMC?

a. Heading
b. VOR/DME position
c. TAS
d. Groundspeed and drift

258. A typical frequency for DME would be:

a. 300 MHz
b. 600 MHz
c. 900 MHz
d. 1200 MHz

259. 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

260. 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

261. 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

262. 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

263. An accurate position fix on the EHSI will be provided by inputs of:

a.
b. FMC, IRS, radio navigation aids
c. AWR, drift and TAS
d.

264. 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

265. 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

266. 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

267. 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 synchronisation 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

268. 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

269. 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

270. The optimum climb and descent speeds used byn 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

271. 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

272. 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 groundspeed

273. 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	D	41	C	81	A	121	C	161	A	201	B	241	D
2	A	42	A	82	C	122	C	162	A	202	D	242	D
3	C	43	A	83	B	123	A	163	C	203	C	243	C
4	A	44	A	84	A	124	B	164	D	204	B	244	C
5	D	45	C	85	B	125	B	165	A	205	B	245	B
6	C	46	B	86	A	126	C	166	B	206	D	246	D
7	B	47	C	87	D	127	B	167	A	207	A	247	C
8	C	48	C	88	B	128	B	168	B	208	B	248	D
9	A	49	A	89	D	129	B	169	B	209	A	249	D
10	B	50	C	90	B	130	D	170	C	210	A	250	B
11	C	51	A	91	C	131	D	171	B	211	A	251	D
12	C	52	A	92	A	132	B	172	A	212	A	252	A
13	C	53	C	93	B	133	D	173	A	213	C	253	C
14	A	54	B	94	A	134	B	174	C	214	C	254	D
15	C	55	C	95	C	135	B	175	B	215	B	255	B
16	D	56	B	96	B	136	B	176	B	216	C	256	B
17	D	57	A	97	B	137	A	177	C	217	B	257	C
18	B	58	D	98	D	138	B	178	A	218	C	258	D
19	A	59	C	99	A	139	A	179	C	219	D	259	C
20	C	60	B	100	C	140	C	180	B	220	C	260	B
21	C	61	A	101	B	141	C	181	B	221	D	261	C
22	B	62	C	102	B	142	A	182	B	222	D	262	A
23	D	63	D	103	D	143	B	183	B	223	C	263	B
24	C	64	B	104	B	144	C	184	C	224	C	264	D
25	B	65	A	105	A	145	B	185	C	225	B	265	C
26	C	66	C	106	A	146	A	186	C	226	B	266	D
27	A	67	C	107	C	147	B	187	C	227	B	267	B
28	C	68	A	108	C	148	A	188	A	228	B	268	C
29	A	69	B	109	C	149	A	189	D	229	C	269	B
30	B	70	C	110	C	150	B	190	C	230	A	270	B
31	D	71	C	111	B	151	B	191	B	231	A	271	B
32	B	72	C	112	B	152	D	192	A	232	C	272	C
33	C	73	C	113	C	153	B	193	A	233	D	273	B
34	B	74	C	114	D	154	C	194	D	234	D		
35	A	75	B	115	D	155	B	195	A	235	B		
36	A	76	A	116	B	156	A	196	C	236	C		
37	C	77	A	117	B	157	B	197	A	237	A		
38	A	78	C	118	C	158	B	198	A	238	A		
39	D	79	B	119	D	159	C	199	A	239	B		
40	B	80	D	120	C	160	C	200	D	240	C		

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. ATC inform a pilot that they will provide a QGH service. The pilot can expect:

    a. headings and heights to fly to arrive overhead the aerodrome
    b. radar vectors to position on final approach
    c. QDM information to position overhead the aerodrome
    d. Radar vectors to position overhead the aerodrome

5. The maximum range an ATC facility at 1369 ft amsl can provide a service to an aircraft at FL350 is:

    a. 280 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' (ie 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 FL 240 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 between the VOR FM modulation and the AM modulation is 235°. The bearing of the beacon from the aircraft is:

    a. 055°
    b. 235°
    c. 145°
    d. 325°

15. In a Doppler VOR (DVOR) the reference signal is ……, the variphase signal is …… and the rotation is ……

    a. FM, AM, clockwise
    b. AM, FM, clockwise
    c. FM, AM, anti-clockwise
    d. AM, FM, anti-clockwise

16. 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

17. 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

18. Flying an ILS approach the equipment senses that the 90 Hz modulation predominates on both the localiser and the glidepath. 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

19. On an ILS approach using a 3.5° glidepath, the height an aircraft, groundspeed 160 kt, should be at 3.5 nm is:

    a. 800 ft
    b. 1050 ft
    c. 900 ft
    d. 1500 ft

20. A category 2 ILS facility is required to provide guidance to:

    a. below 50 ft
    b. below 200 ft
    c. the surface
    d. below 100 ft

21. 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 localiser and no glidepath signal
    b. erratic on both localiser and glidepath
    c. erratic on the localiser and in the correct sense on the glidepath
    d. no localiser signal and in the correct sense for glidepath

22. The azimuth coverage of a 3° glidepath is:

a. +/-35° to 17 nm
b. +/-10° to 25 nm
c. +/-8° to 10 nm
d. +/-10° to 8 nm

23. 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

24. 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

25. 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

26. 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

27. The maximum theoretical range of a radar is determined by:

a. power
b. PW
c. beamwidth
d. PRF

28. 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 nm

29. 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

30. 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

31. 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

32. The AWR operating frequency is:

a. 9375 MHz
b. 9375 GHz
c. 937.5 MHz
d. 93.75 GHz

33. A cloud detected at 60 nm on the AWR of an aircraft flying at FL390 just disappears from the screen when the tilt is selected to 2° UP. If the beamwidth of the radar is 6°, then the altitude of the cloud tops is:

a. 6000 ft
b. 45000 ft
c. 33000 ft
d. 63000 ft

34. 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

35. On a colour AWR display, the heaviest precipitation will be displayed in:

a. amber
b. red
c. yellow
d. blue

36. The SSR code to select when entering an area where a radar service is available from an area where there is no radar service within the JAA area is:

    a. 7000
    b. 7007
    c. 2000
    d. 0000

37. 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

38. The altitude readout 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

39. 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

40. A DME recognises 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

41. 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

42. 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

43. The frequency used by LORAN C is:

a. 100 kHz
b. 100 MHz
c. 190 kHz
d. 190 MHz

44. The accuracy of LORAN C using surface wave fixing is:

a. 20 nm at 1000 nm
b. 1 nm at 2500 nm
c. 1 nm at 1000 nm
d. 20 nm at 2500 nm

45. The coverage of LORAN C is:

a. in specified areas
b. in oceanic areas
c. over land only
d. in oceanic areas in the northern hemisphere

46. 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

47. The model of the earth used for GPS is:

a. WGS90
b. PZ84
c. PZ90
d. WGS84

48. 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

49. The number of SV's required to produce a 3D fix is:

a. 3
b. 4
c. 5
d. 6

50. EGNOS provides a WAAS by determining the errors in …… and broadcasting these errors to receivers using ……

a. X, Y & Z co-ordinates, geostationary satellites
b. X, Y & Z co-ordinates, pseudolites
c. SV range, geostationary satellites
d. SV range, pseudolites

51. The principle error in GNSS is:

a. ionospheric propagation
b. GDOP
c. receiver clock error
d. SV ephemeris error

52. If the signal from a 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

53. The purpose of the PRN codes in NAVSTAR/GPS is to:

a. identify the satellites
b. synchronise the receiver clocks with the SV clocks
c. pass navigation and system data to the receiver
d. all of the above

54. 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

55. The provision of RAIM requires a minimum of …… SVs.

a. 3
b. 4
c. 5
d. 6

56. 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

57. The NAVSTAR/GPS constellation is inclined at …… to the equator with an orbital period of ……

a. 55°, 11 hr 15 min
b. 65°, 11 hr 15 min
c. 65°, 12 hr
d. 55° 12 hr

58. The NAVSTAR/GPS frequency available to non-authorised users is:

a. 1227.6 MHz
b. 1575.42 MHz
c. 1215.0 MHz
d. 1090.0 MHz

59. 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

60. 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

61. The accuracy required of a basic RNAV system is:

a. 5 nm
b. 5°
c. 1 nm
d. 1°

62. 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

63. The navigation database in a 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

64. 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

65. 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

66. Refer to Appendix A. Which diagram shows the MAP display?

a. A
b. C
c. D
d. F

67. 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

68. 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

69. Refer to appendix A, diagram F. What is the required track?

a. 165°
b. 173°
c. 157°
d. 130°

70. 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

71. The JAR25 recommended colour for active route/flight plan is:

    a. yellow
    b. green
    c. magenta
    d. green

72. JAR25 recommends the use of red for:

    a. cautions, abnormal sources and warnings
    b. warnings, flight envelopes and system limits
    c. engaged modes, warnings and cautions
    d. flight director bar, flight envelopes and system limits

73. The JAR25 recommended colour for turbulence is:

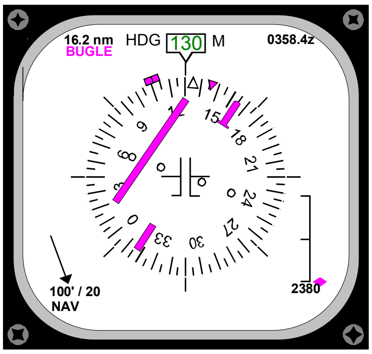
    a. red
    b. black
    c. white or magenta
    d. amber

74. The FMC position is:

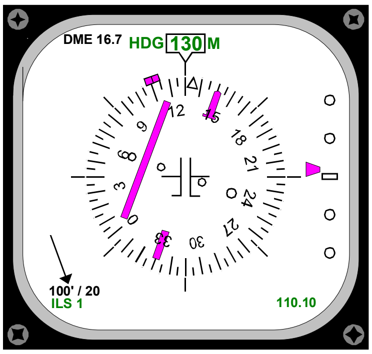
    a. the selected IRS position updated by external reference using Kalman filtering
    b. derived from IRS and external reference positions using the Kalman filtering process
    c. derived from external reference position and monitored against the IRS position using the Kalman filtering process
    d. the external reference position updated by IRS information through the Kalman filtering process

APPENDIX A

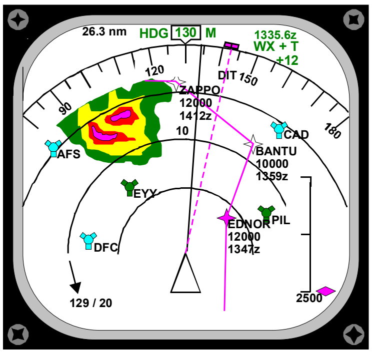
A



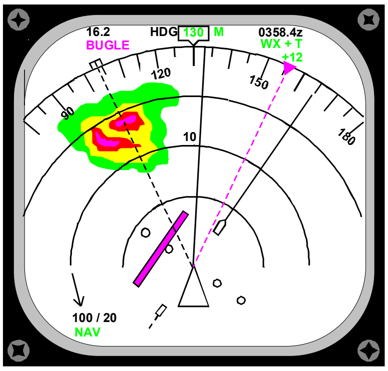
B



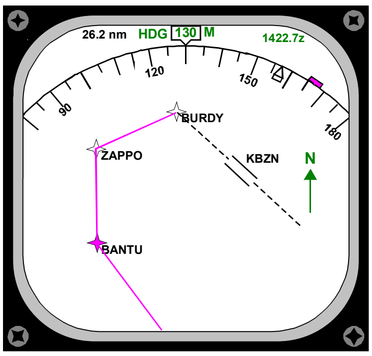
C



D



E



F

ANSWERS TO SPECIMEN EXAMINATION PAPER

1	B	21	B	41	A	61	A
2	C	22	C	42	B	62	A
3	D	23	D	43	A	63	C
4	A	24	B	44	C	64	D
5	A	25	D	45	A	65	B
6	D	26	A	46	B	66	B
7	B	27	D	47	D	67	C
8	C	28	B	48	B	68	B
9	A	29	C	49	B	69	A
10	C	30	B	50	C	70	B
11	D	31	A	51	A	71	C
12	D	32	A	52	D	72	B
13	C	33	C	53	A	73	C
14	A	34	A	54	C	74	B
15	D	35	B	55	C		
16	D	36	C	56	B		
17	A	37	A	57	D		
18	D	38	D	58	B		
19	B	39	D	59	A		
20	A	40	B	60	A		

EXPLANATION of SELECTED QUESTIONS

Q1. Use $c = \frac{f}{\lambda}$

Q5. Line of sight formula: $Range\ (nm) = 1.25\ (\sqrt{H_{TX}} + \sqrt{H_{RX}})$ (H in feet)

Q13. Line of sight formula again! Maximum range at which reception can be achieved is 198 nm.

Q14. The phase difference is the bearing of the aircraft from the beacon (radial).

Q16/17. Draw a diagram!

Q19. Height = Glidepath angle x range x 100 ft

Q28. $Range = \frac{Time\ Interval}{2 \times 6.17}$ nm.

Q33. Altitude of cloud tops $= \left(Tilt - \frac{Beamwidth}{2}\right) \times Range \times 100 + Aircraft\ Altitude$

Q38. The mode C increments in 100 ft steps.

Q39. 1262 MHz is outside the allocated band for DME

Q41. Pythagorus!

Q59. The 50 Hz modulation passes the Nav and System Data message. The PRN codes provide a timing function and SV identification.

Q62. The range displayed is to the waypoint.

Q67. Remember the PLAN display is orientated to TRUE north.