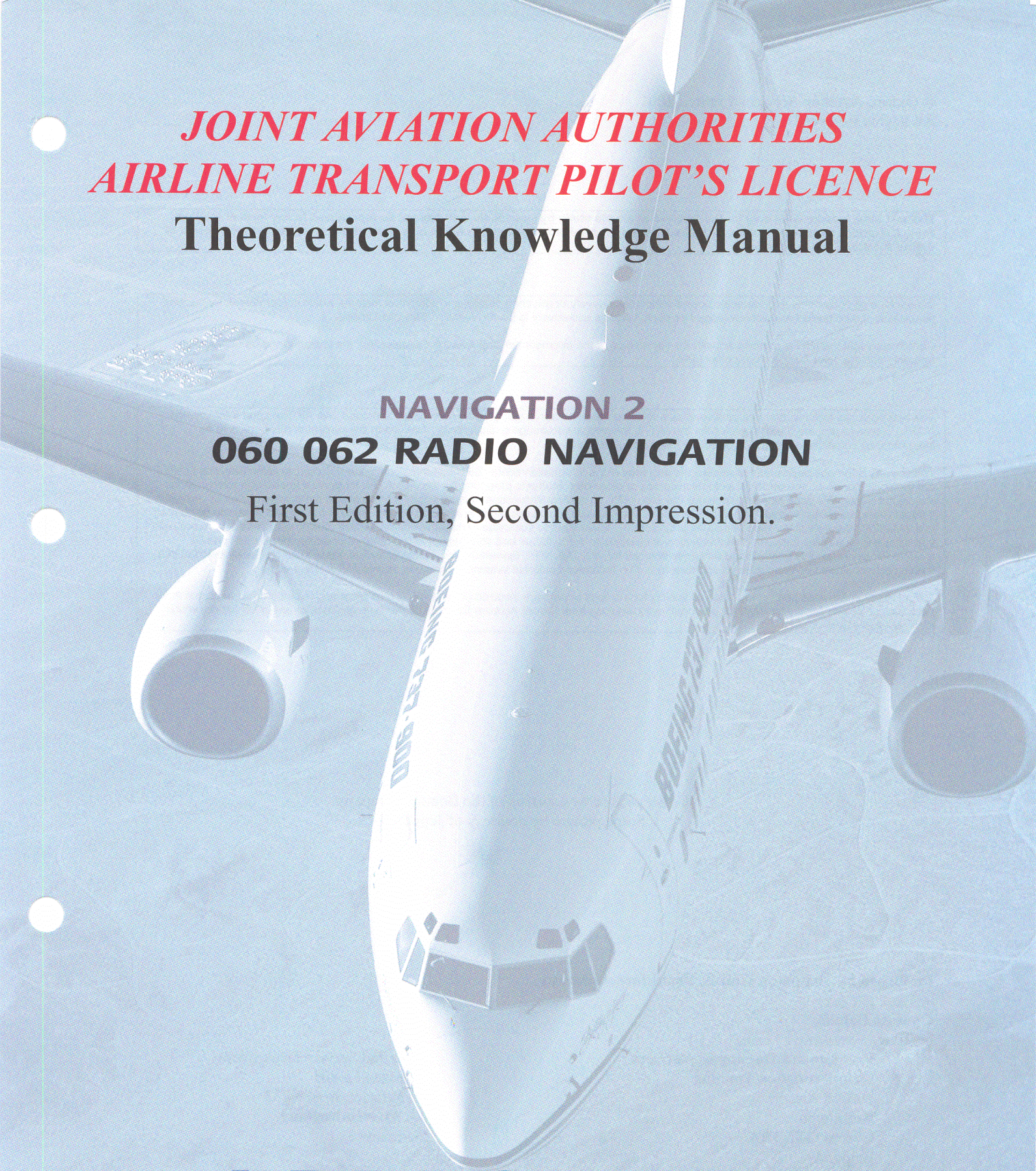
JOINT AVIATION AUTHORITIES AIRLINE TRANSPORT PILOT'S LICENCE

Theoretical Knowledge Manual



NAVIGATION 2

060 062 RADIO NAVIGATION

First Edition, Second Impression.

APPROVED

This learning material has been approved as JAA compliant by the United Kingdom Civil Aviation Authority.

CIVIL AVIATION AUTHORITY

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This text book has been written and published as a reference work to assist students enrolled on an approved JAA Air Transport Pilot Licence (ATPL) course to prepare themselves for the JAA ATPL theoretical knowledge examinations. Nothing in the content of this book is to be interpreted as constituting instruction or advice relating to practical flying.

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FOREWORD

Joint Aviation Authorities (JAA) pilot licences were first introduced in 1999. By the end of 2002, all 33 JAA member states will have adopted the new, pan-European licensing system. Many other countries world-wide have already expressed interest in aligning their training with the syllabi for the various JAA licences. These syllabi and the regulations governing the award and the renewal of licences are defined by the JAA's licensing agency, known as "Joint Aviation Requirements-Flight Crew Licensing", or JAR-FCL.

The introduction of JAA licences is, naturally, accompanied by associated JAR-FCL practical skill tests (tests of flying ability) and theoretical knowledge examinations corresponding to each level of licence: Private Pilot Licence, Commercial Pilot Licence (CPL), CPL with Instrument Rating and Air Transport Pilot Licence (ATPL). The JAR-FCL skill tests and the ground examinations, though similar in content and scope to those conducted by many national authorities, are inevitably different in detail from the tests and examinations set by any individual JAA member state under its own national scheme. Consequently, students who wish to train for JAA licences need access to study material which has been specifically designed to meet the requirements of the new licensing system.

As far as the JAA ATPL ground examinations are concerned, the subject matter to be tested is set out in the ATPL training syllabus contained in the JAA publication, 'JAR-FCL 1 (Aeroplanes)'. Inevitably, this syllabus represents a compromise between the differing academic contents of the national ATPL training syllabi it replaces. Thus, it follows that the advent of the new examinations has created a need for completely new reference texts to cover the requirements of the new syllabus. This series of manuals, prepared by Oxford Aviation Training and published by Jeppesen, aims to cover those requirements and to help student pilots prepare for the JAA ATPL theoretical knowledge examinations.

Oxford Aviation Training (OAT) is one of the world's leading professional pilot schools. It has been in operation for over thirty years and has trained more than 12, 000 professional pilots for over 80 airlines, world-wide. OAT was the first pilot school in the United Kingdom to be granted approval to train for the JAA ATPL. As one of the most active members of the European Association of Airline Pilot Schools, OAT has been a leading player in the pan-European project to define, in objective terms, the depth and scope of the academic content of JAA ATPL ground training as outlined in 'JAR-FCL 1 (Aeroplanes)'. OAT led and coordinated this joint-European effort to produce the JAA ATPL Learning Objectives which are now published by the JAA itself as a guide to the theoretical knowledge requirements of ATPL training.

In less than two years since beginning JAA ATPL training, and despite the inevitable teething problems that national aviation authorities have experienced in introducing the new examination system, OAT has achieved an unsurpassed success rate in terms of the passes its students have gained in the JAA ATPL examinations. This achievement is the result of OAT's whole-hearted commitment to the introduction of the new JAA licensing system and of its willingness to invest heavily in the research and development required to make the new system work for its students. OAT has not only been at the forefront of the effort made to document JAA ATPL theoretical knowledge requirements, but it has also produced associated academic notes of the highest quality and created computer-generated and web-based ATPL lessons which ensure that its students are as well-prepared as possible to succeed in the ground examinations.

continued....

OAT's experience and expertise in the production of JAA ATPL training material make this series of manuals the best learning material available to students who aspire to hold a JAA ATPL. Jeppesen, established in 1934, is acknowledged as the world's leading supplier of flight information services, and provides a full range of print and electronic flight information services, including navigation data, computerised flight planning, aviation software products, aviation weather services, maintenance information, and pilot training systems and supplies. Jeppesen counts among its customer base all US airlines and the majority of international airlines world-wide. It also serves the large general and business aviation markets.

The combination of Jeppesen and OAT expertise embodied in these manuals means that students aiming to gain a JAA ATPL now have access to top-quality, up-to-date study material at an affordable cost.

Manuals are not, of course, the complete answer to becoming an airline pilot. For instance, they cannot teach you to fly. Neither may you enter for the new JAA ATPL theoretical knowledge examinations as a "self-improver" student. The new regulations specify that all those who wish to obtain a JAA ATPL must be enrolled with a flying training organisation (FTO) which has been granted approval by a JAA-authorised national aviation authority to deliver JAA ATPL training. The formal responsibility to prepare you for both the flying tests (now known as "skill tests") and the ground examinations lies with your FTO. However, these OAT/Jeppesen manuals represent a solid foundation on which your formal training can rest.

For those aspirant airline pilots who are not yet able to begin formal training with an FTO, but intend to do so in the future, this series of manuals will provide high-quality study material to help them prepare themselves thoroughly for their formal training. The manuals also make excellent reading for general aviation pilots or for aviation enthusiasts who wish to further their knowledge of aeronautical subjects to the standard required of airline pilots.

At present, the JAA ATPL theoretical knowledge examinations are in their infancy. The examinations will inevitably evolve over the coming years. As the system evolves, syllabus or question modifications, as well as OAT's rapidly growing experience in preparing its students for the examinations, will inevitably lead to the need for changes or updates to the content of the books. The books are supported by a free updating service (available online at www.oxfordaviation.net/shop) which aims to keep pace with changes to the published JAA ATPL Learning Objectives. The online amendments also reflect the continual feedback that OAT receives from the hundreds of its students who pass the examinations, every year.

OAT's knowledge of and involvement in JAR-FCL developments are second to none. You will benefit from OAT's expertise both in your initial purchase of this text book series and in your subscription to the amendment service. OAT and Jeppesen have published what they believe to be the highest quality JAA ATPL theoretical knowledge manuals currently available. The content of these manuals enables you to draw on the vast experience of two world-class organisations, each of which is an acknowledged expert in its field of the provision of pilot training and the publication of pilot training material, respectively.

We trust that your study of these manuals will not only be enjoyable but, for those of you undergoing training as airline pilots, will also lead to success in the JAA ATPL ground examinations.

Whatever your aviation ambitions, we wish you every success and, above all, happy landings.

Oxford, England. January 2002

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NAVIGATION 2

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CHAPTER ONE - INTRODUCTION

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1.1 INTRODUCTION

The radio navigation syllabus encompasses the radio navigation facilities available for the navigation of aircraft during departure, en-route and approach and the radar facilities used for the control of aircraft and for in-flight safety.

The ground and airborne radars will continue to be an essential feature of aviation, however, it is intended in the medium term to replace all other radio navigation facilities with global navigation satellite systems (GNSS).

Overall the syllabus is essentially practical, however, previous knowledge from phase 1, as detailed below, and some theory, to assist in understanding how the equipments operate, is inevitably unavoidable.

1.2 REVISION

The radio theory studied in phase 1 (021 02 05) is essential knowledge for the understanding of the reasons why particular frequencies are used for particular radio navigation facilities and the advantages and limitations they impose. Central to this is understanding of the nature of electro-magnetic radiation and knowledge of the frequency bands in the radio part of the electro-magnetic spectrum. Also essential is a knowledge and understanding of the different propagation modes used and available within the radio band.

A summary of this is provided in the table at the end of this chapter.

1.3 ESSENTIAL KNOWLEDGE

The relevant points to note, from phase 1, are:

1. Phase angle and that phase comparison can only be carried out between two radio waves at the same frequency, and that the measurement is made from the reference wave to the variable wave.

   To determine the phase difference diagrammatically, start from an easily identifiable point on the reference wave, in this case 0 phase (point A) and measure the change in phase angle of the reference wave between this point and the 0 phase point on the variable wave (point B). The change in phase of the reference wave between the two points is 270°, so the phase difference is stated as 270°

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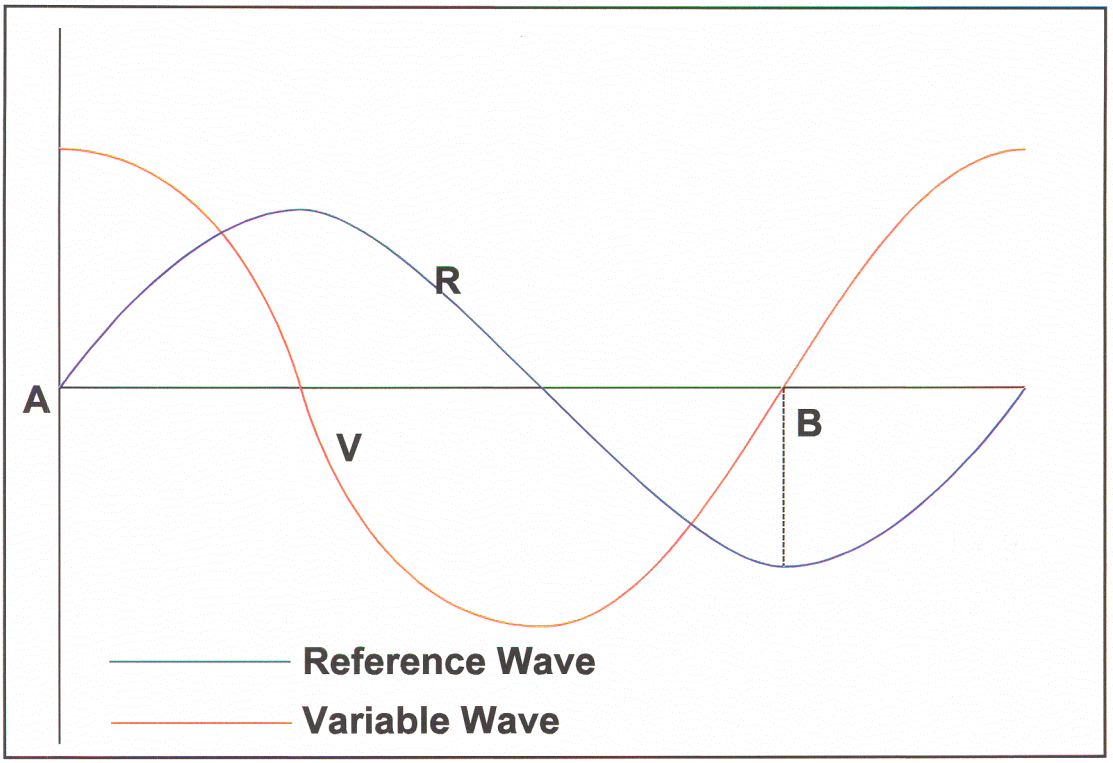

Figure 1.1. Phase Comparison.

2. The factors affecting propagation especially attenuation, reflection, refraction and the causes of fading.

3. Propagation: It should be noted that space wave exists at all frequencies and that in LF and MF both skywave and groundwave exist, since the presence of all propagation modes affects the problems that arise with the systems operating in these frequency bands. An understanding of the properties of the ionosphere and its effect on the transit of radio waves is essential for both terrestrial and space based systems.

4. The two types of modulation (AM and FM) are relevant, when discussing bandwidth it should be noted that the specified bandwidth is at a specified power level and, that outside the specified frequencies, power is still being radiated which can interfere with other transmissions. For example; a broadcast station, emitting on 107.9 MHz has a bandwidth of 150 KHz. The transmitted frequencies will be 107.825 - 107.975 MHz, within the specified power levels, however, emissions at lower power levels will be made both above and below these frequencies. This is a factor in ILS, DME and SSR.

5. The knowledge of polar diagrams for various aerial types is fundamental to the use of ADF, VOR, ILS and radars.

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RADIO PORTION OF THE ELECTRO-MAGNETIC SPECTRUM

Frequency Band	Frequencies	Wavelengths	Propagation Characteristics	Uses
Very Low Frequency (VLF)	3-30 KHz	100-10 Km	Ducting	No civil uses
Low Frequency (LF)	30-300 KHz	10-1 Km	Surface wave (Skywave)	ADF, DECCA, LORAN C
Medium Frequency (MF)	300-3000 KHz	1000-100 m	Surface wave (Skywave)	ADF, Long range communications
High Frequency (HF)	3-30 MHz	100-10 m	Skywave (Surface Wave)	Long range communications
Very High Frequency (VHF)	30-300 MHz	10-1 m	Space Wave	Short range communications, VDF, VOR, ILS Localiser, Marker Beacons
Ultra High Frequency (UHF)	300-3000 MHz	100-10 cm	Space Wave	ILS Glidepath, DME, SSR, SATCOM, SATNAV, Long range radars
Super High Frequency (SHF)	3-30 GHz	10-1 cm	Space Wave	MLS, RAD ALT, AWR, Doppler radars, Short range radars
Extremely High Frequency (EHF)	30-300 GHz	10-1 mm	Space Wave	No civil uses

REVISION QUESTIONS

1. The maximum range at which an aircraft at FL250 can receive transmissions from a VHF R/T station at 300 ft is:

   a. 200 nm
   b. 219 nm
   c. 175 nm
   d. 198 nm

2. The wavelength corresponding to a frequency of 5,045 MHz is:

   a. 59.5 cm
   b. 5.95 cm
   c. 19.8 cm
   d. 1.98 cm

3. The frequency band containing a wavelength of 75 cm is:

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

4. The phase of a variable wave is at 240° as the phase of a reference wave is 090°. The phase difference is:

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

5. The greatest range for a surface wave will be at a frequency of:

   a. 198 KHz
   b. 121.5 MHz
   c. 2,182 KHz
   d. 4,300 MHz

6. At a fixed frequency if the level of ionisation increases, then:

   a. The dead space will increase because of the increase in critical angle.
   b. The dead space will decrease because of a decrease in critical angle
   c. The dead space will increase because of a decrease in the critical angle.
   d. The dead space will decrease because of an increase in the critical angle.

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7. The reduction in the power available in a radio wave as the distance from a transmitter increases is known as:

a. Dissipation
b. Diffraction
c. Attenuation
d. Refraction

8. An advantage of FM when compared with AM is:

a. Less susceptible to static interference
b. Smaller bandwidth
c. Easier to demodulate (ie extract information)
d. More suitable for use at lower frequencies

9. An aircraft is using a night time HF frequency of 5.5 MHz with ATC. The frequency the pilot would expect to use by day is:

a. 3 MHz
b. 12 MHz
c. 15 MHz
d. 18 MHz

10. Which of the following frequencies is likely to experience the most severe static interference?

a. 121.5 MHz
b. 500 KHz
c. 4,300 MHz
d. 5,500 KHz

11. The highest levels of ionisation will be found:

a. At high latitudes in summer
b. At low latitudes in summer
c. At high latitudes in winter
d. At low latitudes in winter

12. Concerning skywave propagation, which of the following is correct?

a. The D-layer attenuates LF and MF frequencies by night.
b. The D-layer attenuates LF and MF frequencies by day.
c. The D-layer attenuates HF frequencies by night.
d. The D-layer attenuates HF frequencies by day.

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ANSWERS

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

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CHAPTER TWO - DOPPLER RADAR

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2.1 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:

a) is completely self-contained and requires no ground based navigation aids.

b) is usable worldwide.

c) is most accurate overland.

d) is less accurate during flight over the sea because the surface winds, tides and currents move the surface in random directions.

e) 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.

2.2 DOPPLER PRINCIPLE

Whenever there is a relative motion between a transmitter and receiver a frequency shift (change) occurs which is proportional to their relative motion. This change in frequency, **fd**, is known as the Doppler shift, Doppler effect, or Doppler frequency.

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In an airborne Doppler system (Figure 2.1.) 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 reflected frequency shift, which is caused by the aircraft's speed along track, ground speed, and speed across track, drift.

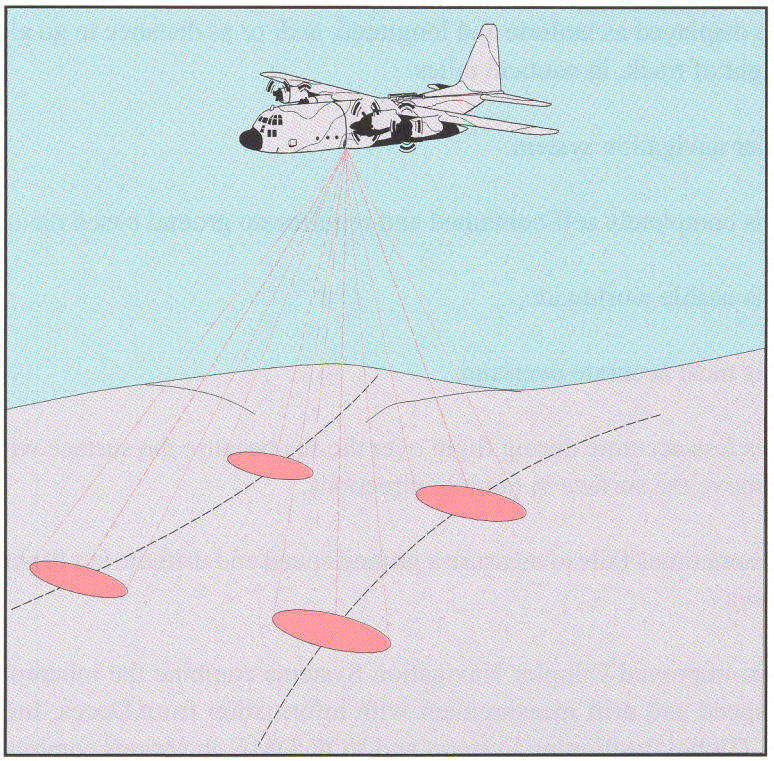

Figure 2.1.

To explain the Doppler principle a separate ground-based transmitter T and receiver R are considered; (Figure 2.2.)

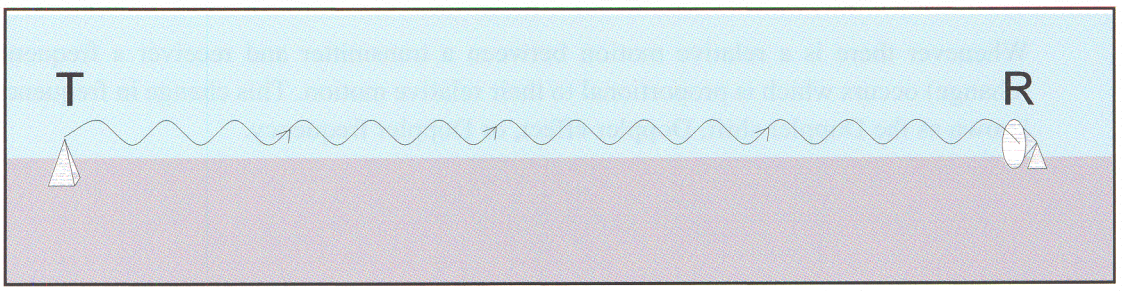

Figure 2.2.

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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.

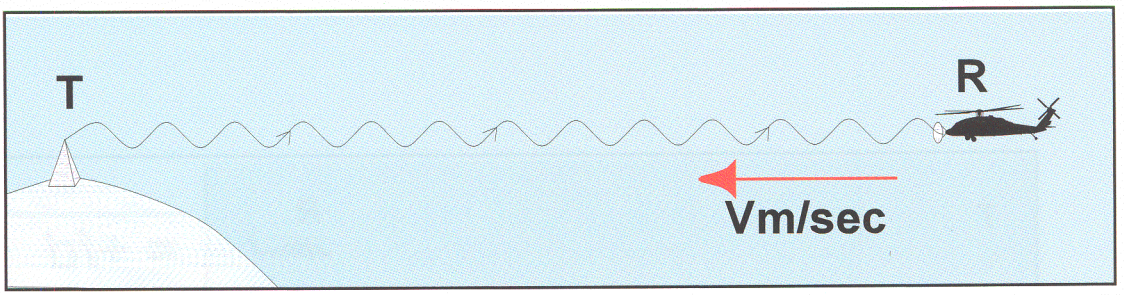

Figure 2.3.

Figure 2.3. depicts R moving towards stationary T at Vm/sec. The speed of the transmission remains constant; but each transmitted wavelength arrives at moving R at a shorter time interval. This is perceived as a wavelength reduction.

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

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 '$\mathbf{f_R}$' is known as the Doppler Shift '$\mathbf{f_D}$'.

Therefore $\mathbf{f_D = f_R - f}$

The formula for frequency shift fd can be written as: $fd = \frac{V}{\lambda}$

Since $\lambda = \frac{c}{f}$, $\mathbf{fd} = \frac{\mathbf{Vf}}{\mathbf{c}}$

Therefore the relationship between frequencies and speeds can also be expressed as:

$$\frac{f_D}{f} = \frac{V}{c}$$

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In other words, the ratio of the frequencies equals the ratio of the speeds.

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 **fd**. Figure 1.4. summarizes the various transmitter and receiver combinations.

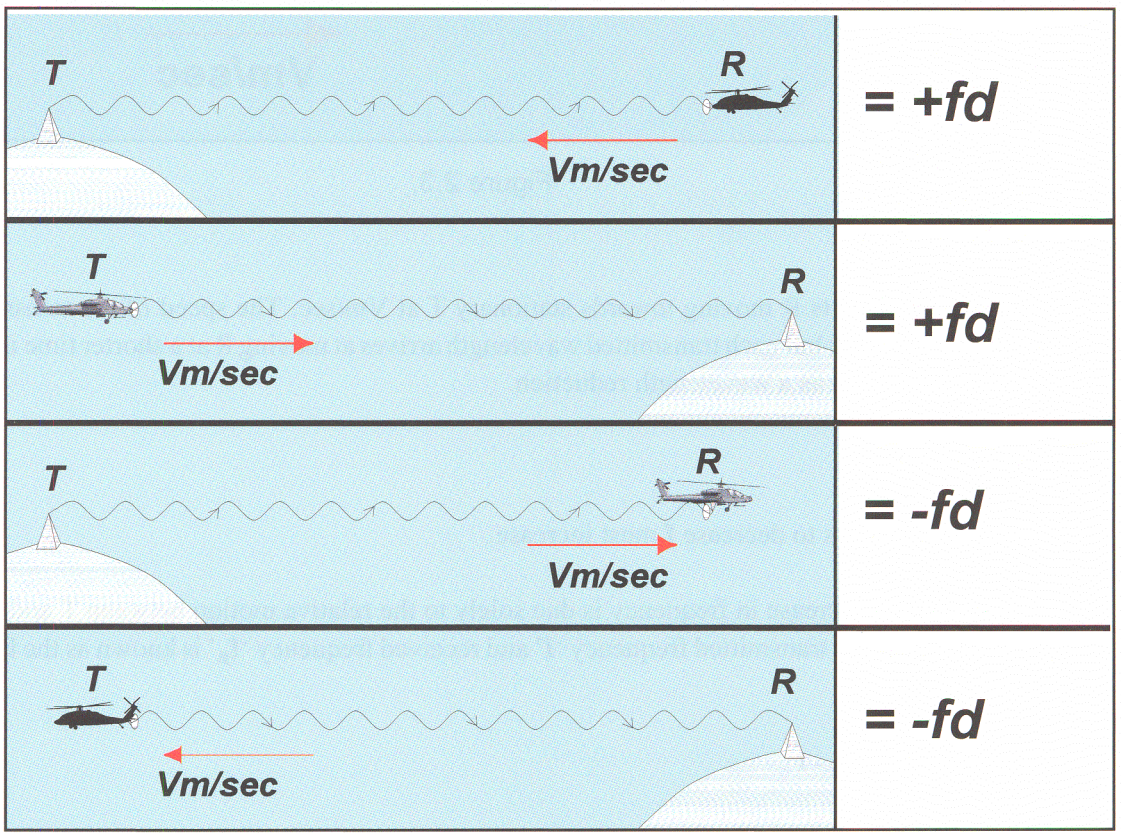

Figure 2.4

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2.3 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 2.5.). 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 2.6.) 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 **8800MHz or 13300MHz, 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.

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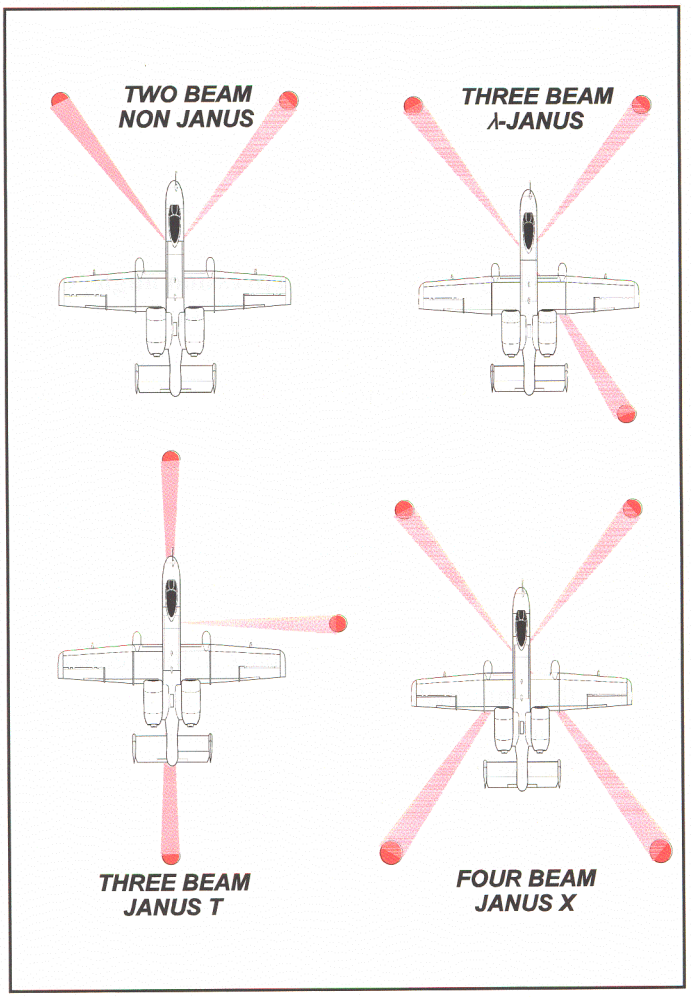

Figure 2.5

2.4 JANUS ARRAY SYSTEM

Figure 2.1. 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.

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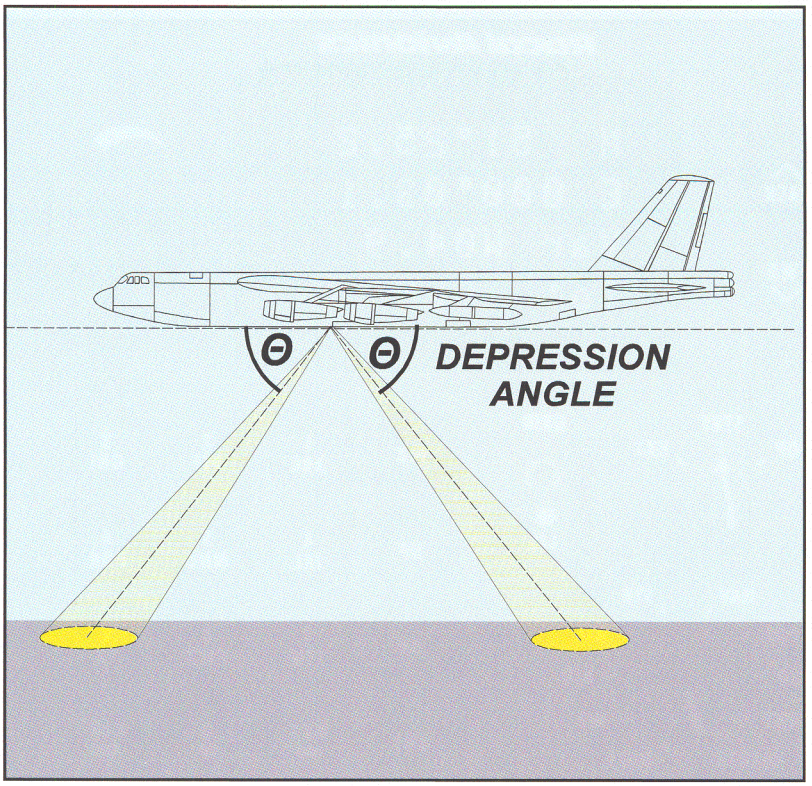

Figure 2.6.

Figure 2.7. 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.

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Figure 2.7. The Racal RNS 252 Navigation Computer Unit.

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2.5 CALCULATIONS [NOT REQUIRED FOR JAA EXAMS]

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 m/sec	Relative speed (kt)
2		300	
3.41			450
2. 26			314
23	2.3		
3.41	7.0		

Answers. Q1. 5kHz. Q2. 5kHz. Q3. 180m/sec; 350kt.

Q4 a). 150m/sec. b) 4.4kHz c) 8799.9956MHz

Q 5. Line
1. 15kHz, 583kt.
2. 6.79Khz, 231.4m/sec.
3. 7.15Khz, 161.7m/sec.
4. 529m/sec, 1028kt.
5. 238.7m/sec, 464kt.

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2.6 QUESTION PAPER

1. A major source of error in the along track component of a Doppler along and across track position display is likely to be:

a) Compass error.
b) Water Bias/Spectrum Distortion.
c) Sea movement error.
d) Vertical speed error.

2. 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

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ANSWER SHEET

QUESTION	ANSWER
1	B
2	B

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CHAPTER THREE - GROUND DIRECTION FINDING

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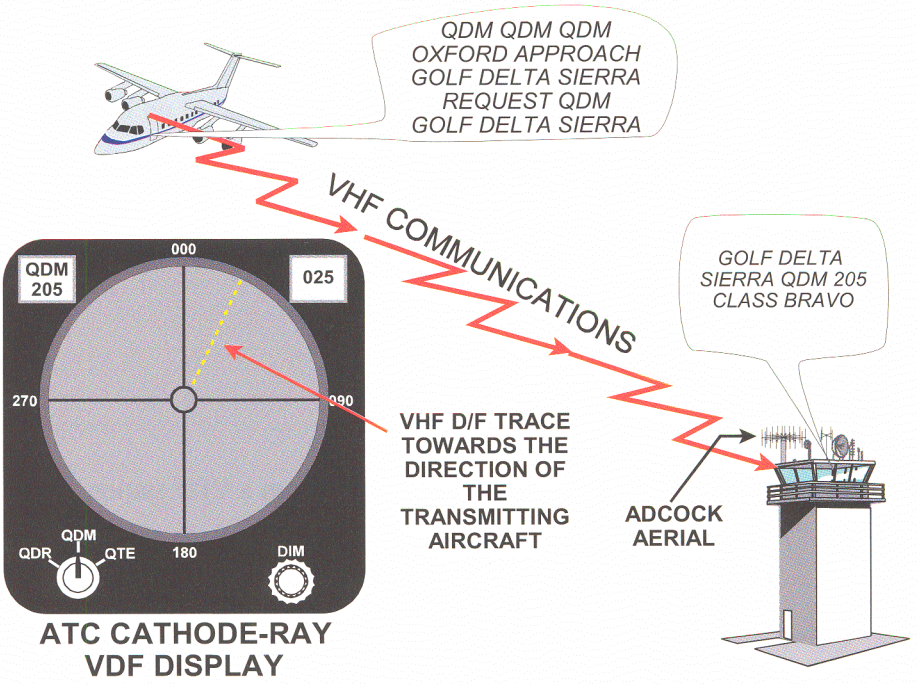

Figure 3.1. Ground Equipment for VHF Direction Finding.

3.1 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 1.1. 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.

3.2 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).

3.3 SERVICE PROVIDED

a) **QDM** - Aircraft's **Magnetic Heading** to steer **in zero wind** to reach the station; used mainly for station homing and letdowns.

b) **QDR** - Aircraft's **Magnetic Bearing** from the station; used for en-route navigation.

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c) **QTE** - Aircraft's **True Bearing** from the station; used for en-route navigation.

d) **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:

e.g. **"QDM QDM QDM OXFORD APPROACH GBDOF Request QDM GBDOF"**

3.4 USE OF SERVICE

a) QTE or QDR:

i) To check true or magnetic tracking **from** a VDF station.

ii) For en route position lines. Two stations will be required for a position fix.

b) QDM

i) To home **to** a VDF station.

ii) For let down in cloud using published procedures.

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

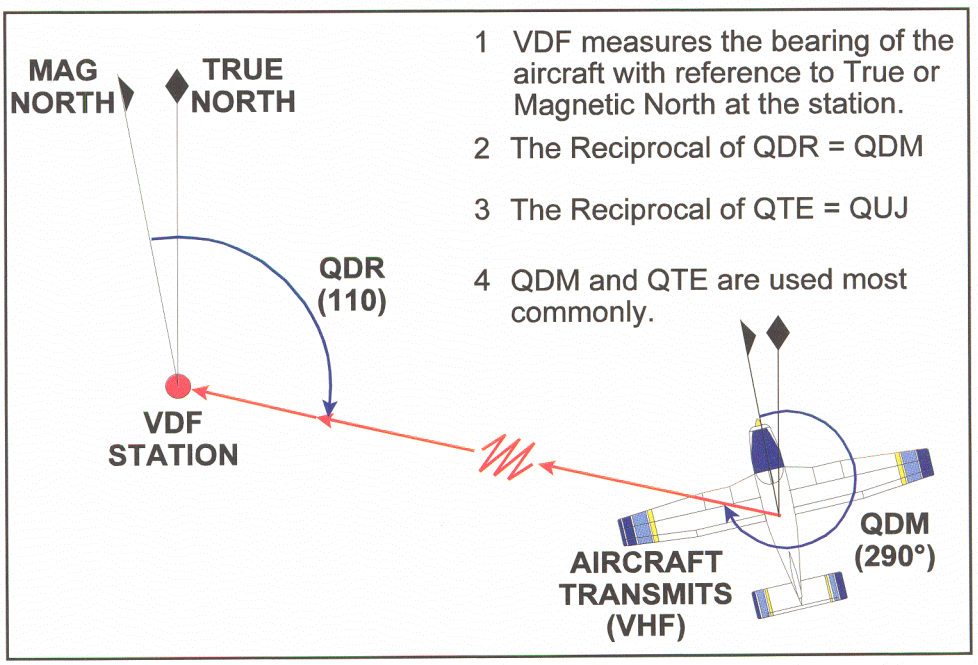

Figure 3.2.

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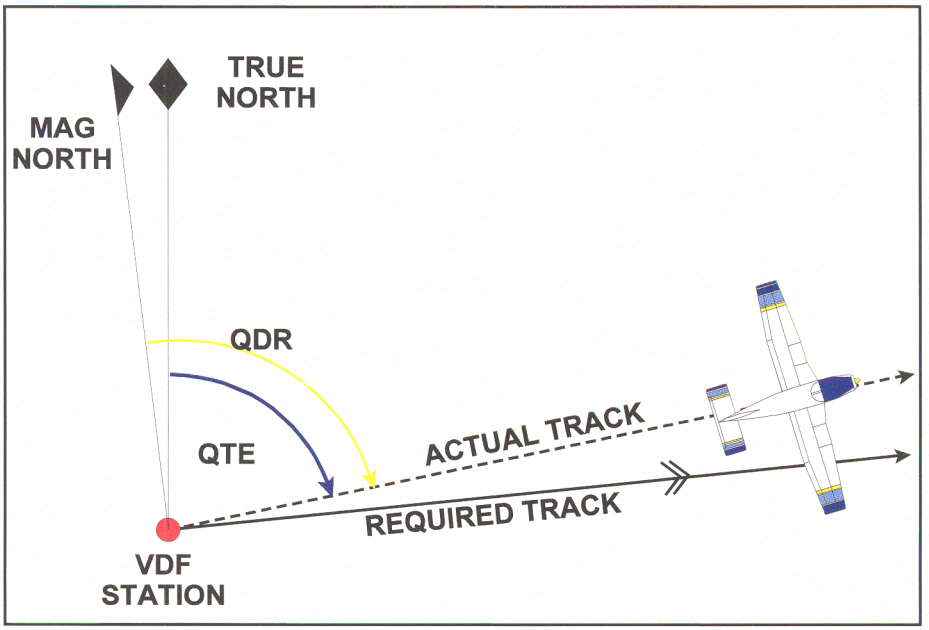

Figure 3.3. The use of QTE/QDR for Checking Track.

3.5 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.

3.6 RANGE OF VDF

a) 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.

b) Intervening high ground will limit range, especially for low flying aircraft in hilly terrain.

c) The power of airborne and ground transmitters will limit ranges.

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d) Gradients of temperature and humidity can give greater than line of sight ranges.

e) Synchronous transmissions by two or more aircraft will cause momentary errors in the bearings.

3.7 FACTORS AFFECTING ACCURACY

a) 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.

b) 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.

c) Poor accuracy in the overhead of a VDF receiver, particularly with the latest Doppler systems.

d) 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.

3.8 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:

a) in distress

b) in urgent need of assistance

c) experiencing difficulties (ie lost)

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

3.9 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.**

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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 1.4 shows an example of a VDF Let-down procedure.

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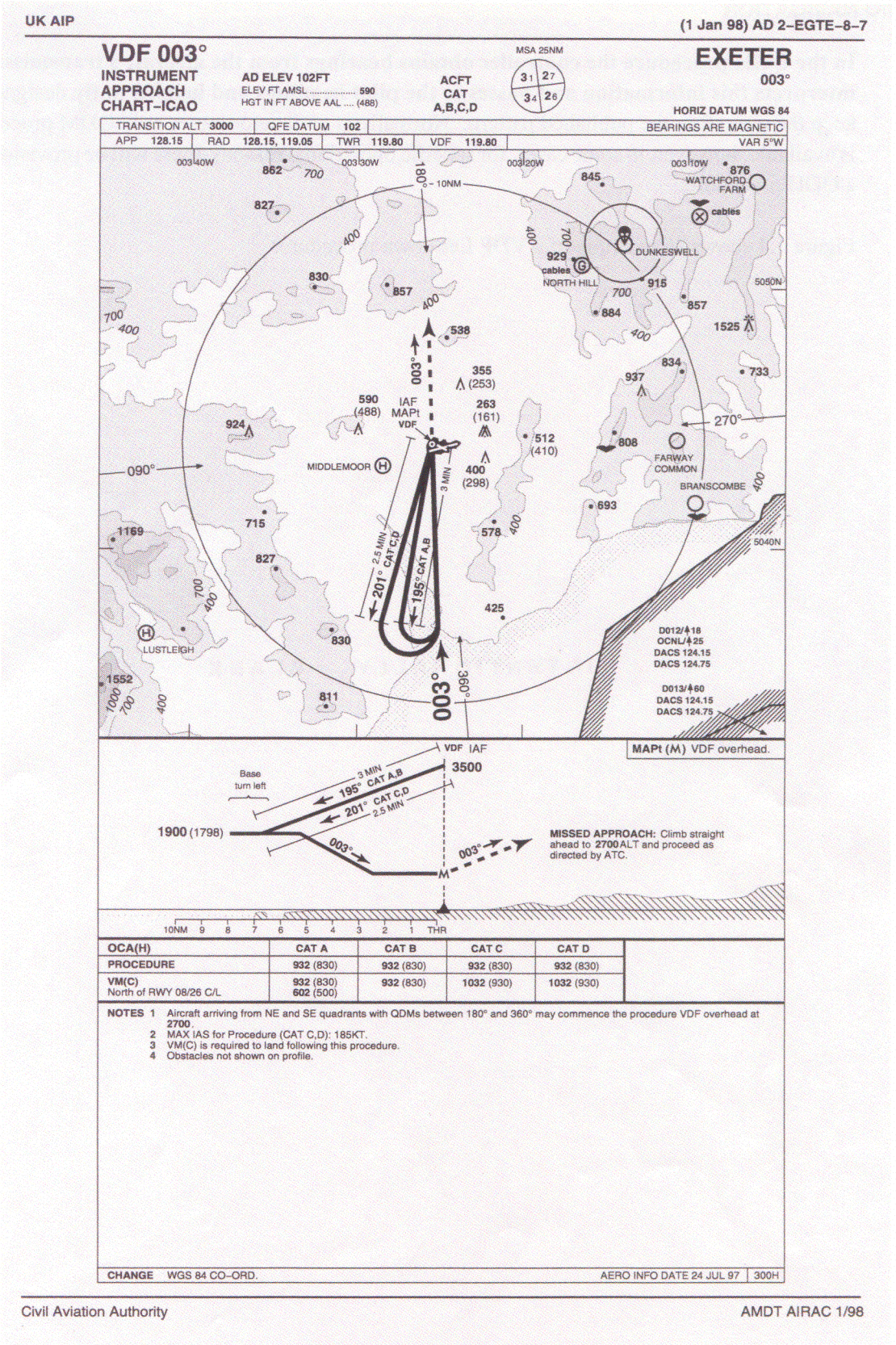

Figure 1.4. VDF Let-Down Procedure

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3.10 GDF 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

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QUESTION PAPER

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

   a) 190'
   b) 1,378'
   c) 37,600'
   d) 84,100'

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

   a) +- 1^0
   b) +- 5^0
   c) +- 2^0
   d) +- 10^0

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

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

4. An aircraft at altitude 9000 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) 141nm
   d) 63.5nm

5. An aircraft is passed a true bearing from a VDF station of 353^0. If variation is 8^0E and the bearing is classified as 'B' then the:

   a) QDM is 345^0 +- 5^0
   b) QDR is 345^0 +- 2^0
   c) QTE is 353^0 +- 5^0
   d) QUJ is 353^0 +- 2^0

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6. An aircraft at19,000ft 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) 216nm

ANSWERS

QUESTION	ANSWER
1	C
2	B
3	B
4	C
5	C
6	A

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CHAPTER FOUR - AUTOMATIC DIRECTION FINDING

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4.1 INTRODUCTION

Automatic Direction Finding (ADF) equipment in the aircraft is used in conjunction with 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 is planned to be phased out in the year 2005 when other more accurate systems like GPS will be readily available to all users.

4.2 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.

4.3 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.

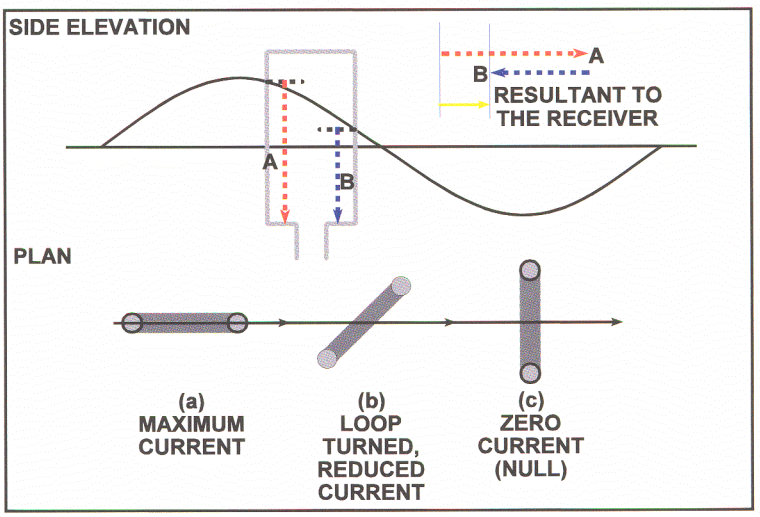

Figure 4.1 A Loop Aerial.

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The polar diagram formed is a figure of eight as shown below (figure 4.2). 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.

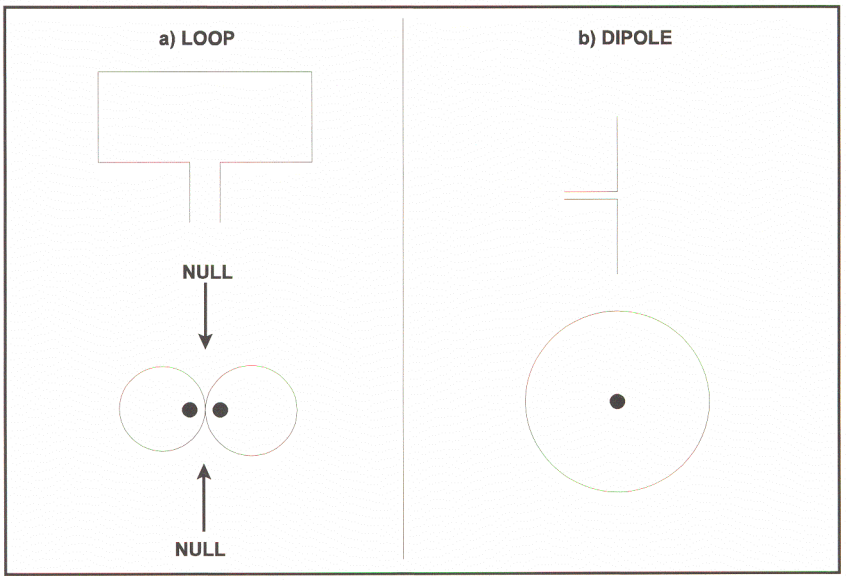

Figure 4.2 Polar Diagrams of Loop and Dipole Aerials

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 4.3), the relative signal strengths of the two signals are shown.

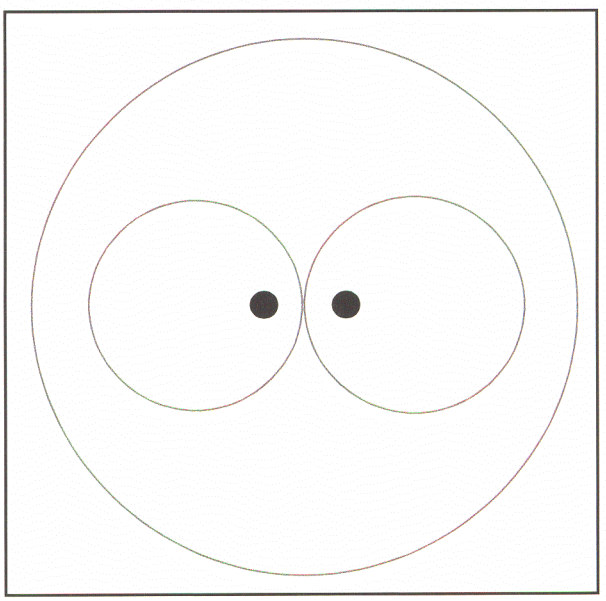

Figure 4.3

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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 4.4). 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.

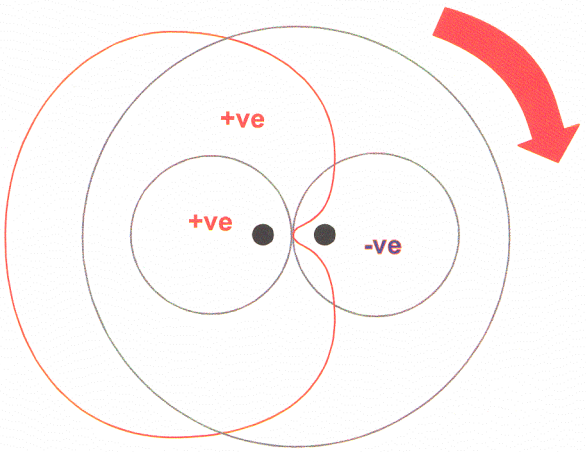

Figure 4.4

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 improved.

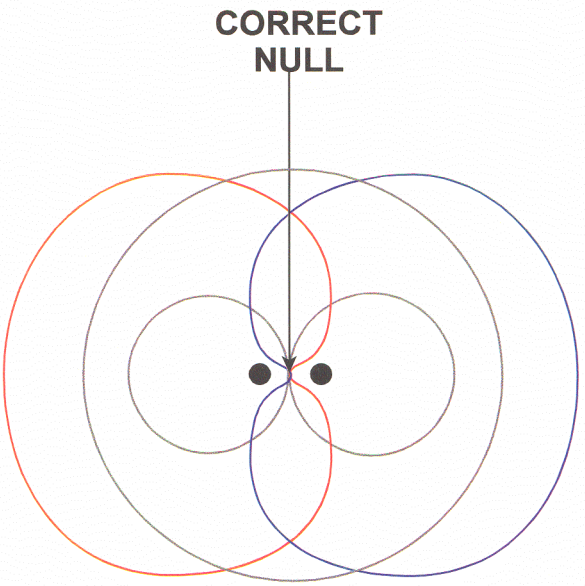

Figure 4.5

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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.

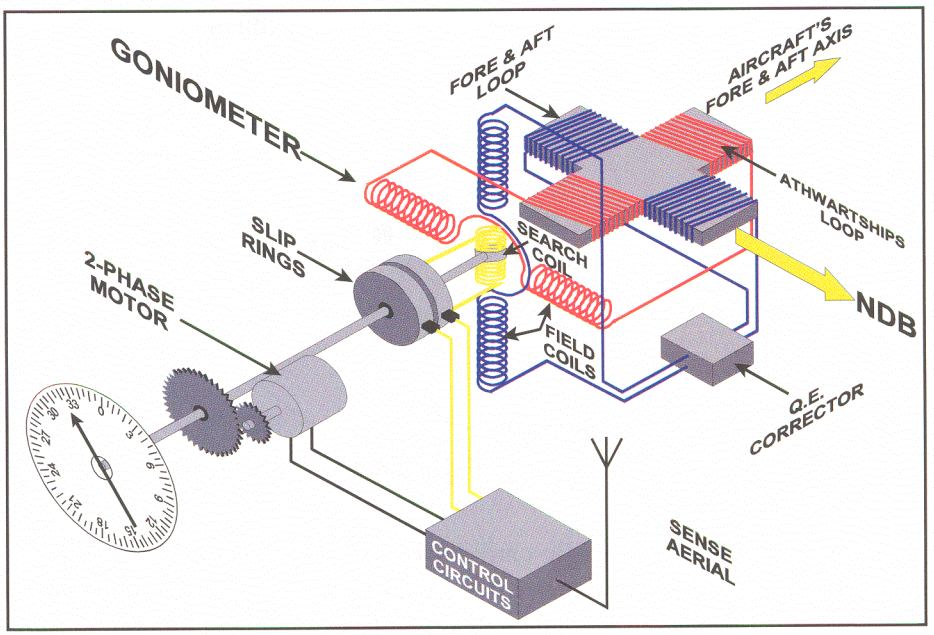

Figure 4.6 A Fixed Loop ADF

4.4 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 NDB,s 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

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4.5 AIRCRAFT EQUIPMENT

The aircraft equipment comprises:

A loop aerial
A sense aerial
A control unit
A receiver
A display which is either a relative bearing indicator (RBI) or a radio magnetic indicator (RMI)

Figure 4.7. Two ADF Receivers.

4.6 EMISSION CHARACTERISTICS AND BEAT FREQUENCY OSCILLATOR (BFO)

The NDB's 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. The BFO, when selected produces an offset frequency within the receiver which when combined with the received frequency produces a tone of say 400 or 1,020 Hz.

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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).

4.7 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 4.8 RBI

Figure 4.9 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.

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4.8 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.

4.9 PLOTTING ADF BEARINGS

The plotting of ADF bearings is dealt with in depth if 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.

4.10 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

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4.11 INBOUND TRACKING

Figure 4.10 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°.

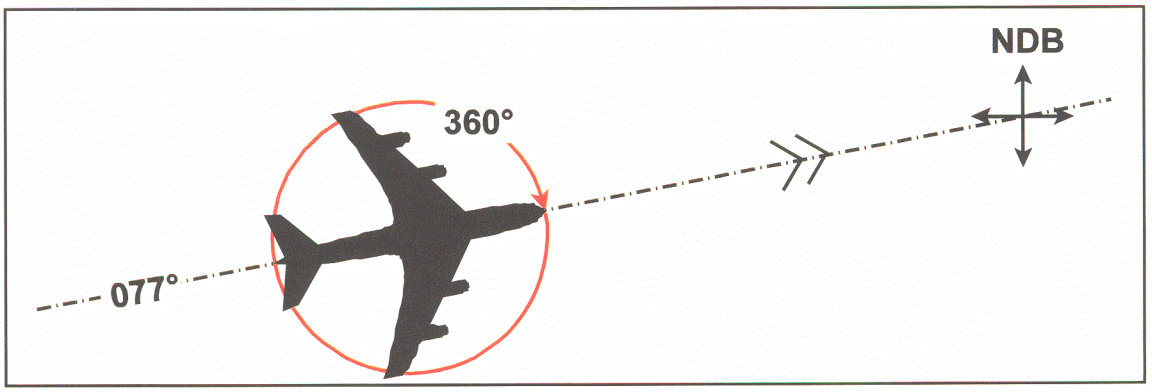

Figure 4.10 Homing in Zero Drift.

Figure 4.11 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.

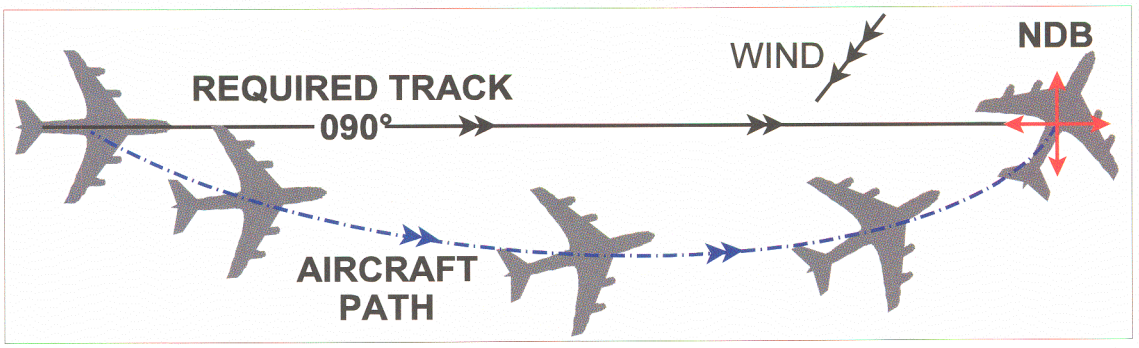

Figure 4.11. Homing Making No Allowance for Drift.

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4.12 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 4.12, 20° **S**tarboard drift is anticipated - 20° is **S**ubtracted from track. The aircraft is heading 060° with a relative bearing of 020°.

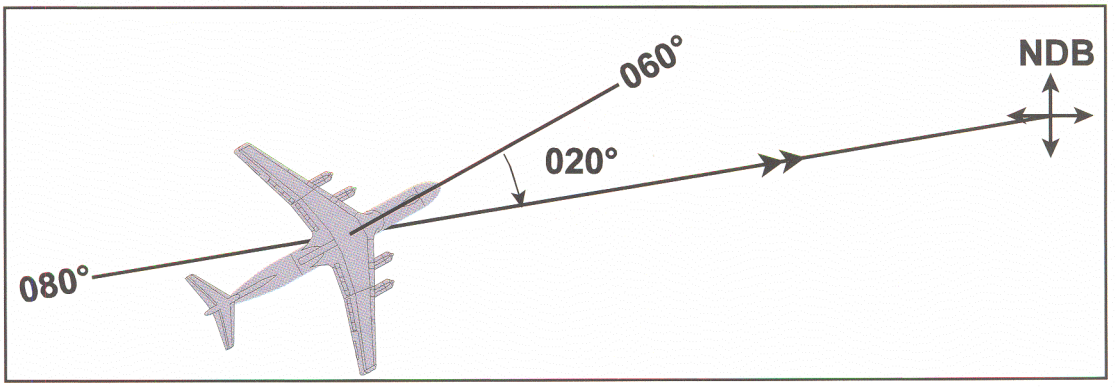

Figure 4.12.

In Figure 4.13, 28° **P**ort drift is anticipated, this is added (**P**lus) to the track value. The aircraft is heading 108°with a relative bearing of 332°.

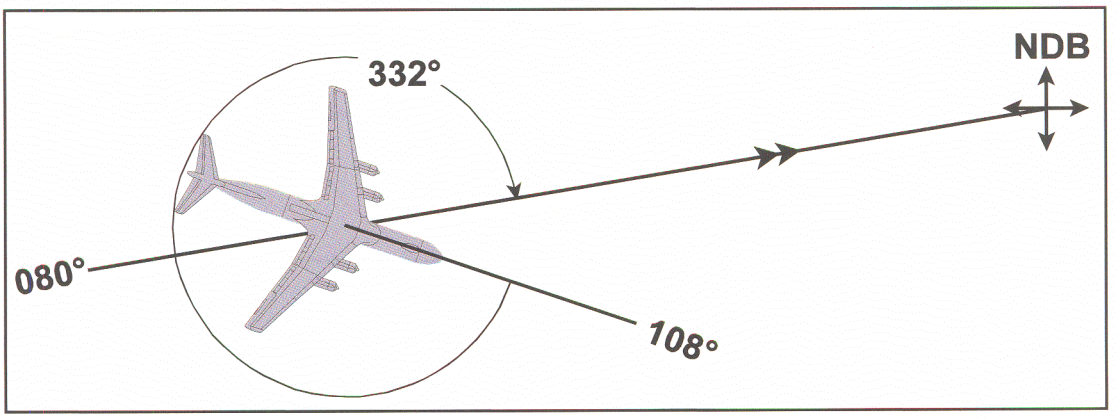

Figure 4.13.

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4.13 OUTBOUND TRACKING

Figure 4.14 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°.**

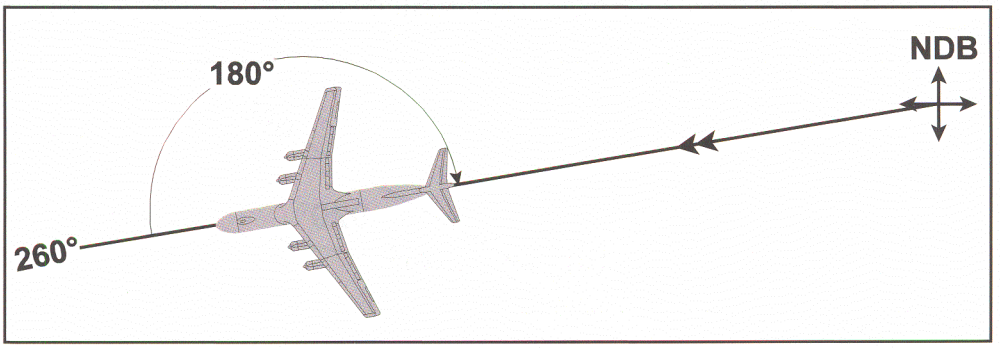

Figure 4.14.

Figure 4.15 shows an aircraft maintaining a track of 100° in crosswind conditions where the drift is known. 23° of **S**tarboard drift is anticipated, this is **S**ubtracted from the track, therefore the heading is 077° with a relative bearing of 203° from the NDB.

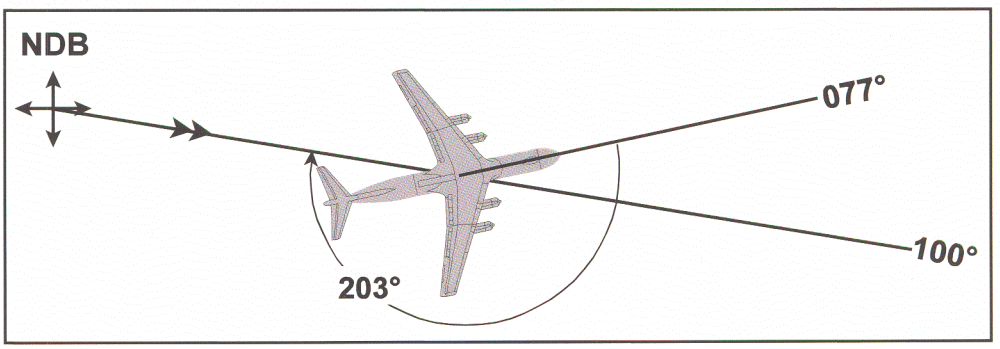

Figure 4.15

In Figure 4.16 20° **P**ort drift is anticipated, this is added (**P**lus) to track giving an aircraft heading of 110° with a relative bearing of 160°.

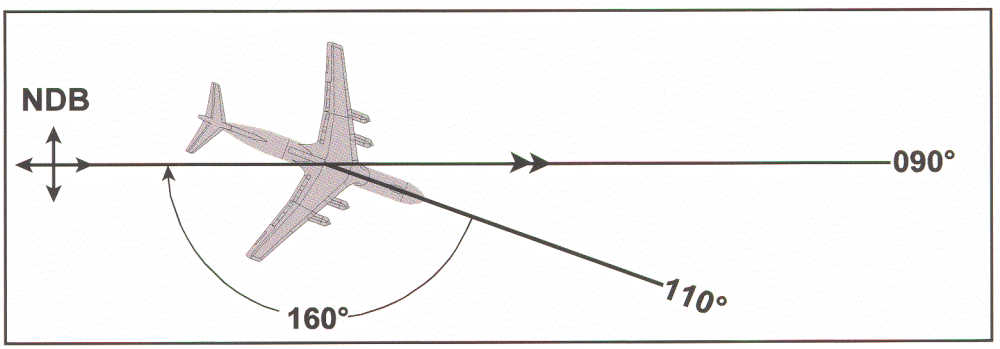

Figure 4.16

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4.14 DRIFT ASSESSMENT AND REGAINING INBOUND TRACK

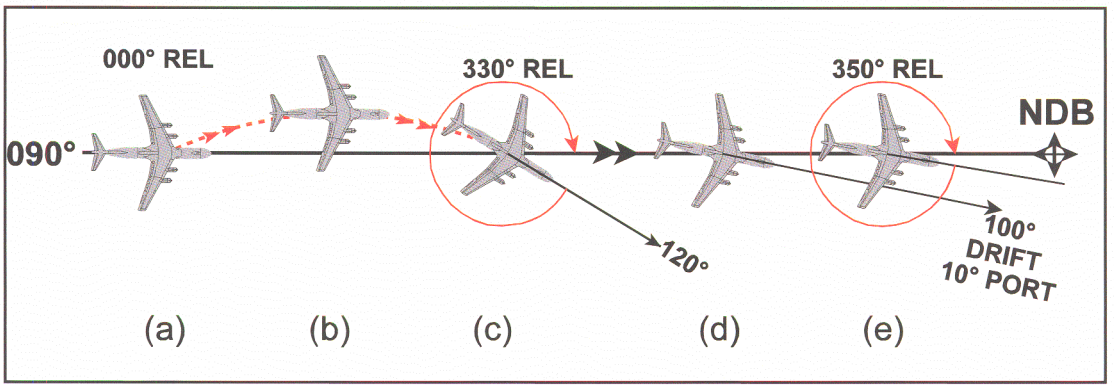

Figure 4.17 Assessing Drift Inbound.

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.

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4.15 DRIFT ASSESSMENT AND OUTBOUND TRACK MAINTENANCE

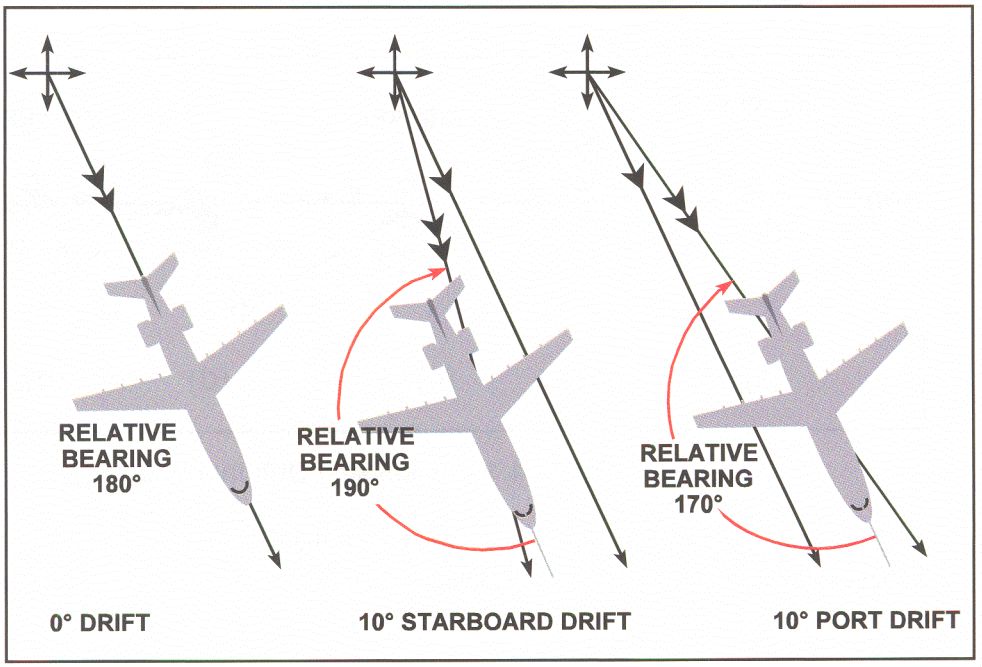

Figure 4.18 Drift Assessment Outbound.

In Figure 4.18 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. See Figure 4.19.

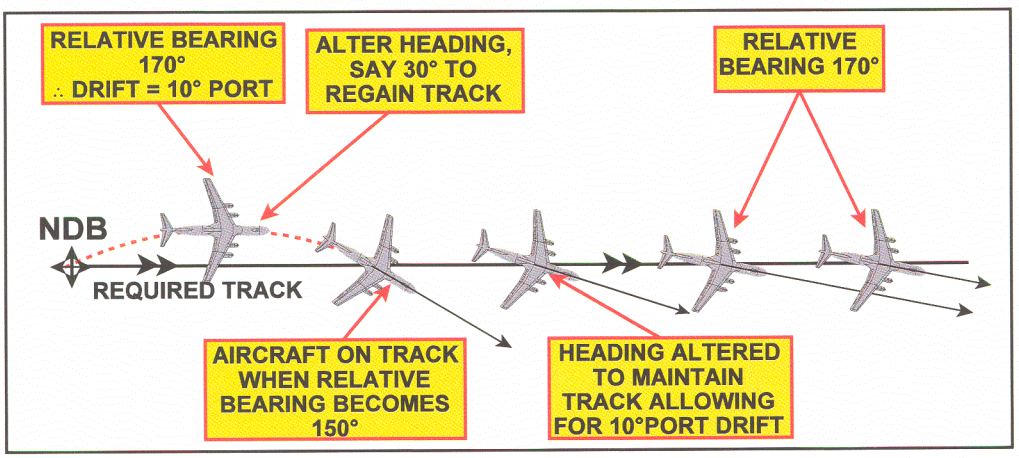

Figure 4.19 Determining Drift and Maintaining Track away from an NDB.

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4.16 HOLDING

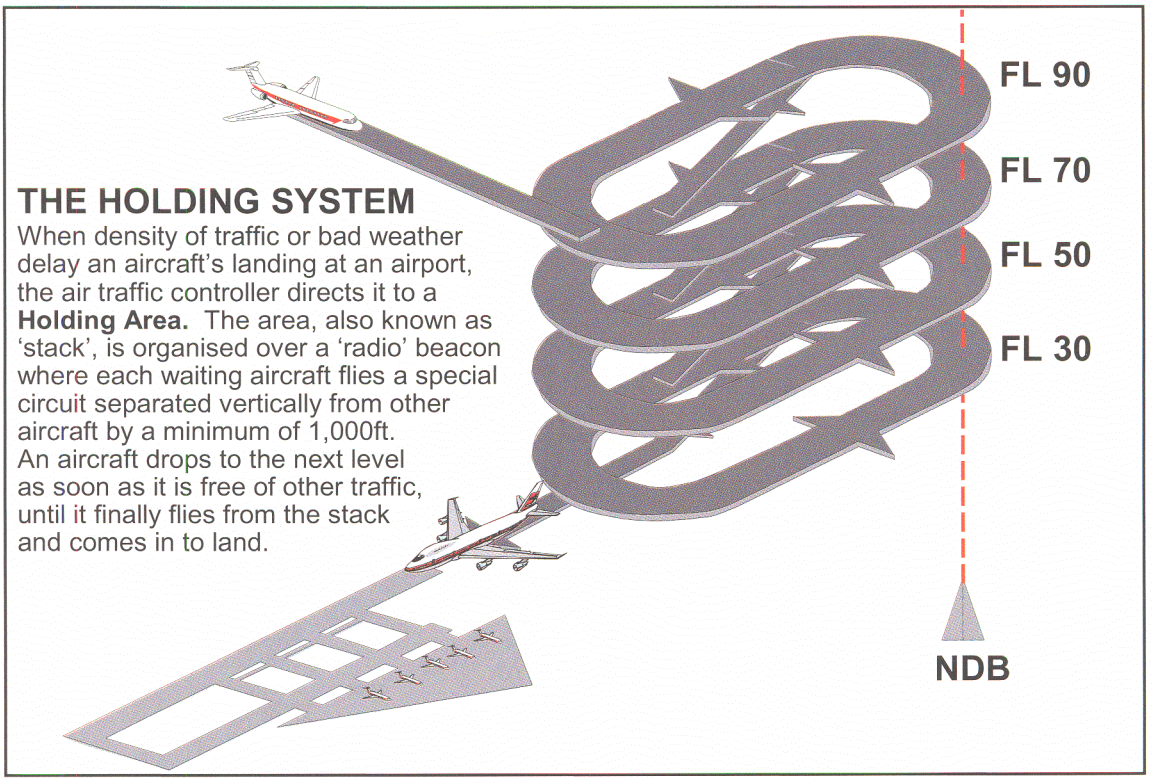

Figure 4.20 The Holding System.

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4.17 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.

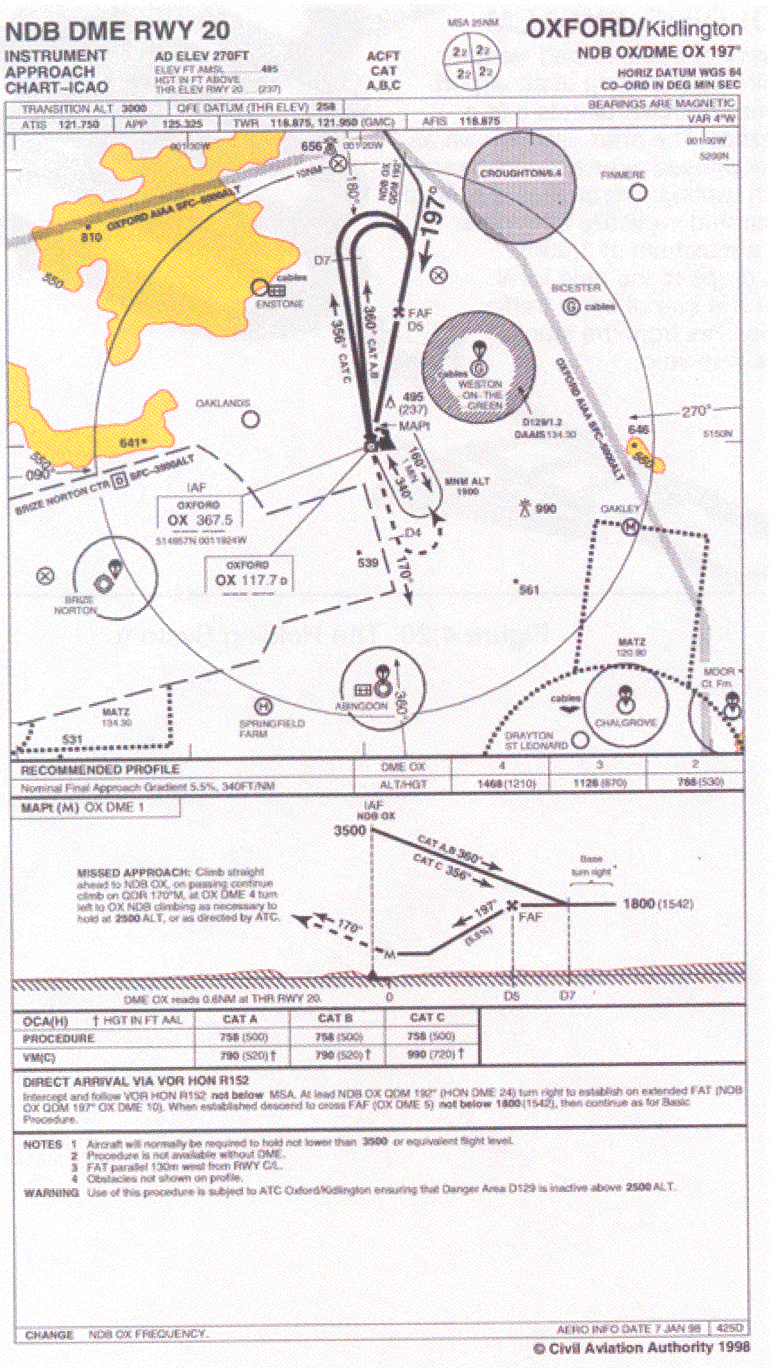

Figure 4.21 Example of an NDB Instrument Approach

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4.18 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 beaing 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.

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- 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 or 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.

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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 on 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 emf's 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.

4.19 FACTORS AFFECTING ADF RANGE

The major factors which effect 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:

Range (nm) over water = 3 x √Wattage.

Range (nm) over land = 2 x √Wattage.

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.

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4.20 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.

4.21 ADF SUMMARY

NDB: Ground transmitter in LF or MF band (190 - 1750 kHz)
Types of NDB: Locator (L) - airfield let-down (25 nm)
En Route - Nav-aid (50 nm or more)

Range (nm) - 3 x √ P (W) over water
- 2 x √ 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

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4.22 QUESTION PAPER

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.

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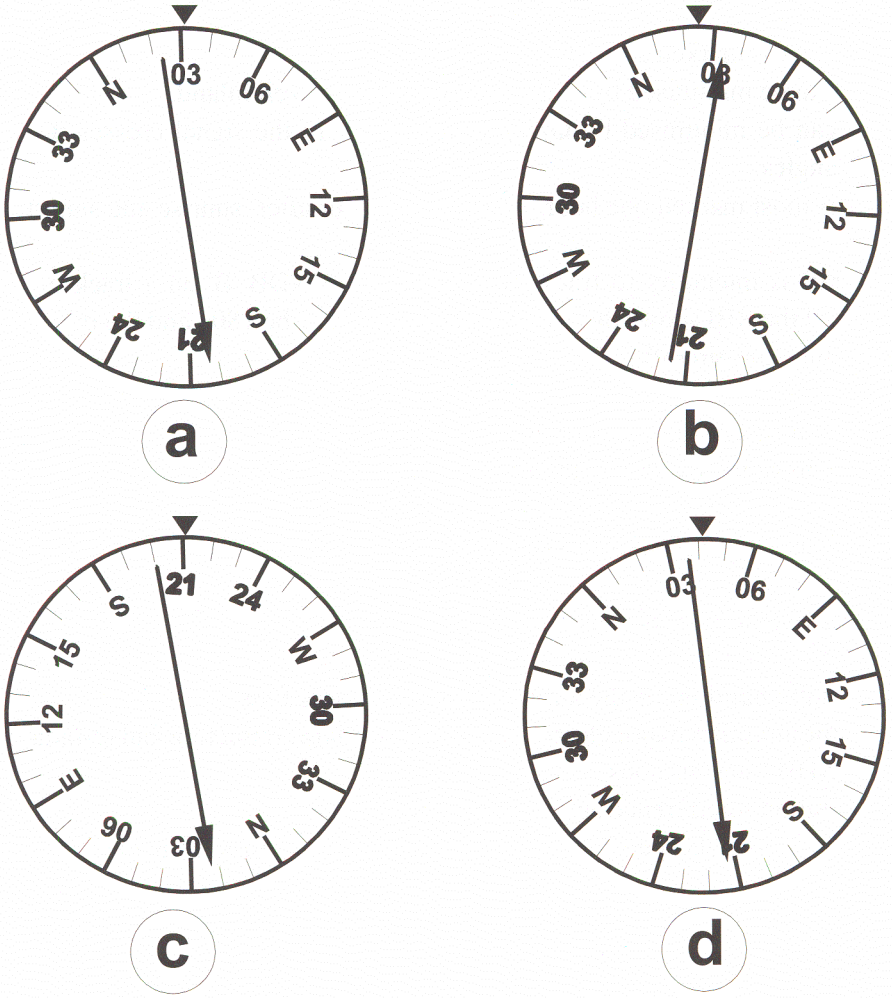
4. An aircraft is tracking away from an NDB on a track of 023^0(T). If the drift is 8^0 port and variation 10^0 west, which of the RMIs illustrated below shows the correct indications?



5. The overall accuracy of ADF bearings by day within the Promulgated Range (DOC) is:

a) ± 3^0
b) ± 5^0
c) ± 6^0
d) ± 10^0

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6. 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

7. 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.

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.

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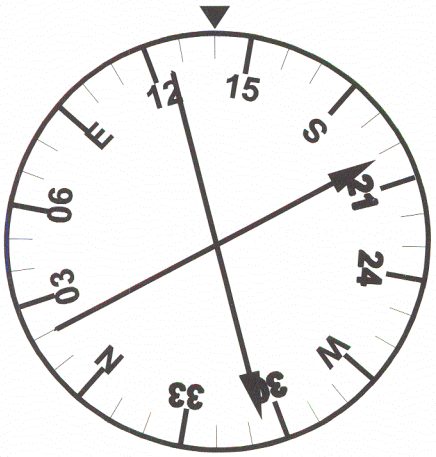
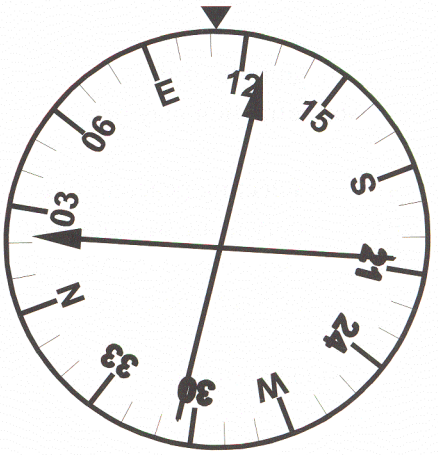
10. An aircraft has an RMI with two needles. Assume that:

i) The aircraft is outbound from NDB Y on a track of 126^0(M) drift is 14^0 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?



a



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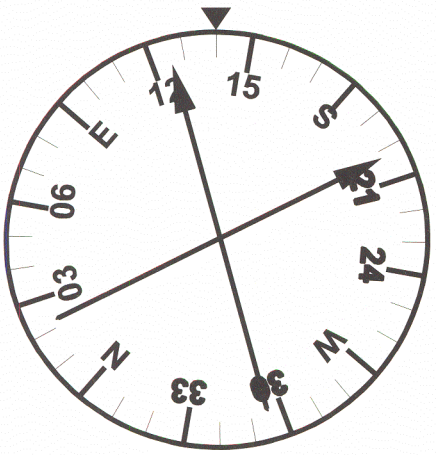

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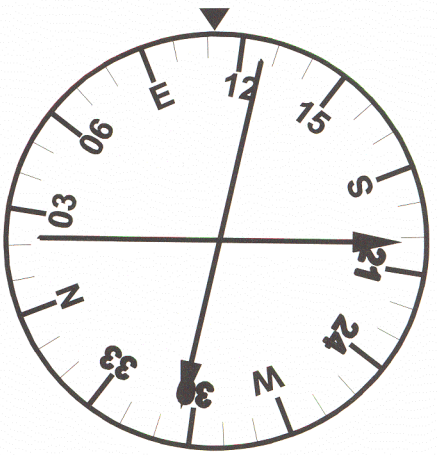

d

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11. Each NDB as 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, cardiod, radial.
b) at the transmitter, limacon, bearing.
c) at the aircraft, limacon, bearing.
d) at the aircraft, cardiod, 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.

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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 235^0(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)

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ANSWERS

QUESTION	ANSWER
01	c
02	d
03	b
04	d
05	b
06	b
07	d
08	d
09	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

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CHAPTER FIVE - VOR

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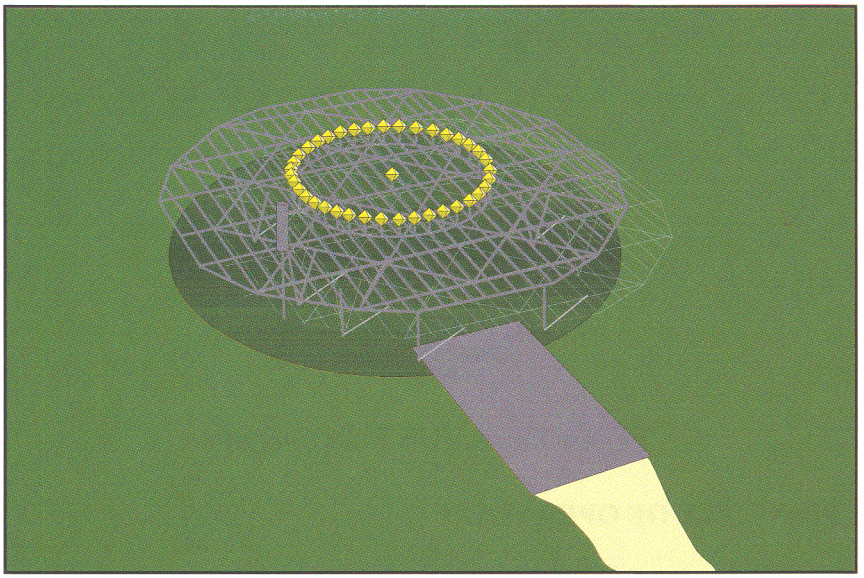

Figure 5.1. A Combined VOR / DME.

5.1 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:

a) Marking the beginning, the end and centre-line of airways or sections of airways.

b) As a let-down aid at airfields using published procedures.

c) As a holding point for aircraft.

d) As a source of en-route navigational position lines.

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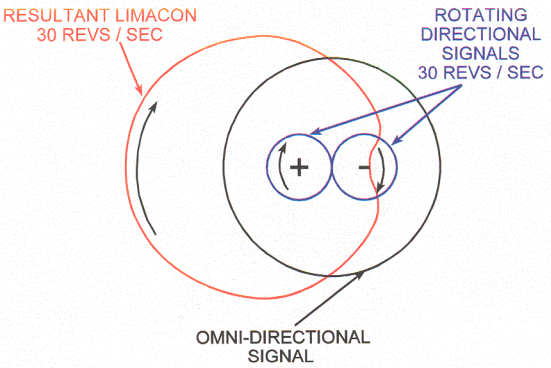

Figure 5.2. A VOR Polar Diagram.

5.2 THE PRINCIPLE OF OPERATION

VOR bearing is obtained by phase comparison:

a) An aircraft's VOR receiver measures the phase difference (angular difference) between two signals from the VOR transmitter:

i) a **30Hz frequency modulated** omni-directional, **reference signal** which produces constant phase regardless of a receiver's bearing from the VOR, and

ii) a **30Hz amplitude modulated variable phase (directional) signal** created by the rotating transmission pattern (limaçon).

b) The 30Hz FM reference signal is synchronised with the 30 revs/sec rotating directional AM signal (limaçon) such that:

i) the two 30Hz modulations are **in phase** to an aircraft's VOR receiver when it is **due magnetic north** of the VOR beacon, and

ii) 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.

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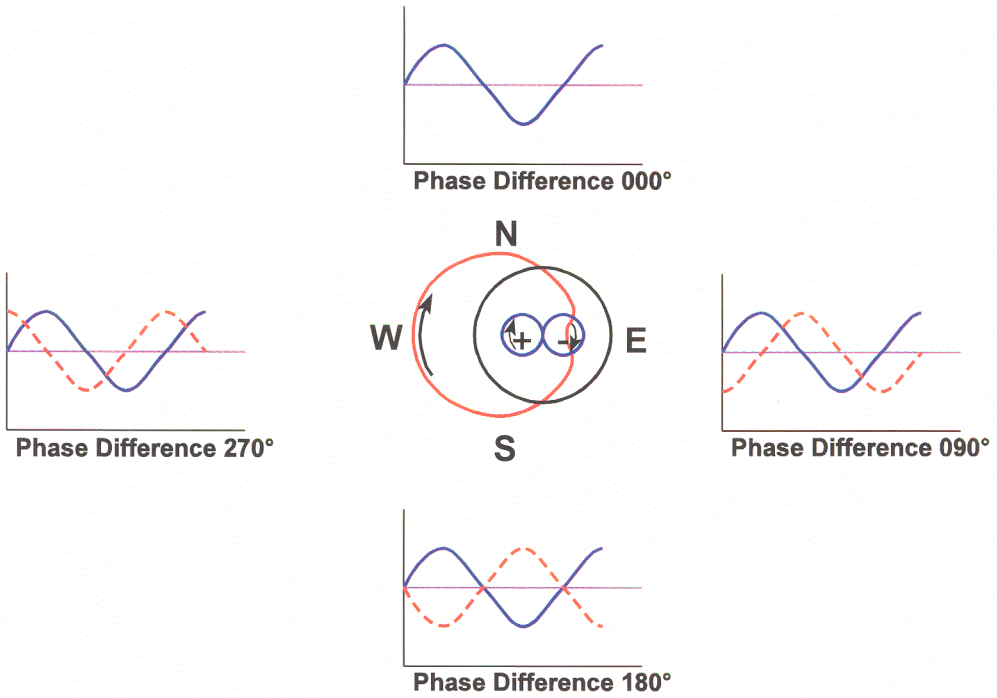

Figure 5.3. Phase Differences Corresponding to the Cardinal Points.

Figure 5.3. 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) A phase diff. of 227° measured at the aircraft = 227° Radial.

b) 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 ident period.

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5.3 TERMINOLOGY

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

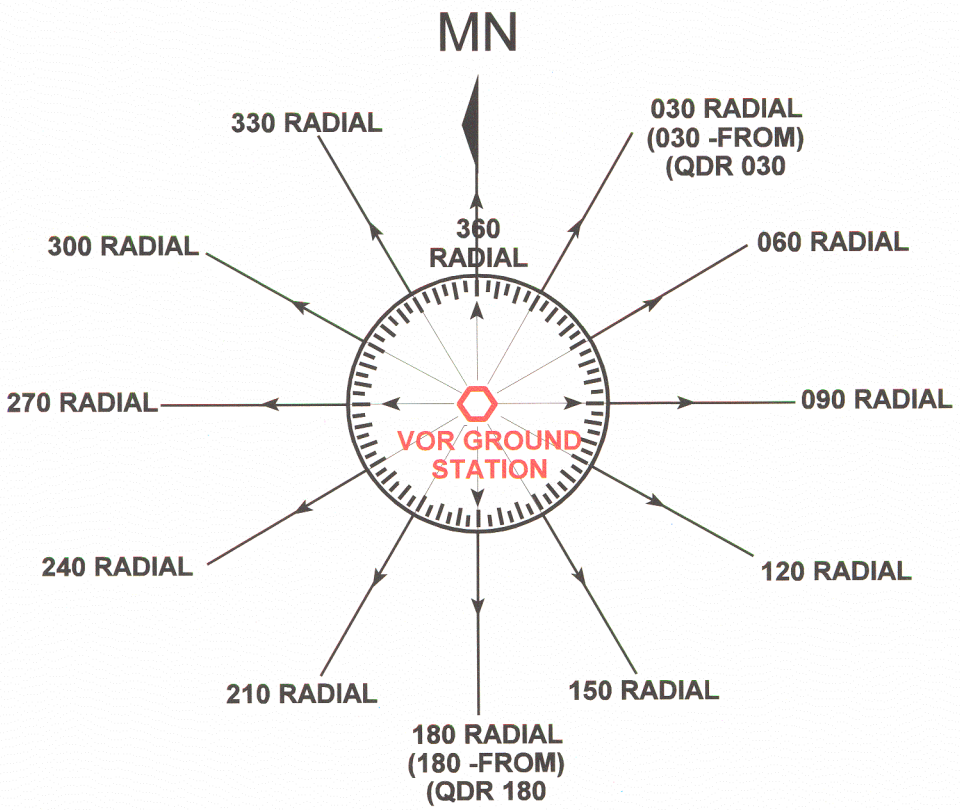

Figure 5.4. A Radial is a Magnetic Bearing **FROM** the VOR (i.e. QDR)

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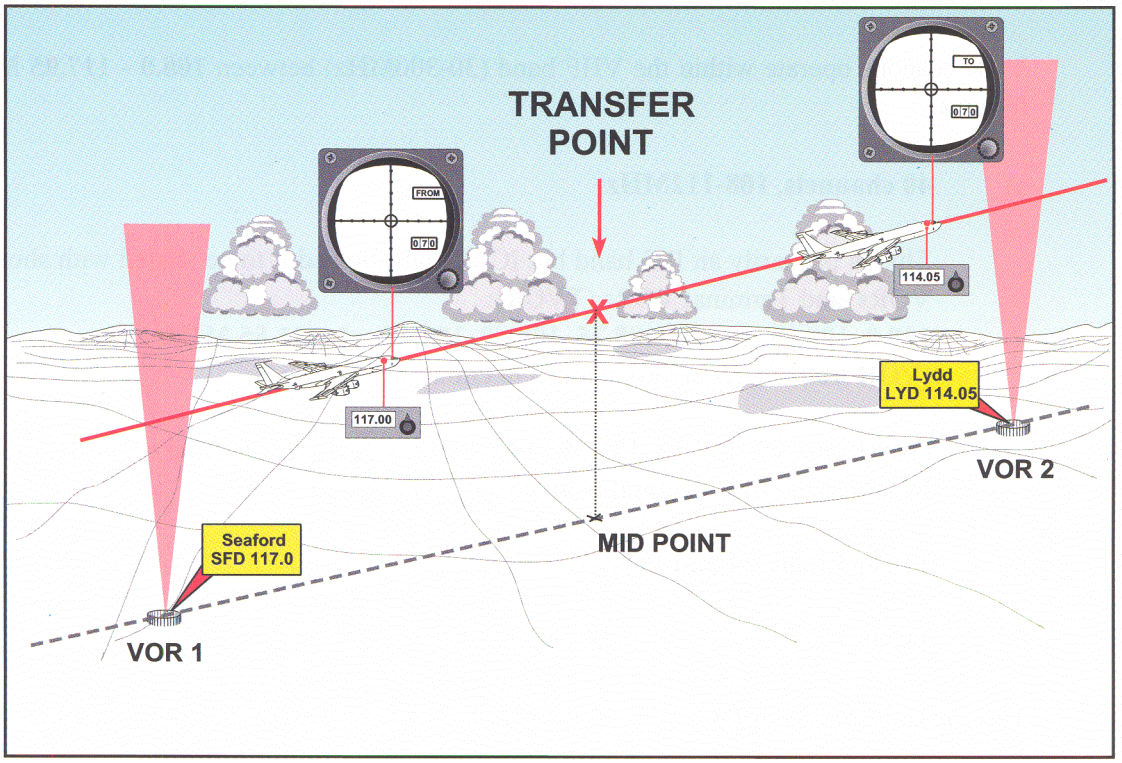

Figure 5.5. Tracking Between Two VORs.

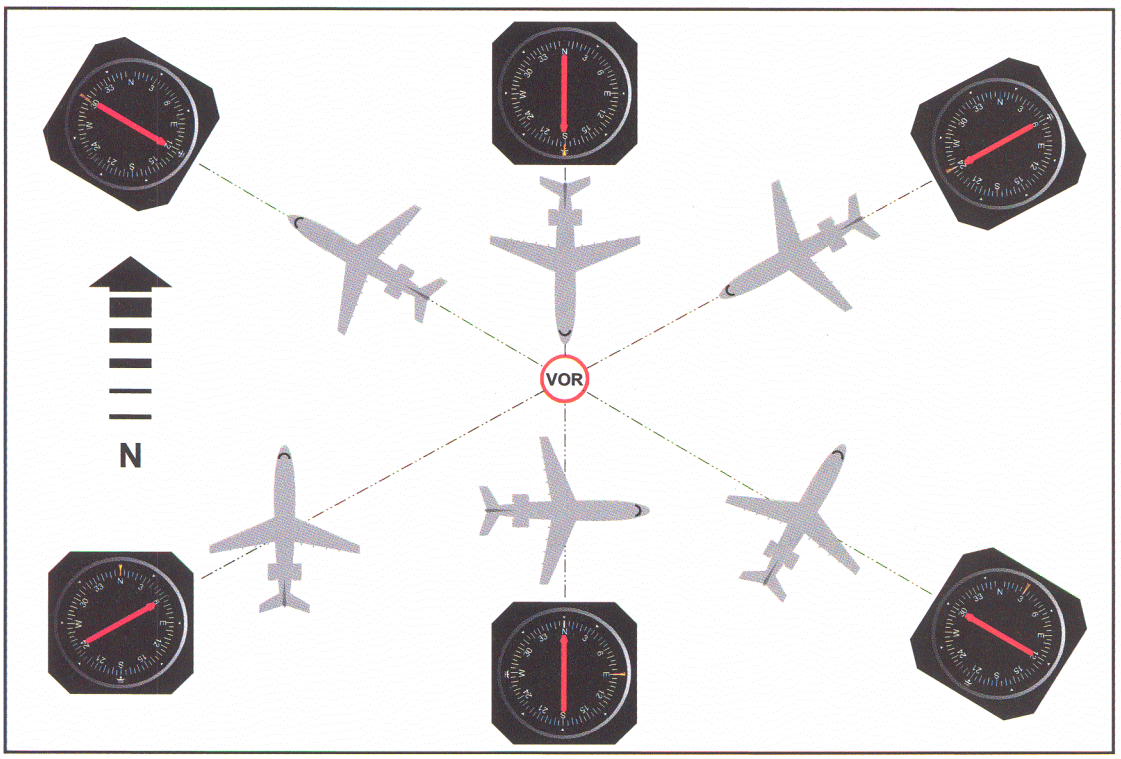

Figure 5.6. RMI Usage.

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5.4 TRANSMISSION DETAILS

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

a) **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)

(108.1, 108.15, 108.30, 108.35 ➜ 111.95 MHz are allocated to the **ILS** localiser. Note that the **first decimal is an odd digit**)

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

112.0, 112.05, 112.1, 112.15 ➜ 117.95 MHz

The emission code is **A9W**: A = main carrier amplitude modulated double side-band.
9 = composite system.
W = combination of telemetry, telephony and telegraphy.

5.5 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).

5.6 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:

a) Bearing information change exceeding 1°.

b) A reduction of >15% in signal strength, of both or either of the 30Hz modulations, or of the RF carrier frequency.

c) A failure of the monitor.

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When the main transmitter is switched off the standby transmitter is brought on-line which 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.

5.7 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 180° test radial. This is not for navigation use but is used to test an aircraft's equipments accuracy before IFR flight. More than +/-4° indicates the equipment needs servicing.

AFIS & ATIS Aerodrome flight and terminal information service broadcast (AFISVOR).

VORTAC - Co-located VOR and TACAN (DME) beacons.

Combination -DBVORTAC

5.8 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.

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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".

5.9 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 $\sqrt{25,000'}$
= 198nm
Separation = 396nm

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 **500** NM. In practice a beacon is protected as far as is deemed necessary and this is not always the anticipated line of sight reception range.

In the UK this protection is denoted by a **DOC, specified as a range and altitude**. E.g a DOC of **50/25000** published in AIPs means that an aircraft should not experience co-frequency interference within 50 NMS 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.

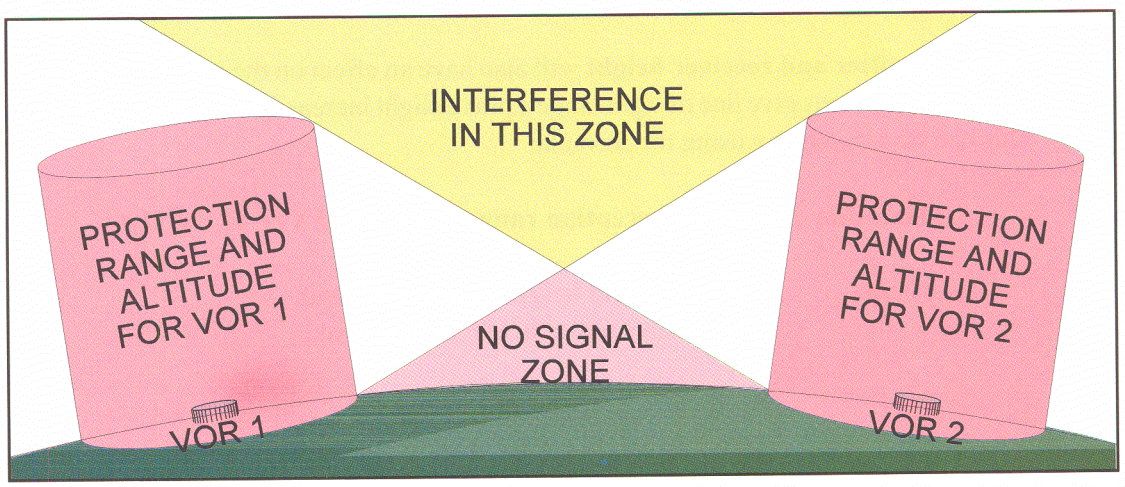

Figure 5.7. Designated Operational Coverage.

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VOR 1: DOC 50/25000 = No interference within 50 NMS range up to 25,000'.

VOR 2: DOC 100/50000 = No interference within 100 NMS range up to 50,000'.

5.10 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** is due to the fact that as an aircraft approaches the VOR the 1° radials get closer together.

5.11 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 , confusion or silence. Once the aircraft has flown through this cone the readings at the aircraft will stabilise.

Coverage. The VOR shall provide signals such as 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.

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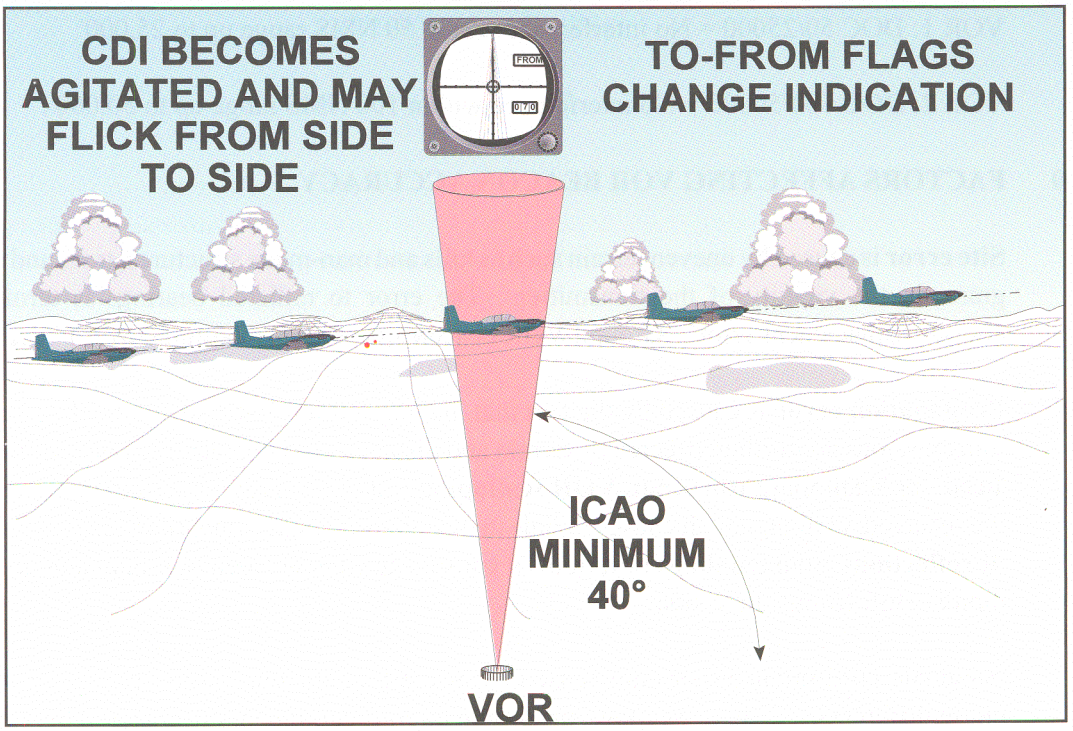

Figure 5.8. The Cone of Confusion.

Question. An aircraft flying at 6,000' enters the cone of confusion of an ICAO maintained VOR. What is the diameter (in nm) of the cone of confusion? (Sine 40° = .643; Sine 50° = .766; Tan 40° = .839; Tan 50° = 1.192; Cos 40° = .766; Cos 50° = .643)

5.12 DOPPLER VORS (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::

a) The reference signal is AM.

b) The variable phase directional signal is FM.

c) 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.

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5.13 VOR AIRBORNE EQUIPMENT

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

a) **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.

b) **The receiver.** This is a box fitted in the avionics bay.

c) **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 in subsequent below.

5.14 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 5.9

This displacement (or deviation) is presented by a Left / Right needle of the dual role (VOR/ILS) indicator. Figure 5.10 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.**

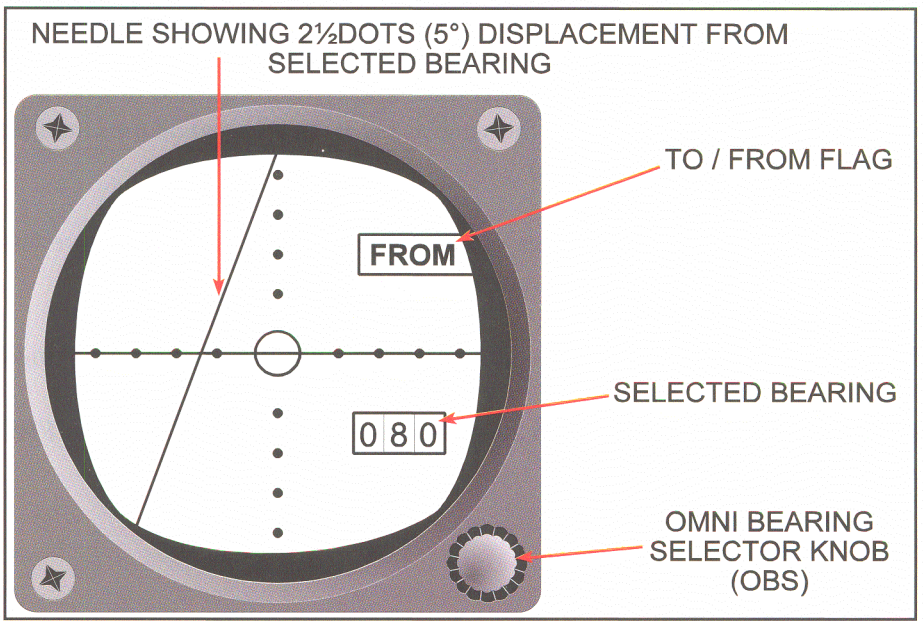

Figure 5.9. VOR / ILS Deviation Indicator.

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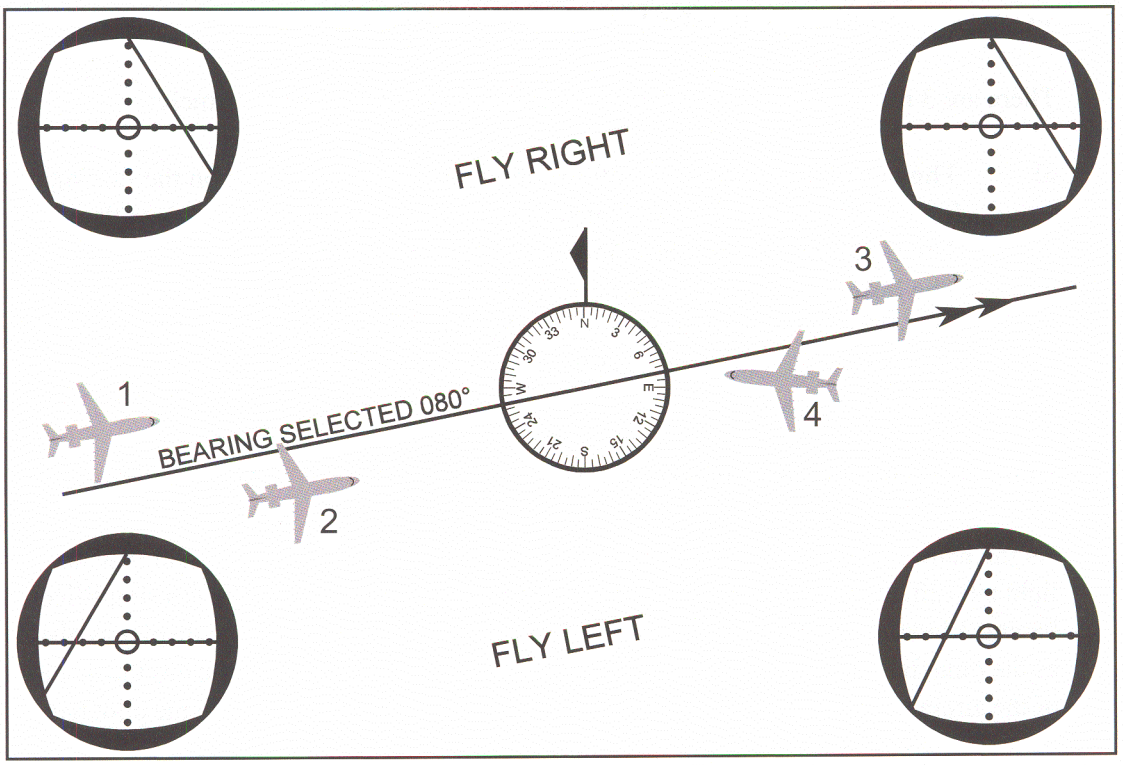

Figure 5.10. Left / Right Indications.

Inspection of Figure 5.10 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 5.9) 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.

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In Figure 5.9, 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 5.10, 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 5.9 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 ie 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:

a) The aircraft's QDM is within about 80° of the bearing selected, in which case 'To' appears

b) 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.

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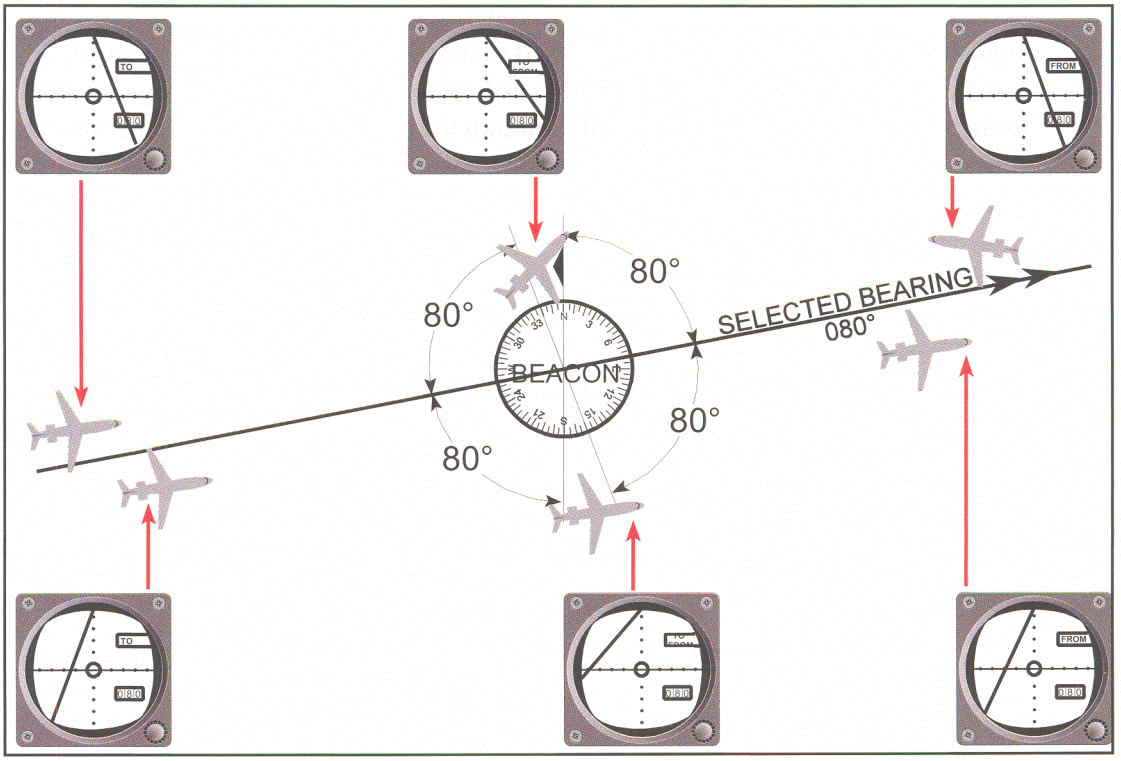

Figure 5.11 To / From Indications.

Figure 5.11. 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.

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5.15 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 foregoing, and with reference to Figure 5.12., 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 being based on the magnetic variation at the aircraft.

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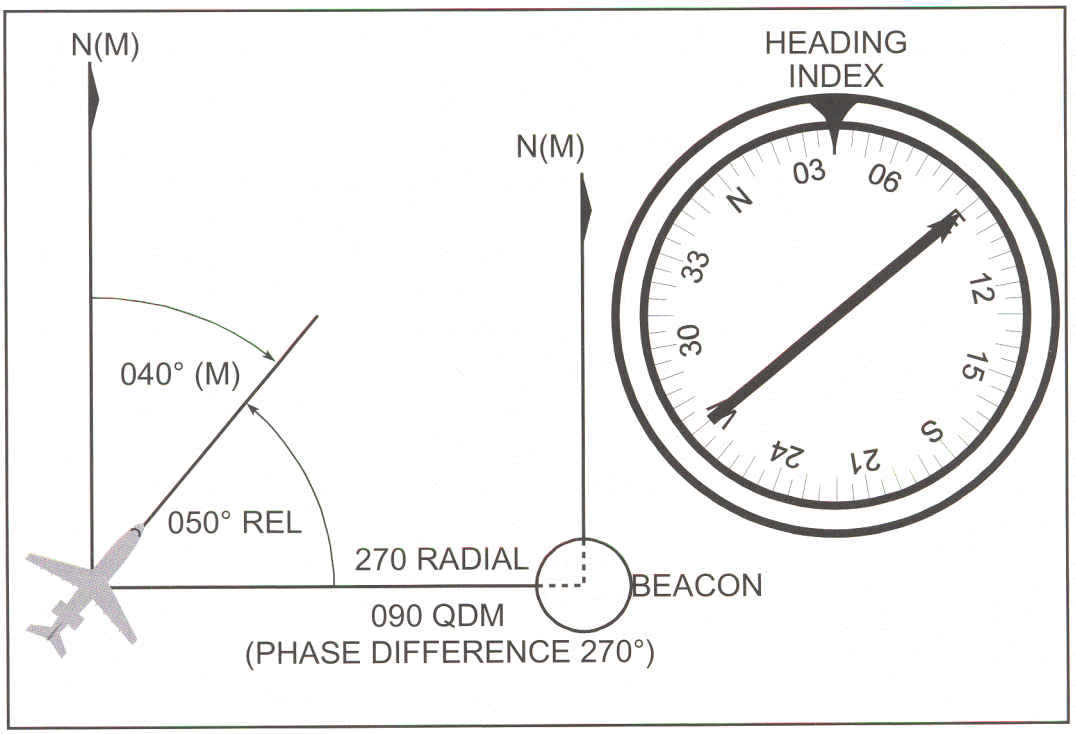

Figure 5.12. VOR QDM on the RMI.

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:

a) 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).

b) Magnetic heading is also displayed, on the same instrument; a considerable asset when homing to a VOR or maintaining a track outbound.

c) 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.

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d) As the pointer gives, automatically, a continuous indication of the VOR bearing, the rate of crossing radials during interception of a radial is easily assessed.

e) 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.

f) ADF bearings can be displayed on an RMI.

5.16 IN-FLIGHT PROCEDURES

Typical use of VOR by an aircraft equipped with both OBI-type deviation indicator and an RMI is illustrated in Figure 5.13.

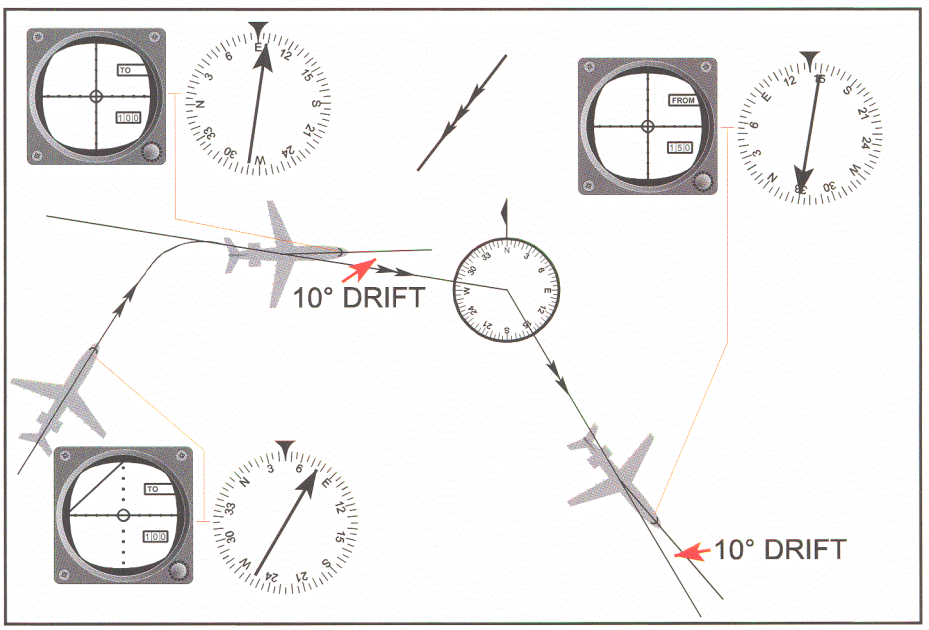

Figure 5.13 In-Flight Procedures.

a) Radial Interceptions.

In Figure 5.13. 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 about15 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).

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b) Inbound Track-keeping.

Having intercepted the inbound radial, the pilot maintains his heading (of 090°(M) in the Figure 5.13. 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).

c) 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 he 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.

d) Outbound Flight.

The aircraft is shown outbound on the 150 radial on the right-hand side of Figure 5.13. 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.

e) Airfield Approach

An airfield approach pattern using VOR and DME is shown at figure 5.14.

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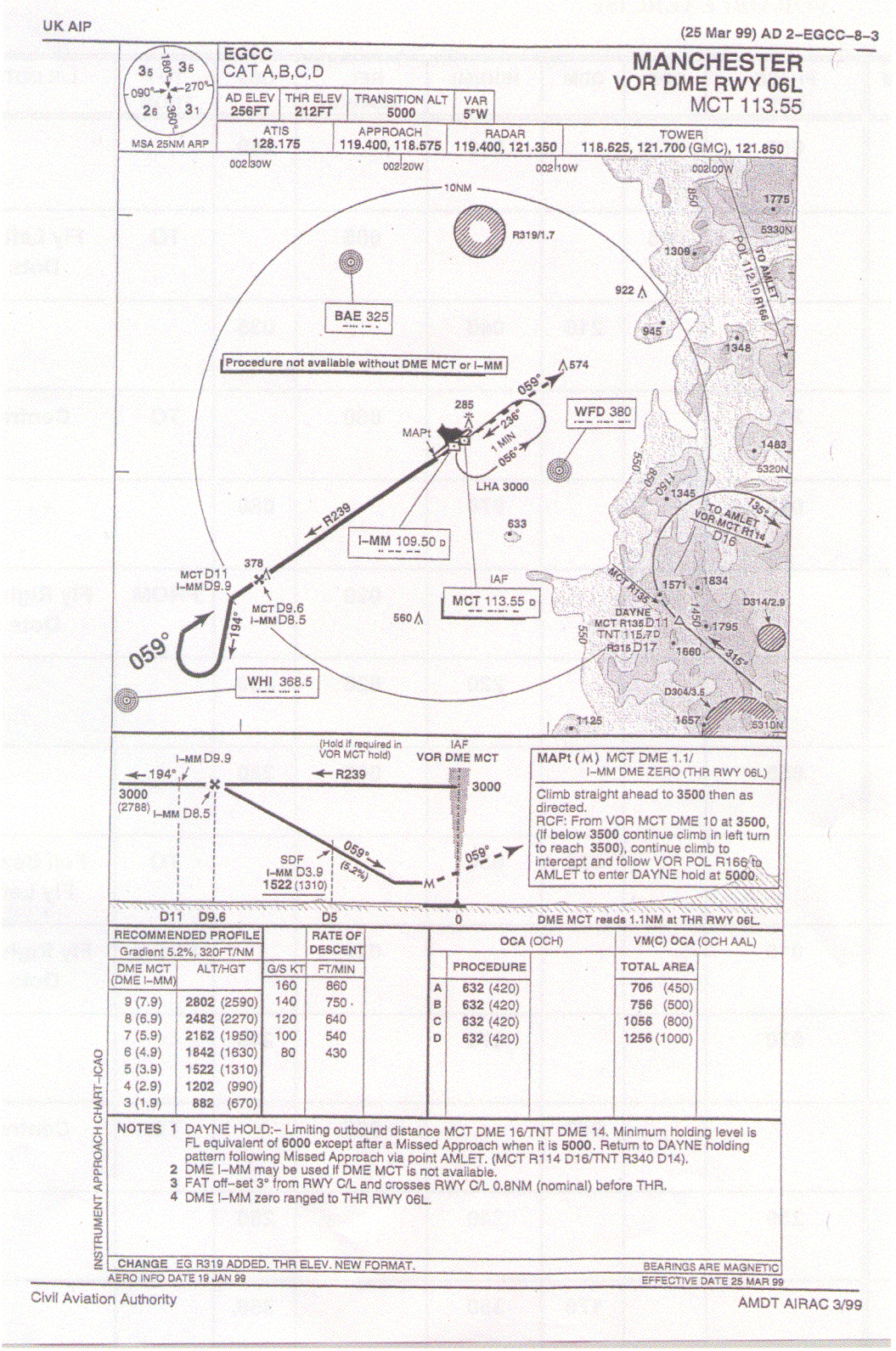

Figure 5.14 Example of a VOR DME Approach pattern

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5.17 VOR OBI EXERCISE

ITEM	PHASE DIFF.	QDR	QDM	HDG(M)	REL. BEARING	OBS	TO / FROM	L/R DOTS
1	050			010		240		
2		035			005		TO	Fly Left 2 Dots
3			216	040		035		
4	225				050		TO	Centre
5	085			070		080		
6		010			020		FROM	Fly Right 4 Dots
7				220	020	250		
8	050				000	220		
9			020	030			TO	Full Scale Fly Left
10	015				020		FROM	Fly Right 3 Dots
11	070			075		240		
12			063		005		TO	Centre
13	250			240		250		
14			170	350		350		
15		020			020		FROM	Fly Left 1 Dot

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5.18 ANSWERS TO VOR OBI EXERCISE.

ITEM	PHASE DIFF.	QDR	QDM	HDG(M)	REL. BEARING	OBS	TO / FROM	L/R DOTS
1	050	***050***	***230***	010	***220***	240	***TO***	***Fly Left 5 dots***
2	***035***	035	***215***	***210***	005	***219***	TO	Fly Left 2 Dots
3	***036***	***036***	216	040	***176***	035	***FROM***	***Fly Left 1/2 Dot***
4	225	***225***	***045***	***355***	050	***045***	TO	Centre
5	085	***085***	***265***	070	***195***	080	***FROM***	***Fly Left 2 1/2dots***
6	***010***	010	***190***	***170***	020	***018***	FROM	Fly Right 4 Dots
7	***060***	***060***	***240***	220	020	250	***TO***	***Fly Left 5 Dots***
8	050	***050***	***230***	***230***	000	220	***TO***	***Fly Right 5 Dots***
9	***200***	***200***	020	030	***350***	***030 (+)***	TO	Full Scale Fly Left
10	015	***015***	***195***	***175***	020	***021***	FROM	Fly Right 3 Dots
11	070	***070***	***250***	075	***175***	240	***TO***	***Fly Right 5 Dots***
12	***243***	***243***	063	***058***	005	***063***	TO	Centre
13	250	***250***	***070***	240	***190***	250	***FROM***	***Centre***
14	***350***	***350***	170	350	***180***	350	***FROM***	***Centre***
15	***020***	020	***200***	***180***	020	***018***	FROM	Fly Left 1 Dot

5.18 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 fluctuates

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

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5.19 QUESTION PAPER

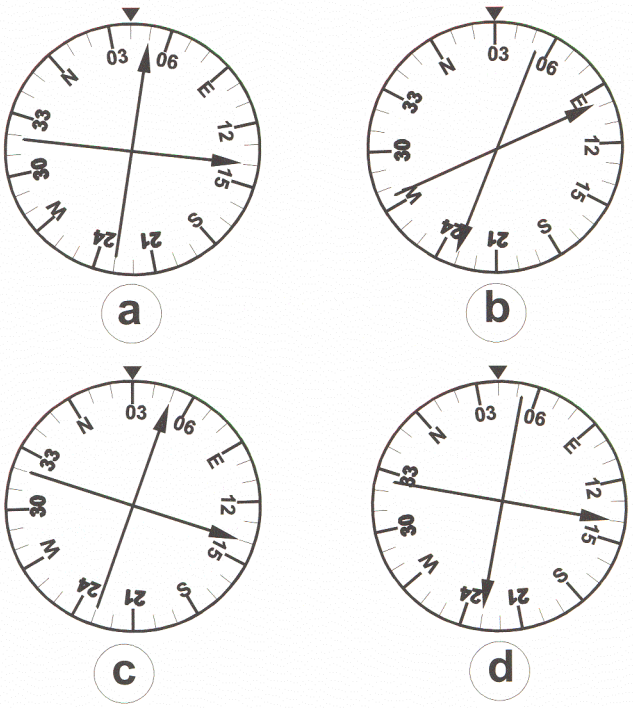
1. Assuming the maximum likely error in VOR to be 5.5^0, what is the maximum distance apart that beacons can be situated on the centre line of a UK airway in order that an aircraft can guarantee remaining within the airway boundary ?

   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 totravel.

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 ?



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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) 270 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 330^0 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 mea n sea level ?

a) 276 nm
b) 256 nm
c) 281 nm
d) 257 nm

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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 along the 064 radial. With 064 set on the OBS the deviation indicator shows FROM, with 4 dots fly Left. If the range is 45 nm where is the aircraft relative to the inbound 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) 231nm
d) 198nm

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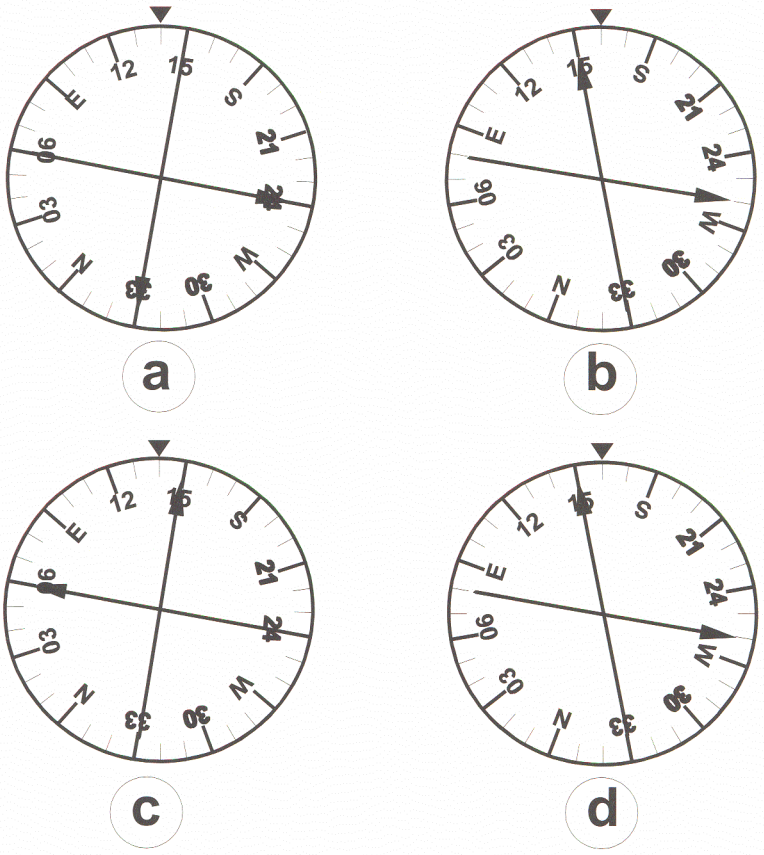
14. An aircraft is on the airway boundary range 100 nm from a VOR marking the airway centre line. Assuming that each dot equates to 2°, how many dots deviation will be shown on the deviation indicator

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 10^0 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 100^0 from the NDB.



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17. Assuming the maximum likely error in VOR to be 5^0, 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. A VOR is providing satisfactory signals, in accordance with the ICAO specifications, to an aircraft within the DOC at 42500ft, groundspeed 480kt. The approximate time that the aircraft is in the "cone of confusion" is:

a) 1.75min.
b) 1.50 min.
c) 2min.
d) 3min.

	30°	40°	50°	60°	
SINE	.5	.643	.766		.866
TAN	.577	.839	1.192	1.732	
COS	.866	.766	.643	.5	

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 10^0W 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 287^0M with 14^0 starboard drift. If the variation is 6^0W what is the phase difference between the reference and variable phase components of the VOR transmission:

a) 121^0
b) 295^0
c) 301^0
d) 315^0

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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) 202nm
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. The emission designator and the shape of the polar diagram transmitted by a VOR station are:

	DESIGNATOR	SHAPE
a)	J3E	a cardioid
b)	A3E	a cardioid
c)	A8W	a limacon
d)	A9W	a limacon

25. The RMI indicates the aircraft magnetic heading. To convert the RMI bearings of NDB's and VOR's 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

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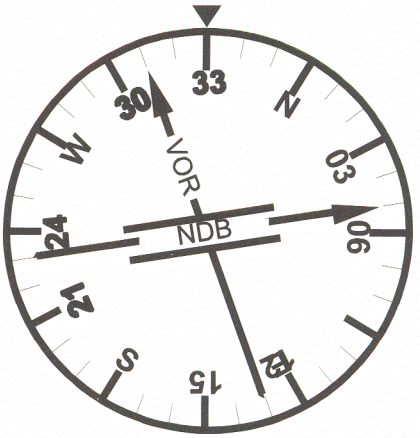
26. Both the VOR and the ADF in an aircraft are correctly tuned and identified. The indications from both are shown on the RMI illustrated.



Use the information to answer the following:

The information given on the RMI indicates :

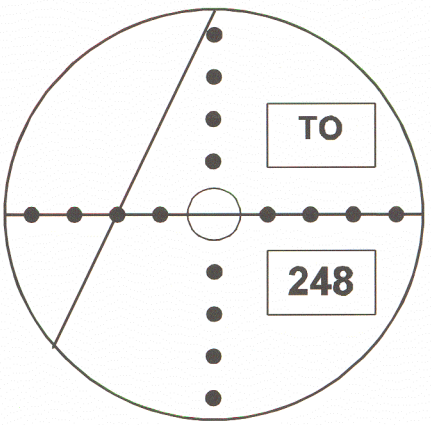
a) that the aircraft is heading 033^0(M), is on the 310 radial from the VOR, and bears 050^0(M) from the NDB.

b) that the aircraft is heading 330^0(M), is on the 310 radial from the VOR, and bears 050^0 from the NDB.

c) that the aircraft is heading 330^0(M), is on the 130 radial from the VOR, and bears 050^0(M) from the NDB.

d) that the aircraft is heading 330^0(M), is on the 130 radial from the VOR, and bears 230^0(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

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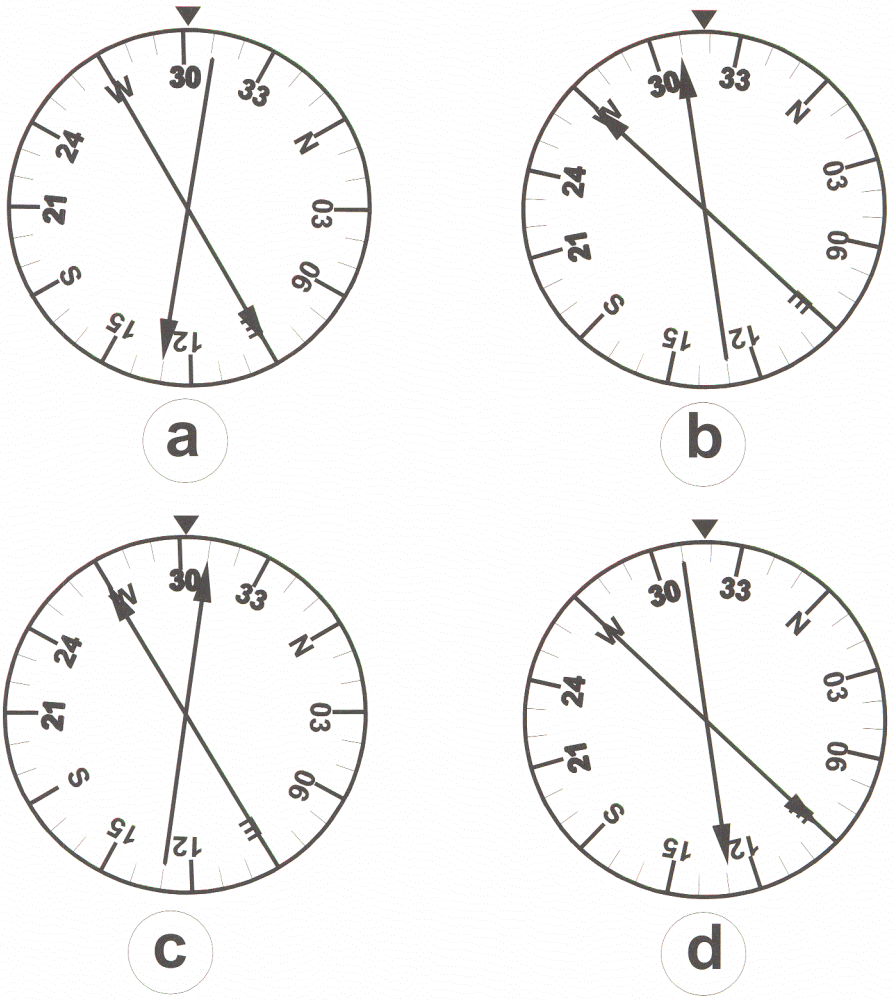
28. The normal maximum error which might be expected with a VOR bearing obtained within the DOC is:

a) plus or minus 1^0
b) plus or minus 2^0
c) plus or minus 5^0
d) plus or minus 10^0

29. An aircraft is tracking away from VOR "A" on the 310 radial with 8^0 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 ?



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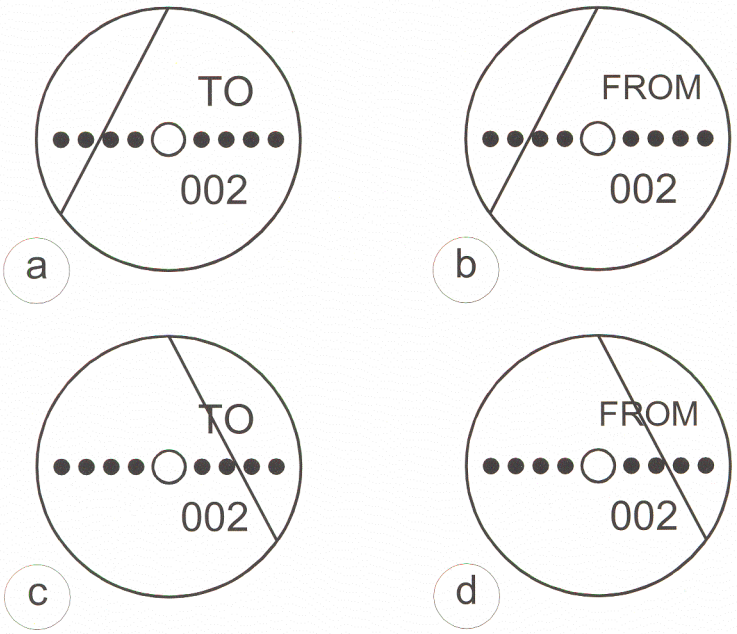
30. An aircraft bears 175^0(M) from a VOR. If the aircraft OBS is set to 002 its heading is 359^0(M) which diagram below represents the aircraft VOR/ILS deviation indicator? (assume 1 dot = 2^0)



31. 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.

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VOR ANSWERS

QUESTION	ANSWER	QUESTION	ANSWER
1	b	21	c
2	c	22	c
3	d	23	a
4	a	24	d
5	a	25	c
6	a	26	d
7	d	27	a
8	a	28	c
9	a	29	a
10	a	30	a
11	c	31	a
12	b	32	
13	c	33	
14	d	34	
15	b	35	
16	a	36	
17	c	37	
18	c	38	
19	b	39	
20	c	40	

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CHAPTER SIX - INSTRUMENT LANDING SYSTEM

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6.1 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.

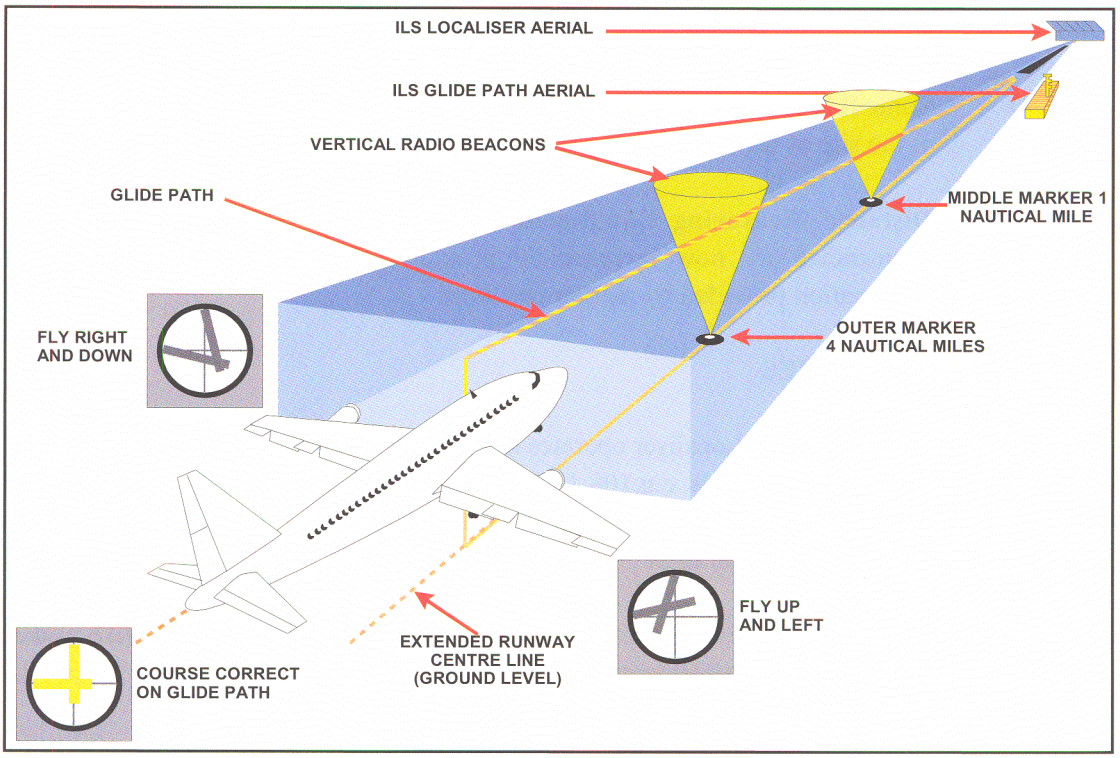

Figure 6.1. The Instrument Landing System (ILS)

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6.2 ILS COMPONENTS

a) The system requires a suitable ground installation and airborne equipment. The ground installation has three distinct components as shown in figure 6.1, namely localiser, glide path and marker beacons; in some installations a back course may also be available.

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

c) **The glide path** (GP) transmitter operates in the UHF band, 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.

d) **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

e) **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.

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

g) **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.

6.3 ILS FREQUENCIES

a) **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.

b) **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.

.

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

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d) **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.

6.4 DME PAIRED WITH ILS CHANNELS

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

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

c) 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.

6.5 ILS IDENTIFICATION

a) 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.

b) The Ident on the localiser transmission is a 2 or 3 letter morse signal at 7 groups/min. The first letter is usually "I".

c) **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.

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6.6 MARKER BEACONS

a) ILS 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 elliptical or bone shaped in plan view. Figures 6.2a and 6.2b 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

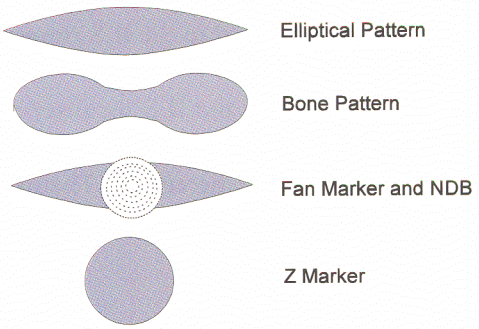

Figure 6.2a Marker Beacon Radiation Patterns

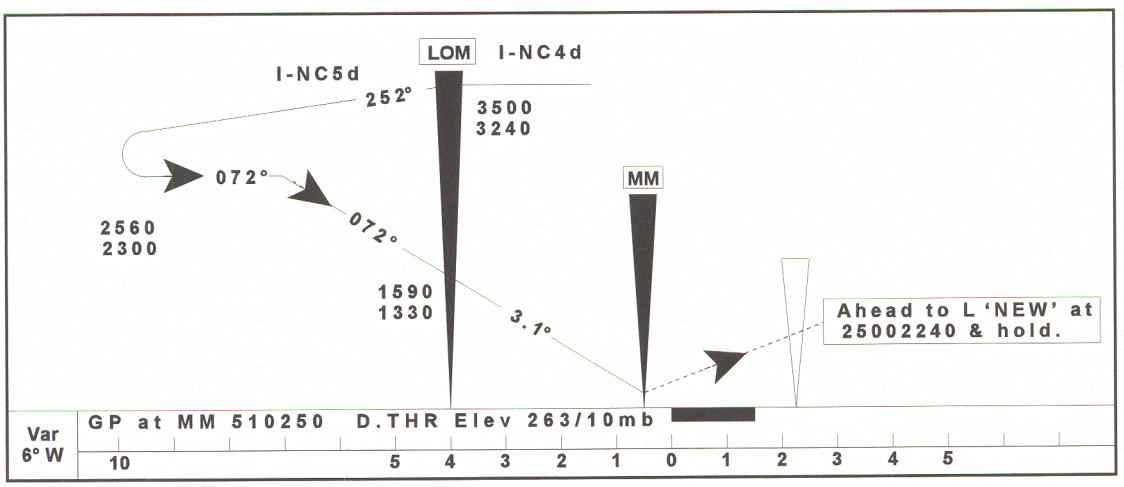

Figure 6.2b. The Outer Marker and the Middle Marker.

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	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**	**6dots /sec**	3000 Hz	**High**	75 - 450m (250' - 1,500')

b) **Z markers**

These 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.

6.7 GROUND MONITORING OF ILS TRANSMISSIONS

a) 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.

b) 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.

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6.8 ILS COVERAGE

a) **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 of ±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.

b) **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.

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

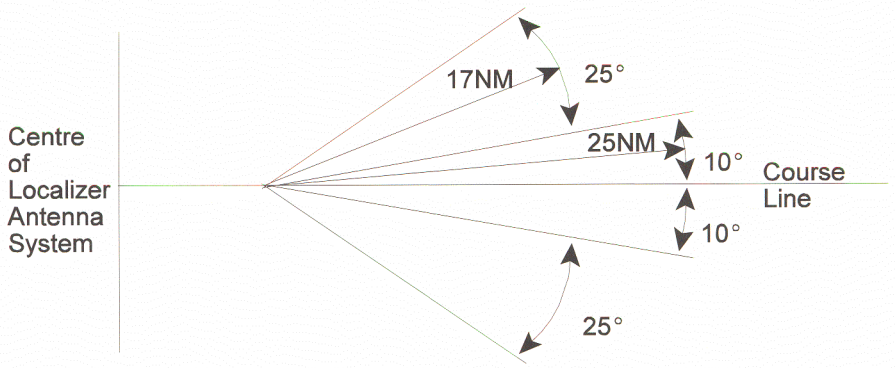

Figure 6.3a Localiser Coverage

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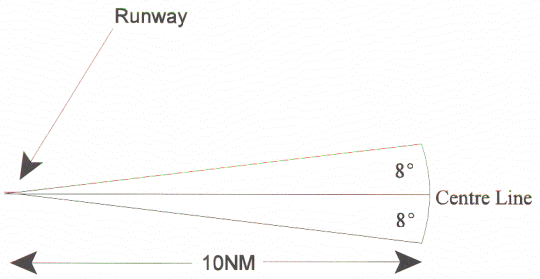
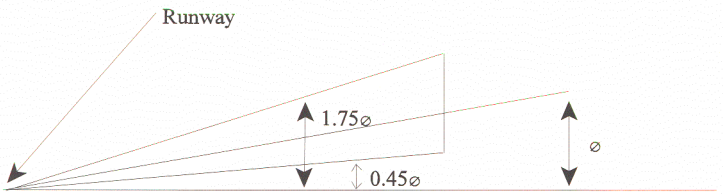


Figure 6.3b Glide Path Coverage



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

Elevation Cover

Figure 6.3c Glide Path Vertical Coverage

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6.9 ILS PRINCIPLE OF OPERATION

a) THE LOCALISER

The localiser antenna produces two overlapping lobes along the runway approach direction (QDM) as shown in figure 6.4. The lobes are transmitted on a **single VHF** ILS frequency.

In order that an aircraft's ILS receiver can distinguish between the lobes:

i) the **right hand lobe** (the blue sector) has a **150Hz** modulation

ii) 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 fro 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.

b) Back-course ILS

There is always some overspill of radiation behind the **localiser aerial** so ILS indications are received on aircraft equipment. Back-course ILS is used in some countries but there is no provision for back-course ILS in the United Kingdom. **Ignore any back-course indications in the United Kingdom.** The back-course ILS has the following disadvantages:

i) There is no glide-path.

ii) It is less accurate than a front course ILS.

iii) The CDI needle (localiser) is sense reversed. (Flying to R/W).

iv) Usually there are no range-check markers.

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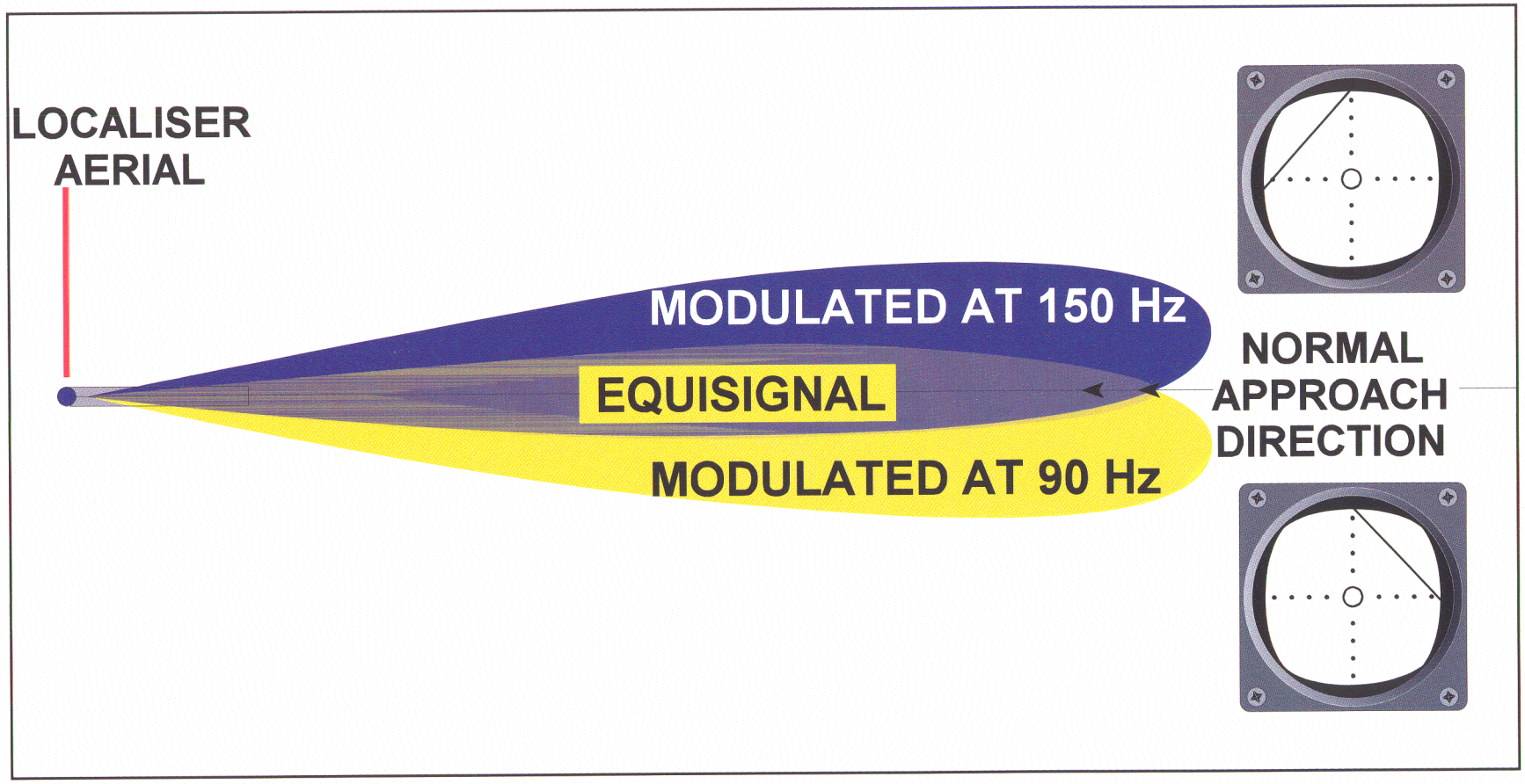

RA7-F6

Figure 6.6. Localiser Radiation Pattern

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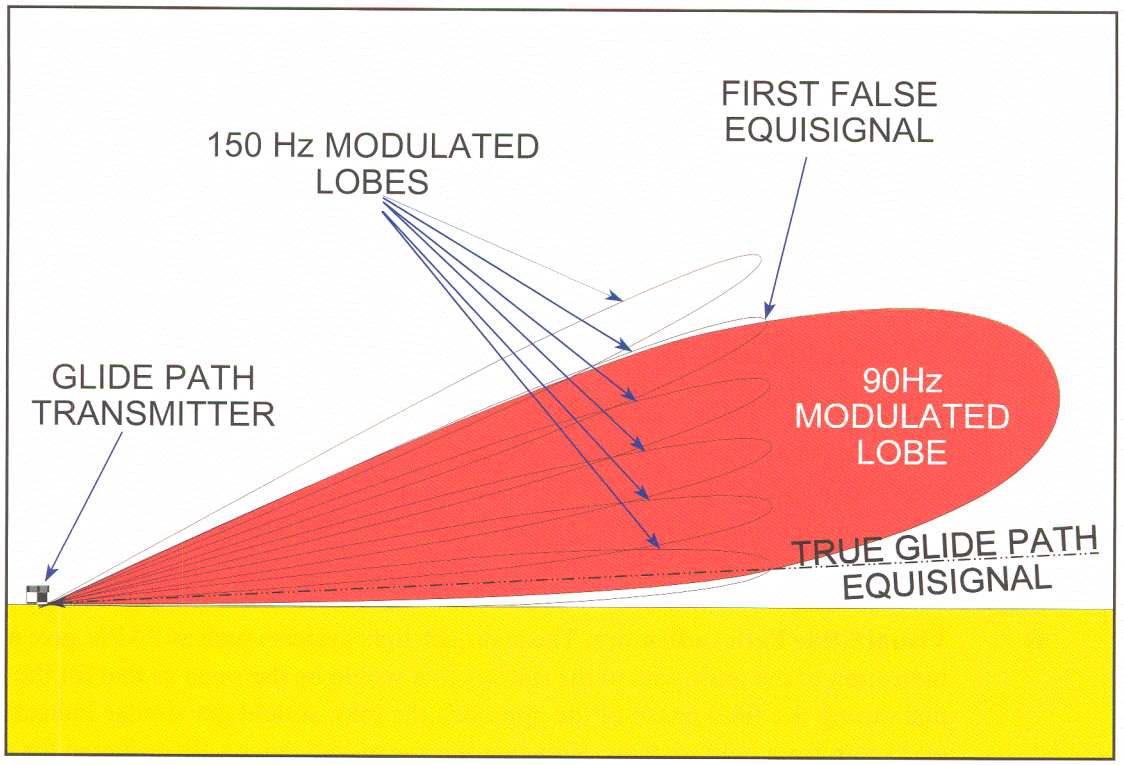

Figure 6.4. Glide Path Radiation Pattern.

c) **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 6.5.

d) **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:

i) Metallic structures situated at the transmission point, and ground reflections.

ii) The height and propagation characteristics of the aerial

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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.

e) **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.

f) **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.

6.10 ILS PRESENTATION AND INTERPRETATION

a) **Indicators.** Localiser and glide path information can be displayed:

i) on a Course Deviation Indicator (CDI) or

ii) on the Horizontal Situation Indicator (HSI).

Interpretation of a CDI display is shown in figure 6.5. The HSI display is shown at figure 6.6. 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.

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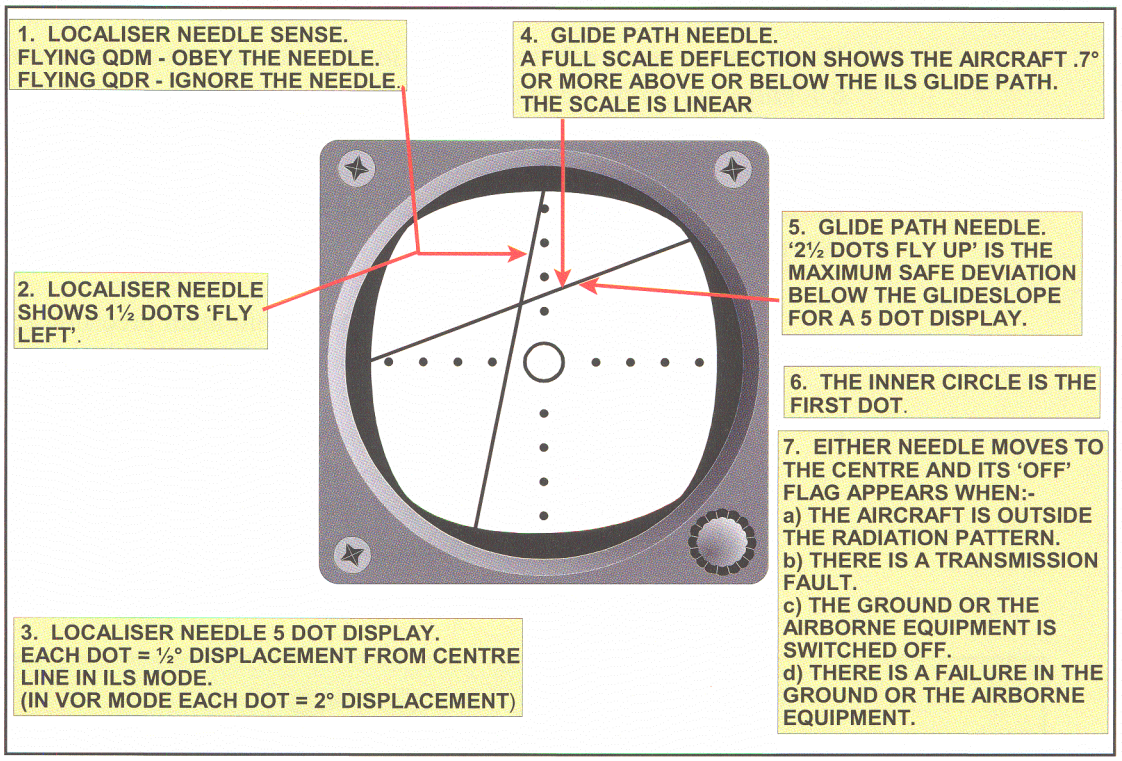

Figure 6.5. ILS Course Deviation Indicator.

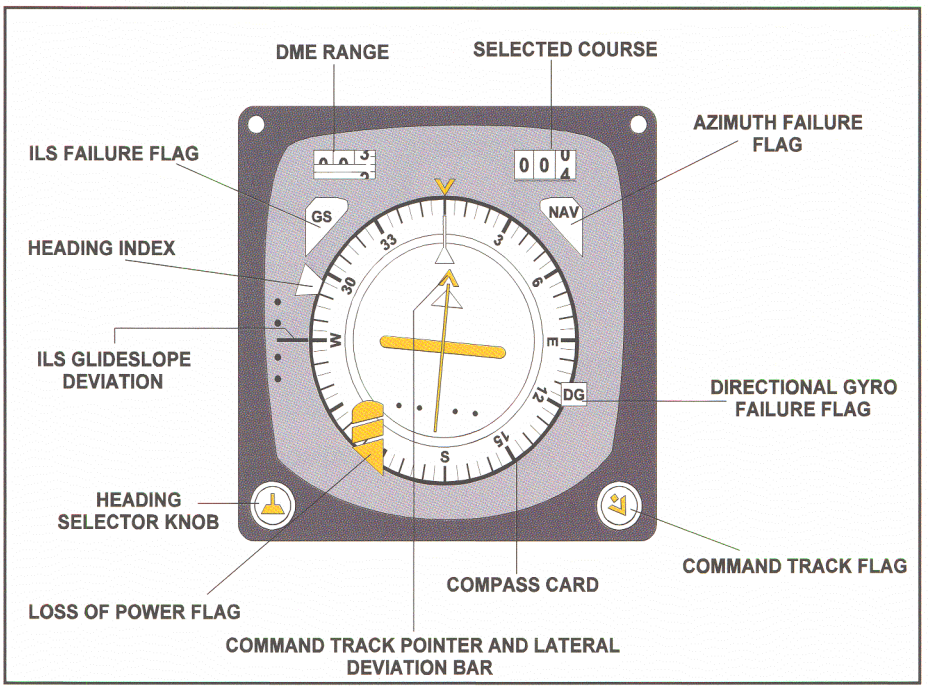

Fig. 6.6 A Typical HSI

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b) **Localiser Indications.**

i) **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.

ii) **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.

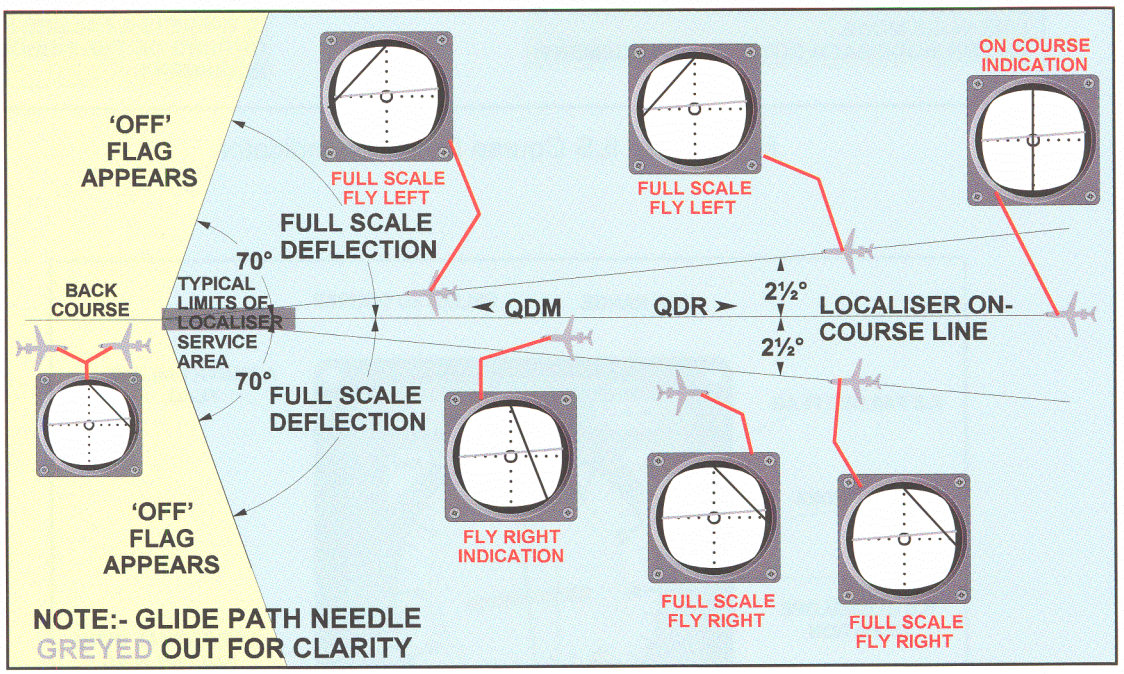

Figure 6.7. Localiser.

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c) **Glide Path Indications**

The glide path indication for fly up or fly down is shown in figure 6.8. Full scale deflection indicates that the aircraft is 0.7° or more above or below the glide path. The sensitivity is 0.14° per dot. Note that **the maximum safe deviation below the glideslope** is **half full-scale deflection** i.e. 2.5 dots fly up.

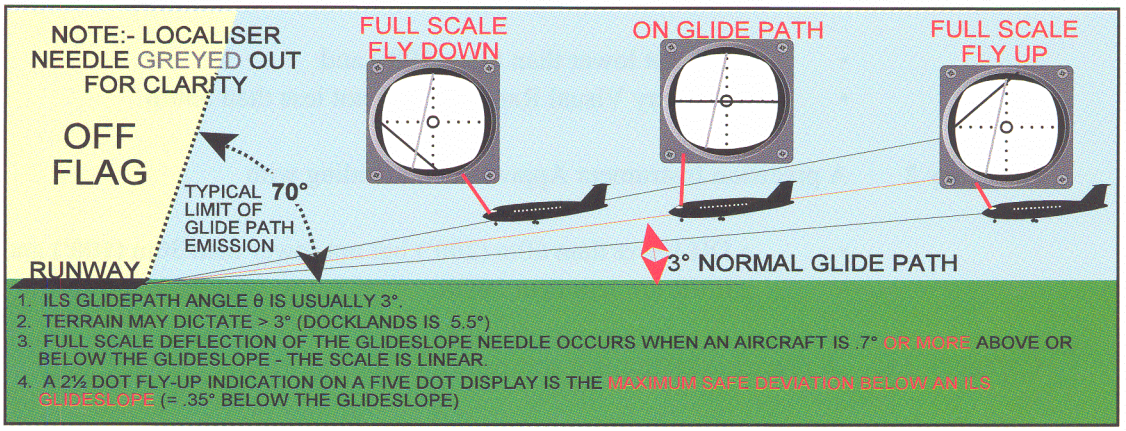

Figure 6.8. Glide Path.

6.11 ILS CATEGORIES

a) 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**.

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b) 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.**

b) 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.

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6.12 ERRORS AND ACCURACY

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

i) beam bends caused by atmospheric conditions

ii) scalloping caused by reflections and

iii) 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.

b) 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.

c) 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.

6.13 FACTORS AFFECTING RANGE AND ACCURACY

a) **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:

i) **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.

ii) **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 depends upon the object creating the disturbance.

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iii) **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.

b) **Weather**. Snow and heavy rain attenuates the ILS signals thereby reducing the range and degrading the accuracy.

c) **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.

6.14 ILS APPROACH CHART

a) An Instrument Approach Chart for an ILS Approach is shown in Figure 6.9.
The instrument approach can be divided into the following 3 segments:

i) Initial approach - procedure up to the IAF (initial approach fix)

ii) Intermediate - procedure between IAF and FAF (final approach fix)

iii) final approach- procedure after FAF.

b) 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).

c) 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.

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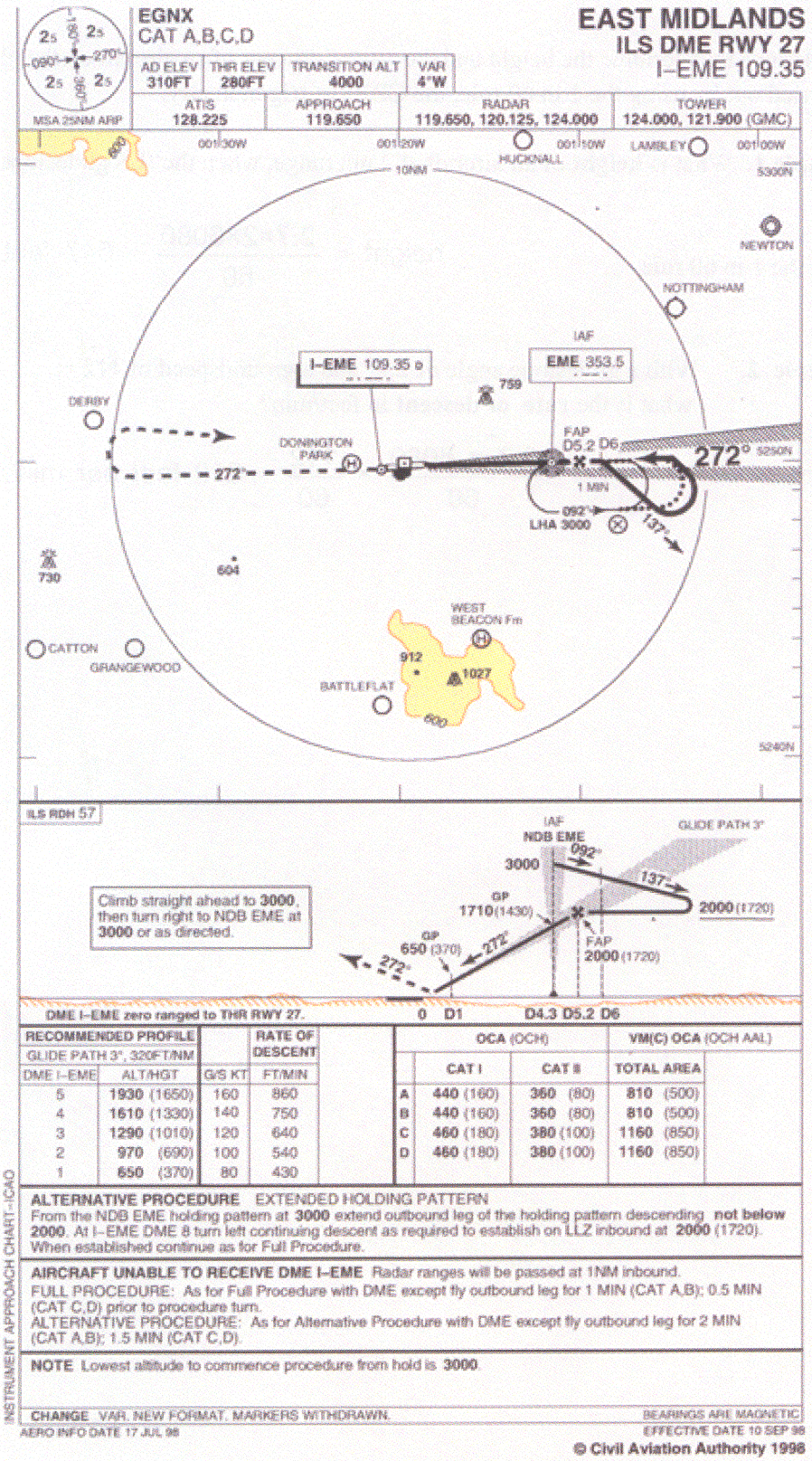

Figure 6.9 ILS Approach to Runway 27 at East Midlands Airport

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6.15 ILS CALCULATIONS. [NOT NECESSARY FOR JAA EXAMS]

Calculations to determine the height and the rate of descent of an aircraft on the glideslope can be carried out by using the 1 in 60 rule, the CRP5 or trigonometry.

Example 1. What is **height** of an aircraft at 2 nm range, when the ILS glideslope is 2.7°?

Using the 1 in 60 rule

$$\text{height} = \frac{2.7 \times 2 \times 6080}{60} = 547 \text{ feet}$$

Example 2. With a glideslope angle of 2.7° and a groundspeed of 112 kt, what is the **rate of descent** in feet/min?

RoD =

$$\frac{2.7 \times 6080}{60} \times \frac{112}{60} = 510 \text{ feet per minute}$$

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6.16 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 approaches
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 das/s	400 Hz	6.5 - 11.1 km
MM	orange	3 dit-da/s	1300 Hz	1050m
IM	white	6 dits/s	3000 Hz	75 - 450m
(Z	cylindrical vertical radiation)			

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° , (plus 10nm > 35 °)
GP:	10nm ± 8° ; 0.45 to 1.75 ϕ.

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 ϕ. 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

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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.

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6.17 QUESTION PAPER

1. The coverage of an ILS localiser extends to _____either side of the on course line out to a range of _____nm.

   a) 10^0 35
   b) 35^0 10
   c) 35^0 17
   d) 25^0 25

2. The upper and lower limits of an ILS glide path transmitter having a 3.5^0 glide slope are:

   a) 6.125^0 1.575^0
   b) 7.700^0 1.225^0
   c) 5.250^0 1.350^0
   d) 3.850^0 3.150^0

3. The minimum angle at which a false glide path is likely to be encountered in the UK 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 150Hz signals than 90Hz 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.

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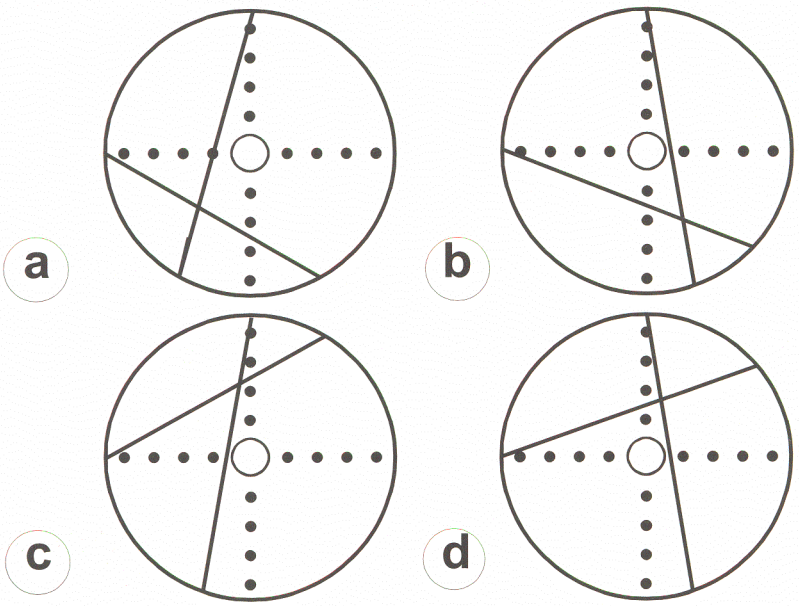
6. In elevation the upper and lower limits of an ILS glide path transmitter having a 3.0 degree glide slope are:

a) 0.35^0 0.70^0
b) 3.00^0 at least 6^0
c) 5.25^0 1.35^0
d) 10.00^0 35.00

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) 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.

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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 when using ILS is given as:

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) $\pm 8^0$ out to 10nm
b) $\pm 10^0$ out to 8nm
c) $\pm 12^0$ out to 17nm
d) $\pm 35^0$ 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°, and is flying downwind 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.

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ANSWER SHEET

QUESTION	ANSWER		
1	c	21	
2	a	22	
3	a	23	
4	c	24	
5	b	25	
6	c	26	
7	a	27	
8	d	28	
9	b	29	
10	d	30	
11	b	31	
12	b	32	
13	a	33	
14	b	34	
15		35	
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19		39	
20		40	

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CHAPTER SEVEN - MICROWAVE LANDING SYSTEM

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7.1 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 (2000) and it is 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.

7.2 ILS DISADVANTAGES

ILS has the following disadvantages:-

a) There are only 40 channels available worldwide.

b) The azimuth and glideslope beams are fixed and narrow. As a result, aircraft have to be sequenced and adequately separated which causes landing delays.

c) There are no special procedures available for slower aircraft, helicopters, and Short Take Off and Landing (STOL) aircraft.

d) 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.

e) 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).

7.3 THE MLS SYSTEM

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

a) There are **200 channels** available worldwide.

b) **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.**

c) 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.**

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d) 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.

e) 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.

f) **The MLS has a built-in DME**.

g) MLS is compatible with conventional localiser and glidepath instruments, EFIS, auto-pilot systems and area navigation equipment.

h) MLS gives positive automatic landing indications plus definite and continuous on/off flag indications for the localiser and glideslope needles.

i) The identification prefix for the MLS is an 'M' followed by two letters.

j) The aim is for **all** MLS equipped aircraft to operate to CAT III criteria.

Figures 7.1, 7.2, 7.3 below show some of these features.

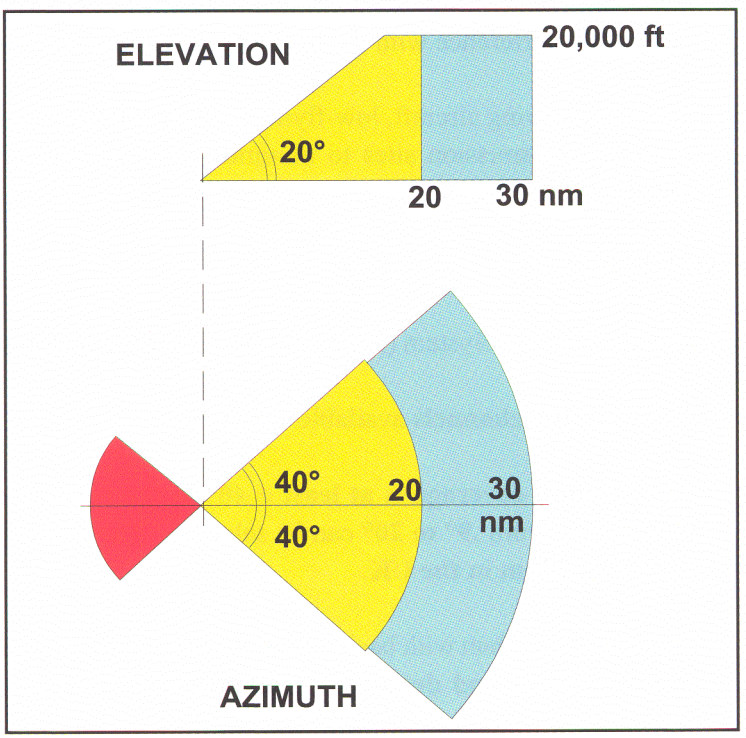

Figure 7.1. MLS Coverage.

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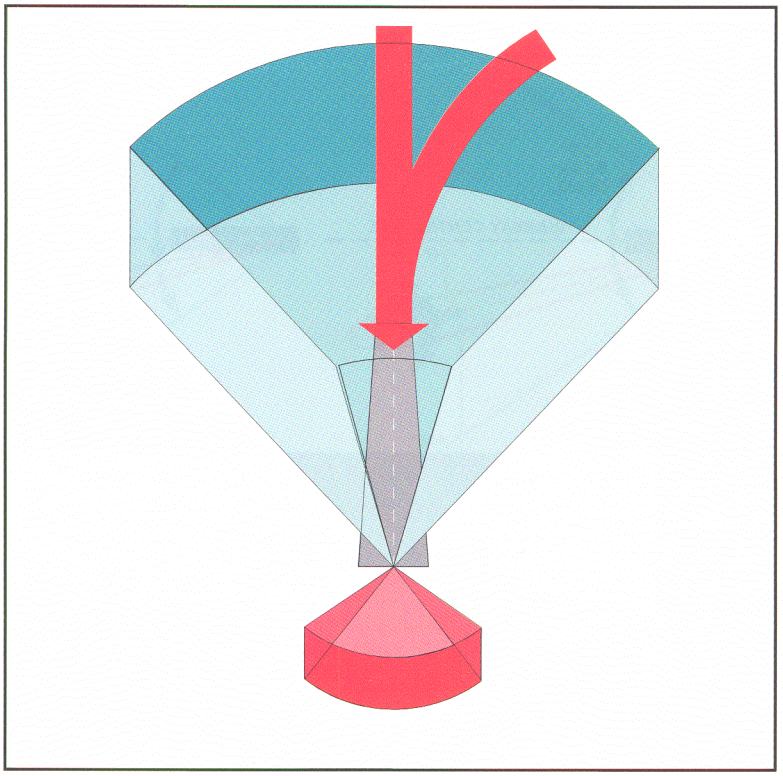

Figure 7.2. Approach Coverage Volume.

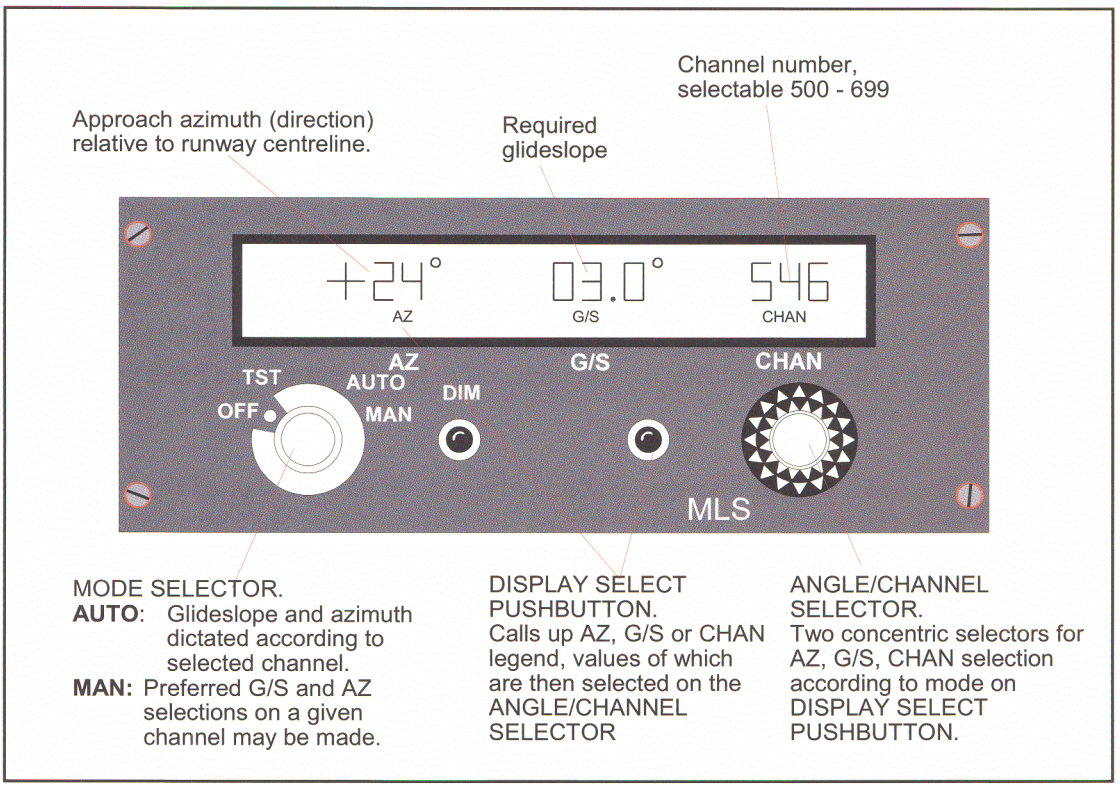

Figure 7.3. Typical MLS Flight Deck Control Panel.

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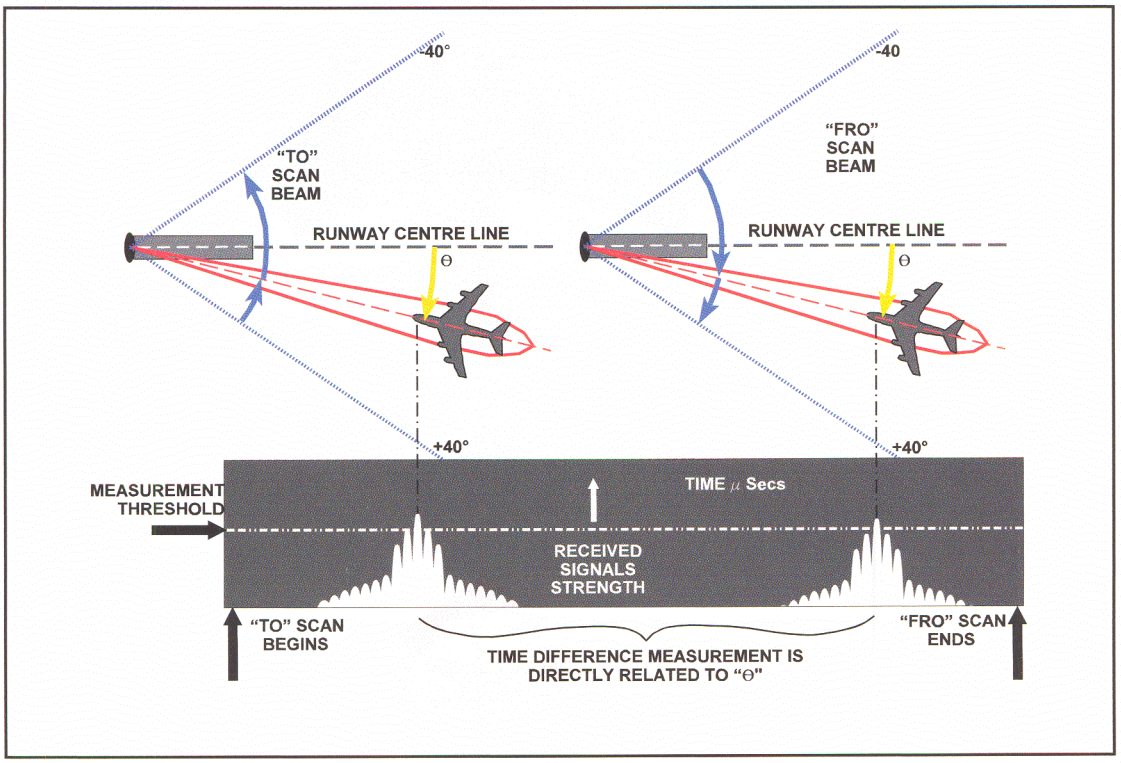

Figure 7.4.

7.4 PRINCIPLE OF OPERATION

MLS employs the principle of Time Division Multiplexing (TDM) (see fig 7.5) 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.

a) **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 μ sec between the reception of a **'to'** and **'fro'** scanning beam.

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 $\pm$ the runway direction. (See Figure 7.4).

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b) **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'.

c) **Other components** of the system are:

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

ii) Back azimuth Gives overshoot and departure guidance ± 20° of runway direction up to 15° in elevation.

iii) 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.

iv) Transmission of auxillary data. This consists of:

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

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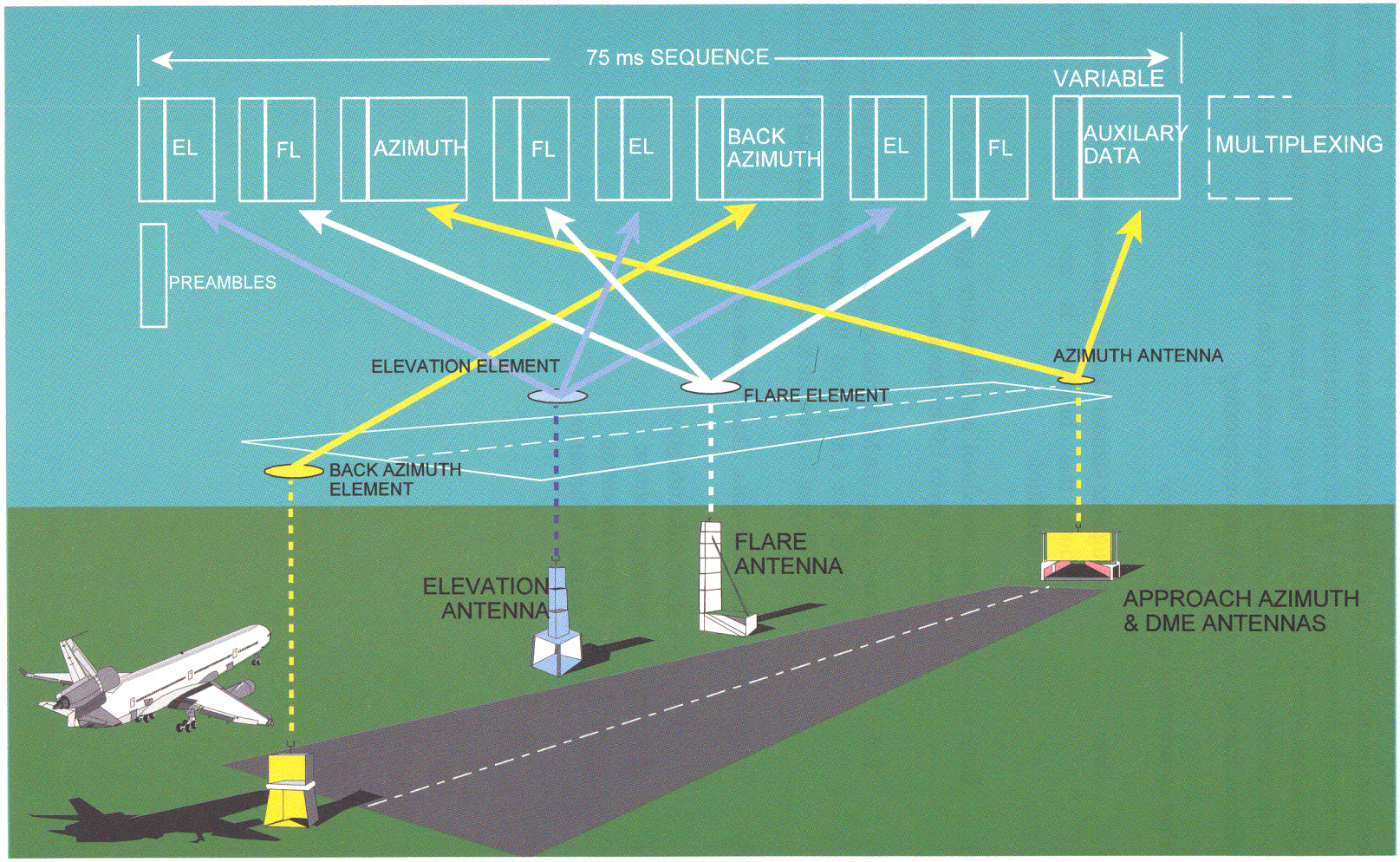

Figure 7.5. TRSB Component Site

7.5 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.

a) **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.

b) **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 7.6.

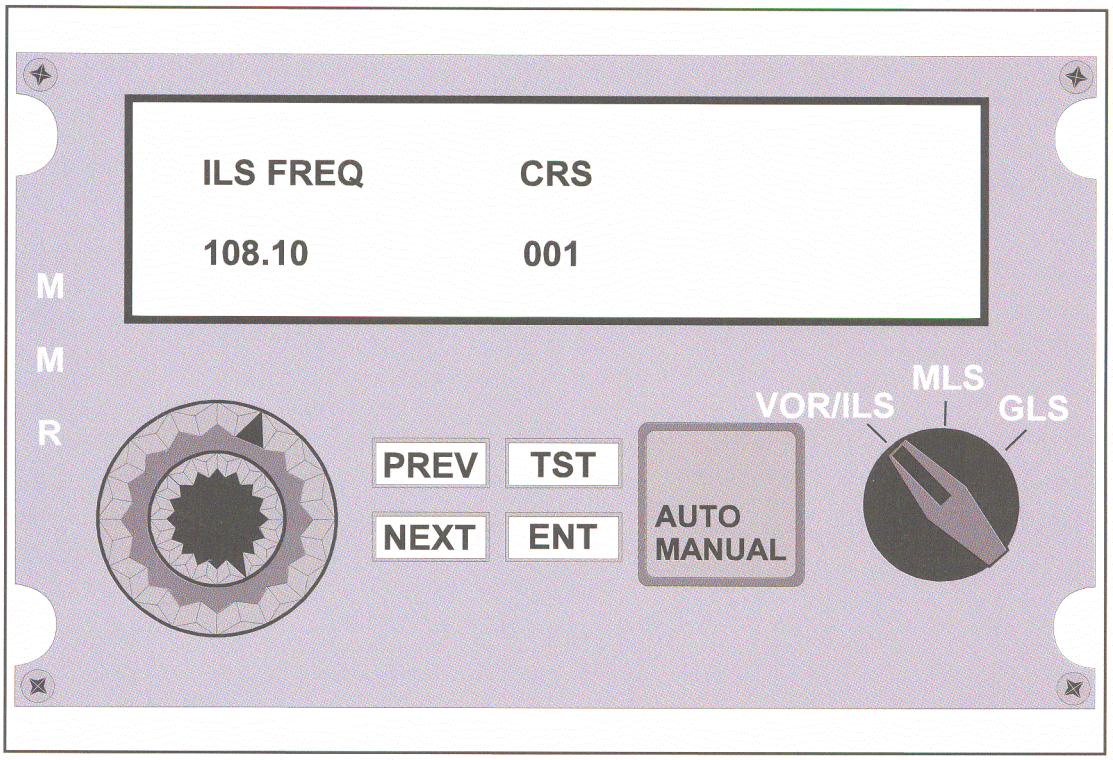

Figure 7.6. MRR Control Panel.

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7.6 QUESTION PAPER

1. The coverage of the Micro-wave Landing System in UK extends to _____nm up to a height of _____and _____degrees either side of the on course line.

a) 20nm; 20000ft; 40 degrees.
b) 35nm; 5000ft; 40 degrees.
c) 35nm; 5000ft; 20 degrees.
d) 17nm; 2000ft; 35 degrees.

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ANSWERS

QUESTION	ANSWER
01	a

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CHAPTER EIGHT - RADAR PRINCIPLES

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8.1 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.

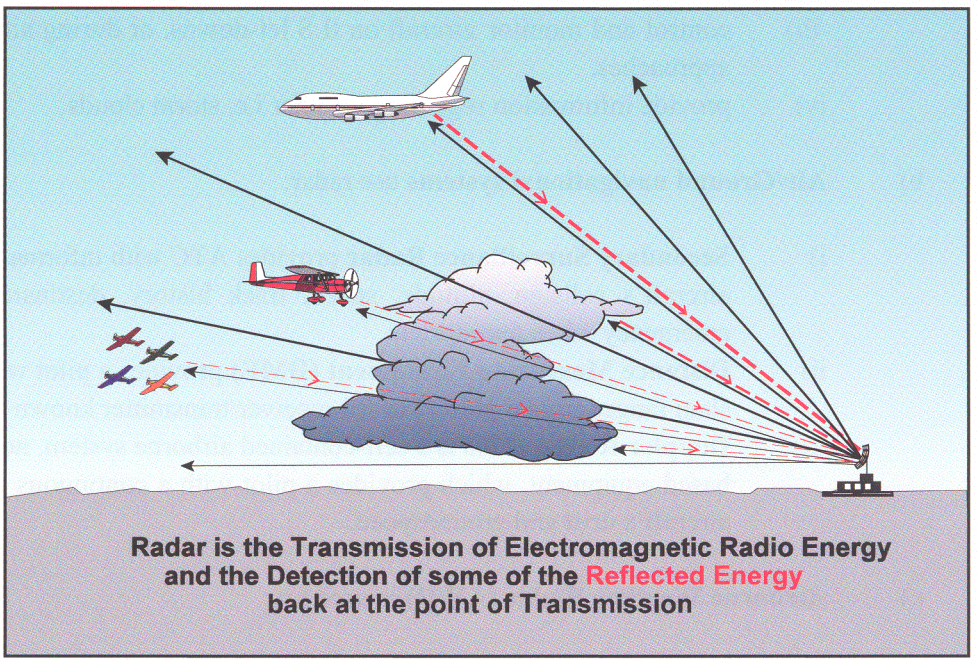

Figure 8.1

8.2 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.

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8.3 RADAR APPLICATIONS

Radar has a wide range of applications as follows:

a) **Air Traffic Control** uses radar to :

i) 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.
ii) provide radar talk-down to a given runway: (Surveillance Radar Approach (SRA) or a military Precision Approach Radar (PAR))
iii) control and monitor aircraft on ILS let-downs, or during airfield instrument approaches.
iv) provide information regarding weather i.e. storm clouds.

b) **Air/Ground navigational systems** use radar:

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

c) **Airborne Weather Radar (AWR)** is used to:

i) depict the range and bearing of clouds.
ii) indicate areas of the heaviest precipitation and associated turbulence.
iii) calculate the height of cloud.
iv) ground map.

8.4 RADAR FREQUENCIES

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

a) these frequencies are free from external noise/static and ionospheric scatter.

b) the shorter wavelengths produce narrow, efficient beams for target discrimination and bearing measurement.

c) the shorter wavelengths can produce shorter pulses.

d) efficient reflection from an object depends upon its size in relation to the wavelength; shorter wavelengths are reflected more efficiently.

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8.5 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.

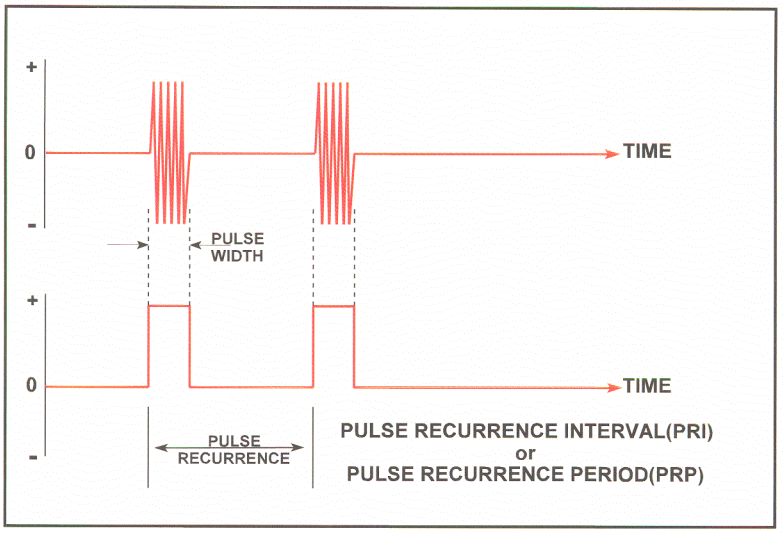

Figure 8.2. Pulse Technique.

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).**

$$PRI = \frac{1}{PRF}$$

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

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8.6 DISTANCE MEASUREMENT - ECHO PRINCIPLE

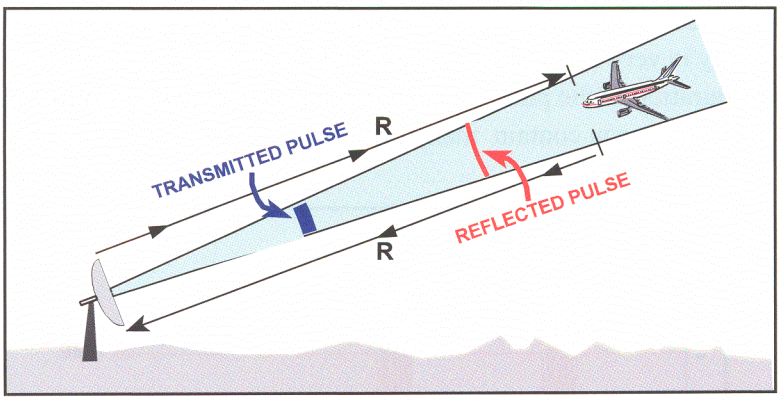

Figure 8.3.

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 8.3.

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

$$\text{Distance} = 300{,}000{,}000 \times \frac{500}{1{,}000{,}000 \times 2} m \qquad = 75000 \text{ m} \qquad = 75\text{km} \qquad \text{or}$$

$$\text{Distance} = \frac{162{,}000 \times 500}{1{,}000{,}000 \times 2} \qquad = \qquad 40.5 \text{ nm}$$

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

Other methods of calculating the range are:

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

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

Range = $\frac{500}{12.36}$ = 40.45nm

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8.7 THEORETICAL MAXIMUM RANGE

a) Relationship to PRF

Maximum theoretical range is determined by the PRF ie the number of pulses transmitted in one second (pps) Each pulse must be allowed to travel to the most distant object planned before 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 then the lower the PRF used.

b) 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 200nm?

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. 405pps,
3. 882pps,
4. 203nm

c) 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.

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8.8 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 8.4 shows the Plan Position Indicator (PPI) display and fig.8.5. 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 then the narrower will be the beam.

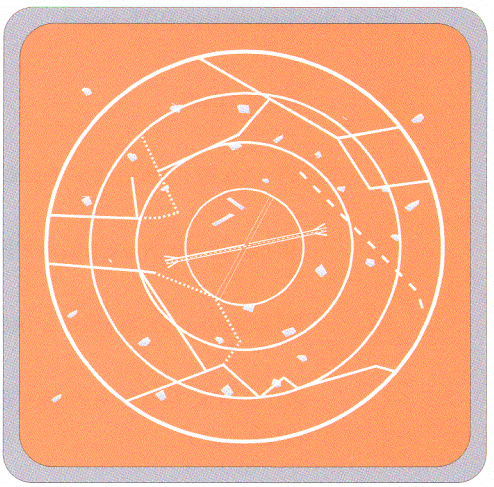

Figure 8.4. A PPI Display of Primary Raw Radar.

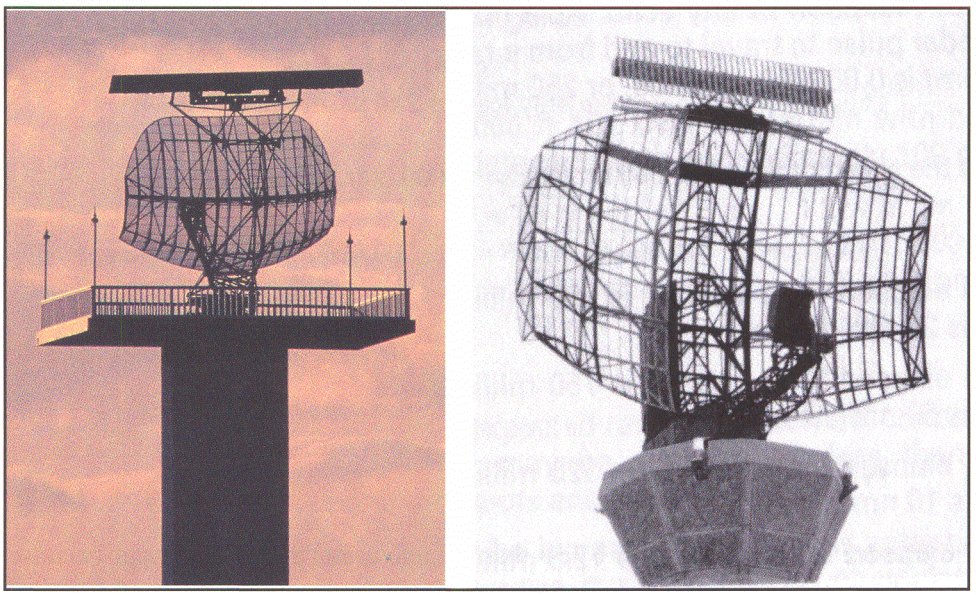

Figure 8.5. Typical Radar Antennae.

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8.9 THE RANGE OF PRIMARY RADAR

a) 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:

i) **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:

Theoretical range (nm) = $\sqrt[4]{}$ (power in watts).

i.e the power has to increased by a factor of 16 to double the range

ii) **Characteristics of reflecting objects.**

Metal is 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.

iii) **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:

$$\text{Max. Theoretical range (nm)} = 1.23 \times (\sqrt{Ht._1} + \sqrt{Ht._2})$$

$Ht._1$ = Height of radar station in feet amsl; $Ht._2$ = height of target in feet amsl.

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iv) **Wavelength and Attenuation by Raindrops**

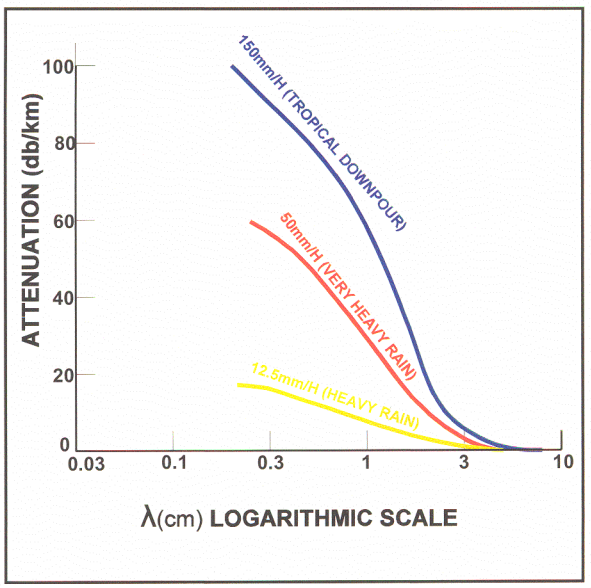

Figure 8.6. Attenuation by Raindrops.

It can be seen from Figure 8.6. 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.

v) **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** ie 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.

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b) Minimum Range.

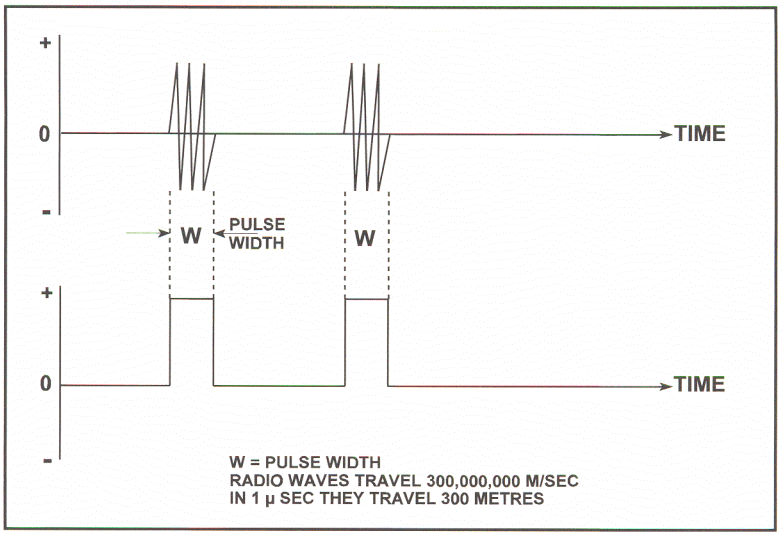

Figure 8.7. Pulse Width Decides Minimum Range.

Restoration time, a design factor that affects the time taken for a receiver to recover to normal after transmission has occurred, **and the pulse width decides the minimum range**. With reference to Figure 8.7., 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.

(1or 2μs are used for medium range radars and about 5μs for long range radars).

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

Answer: 3.3μs

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8.10 RADAR MEASUREMENTS

a) 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.

b) Range

This has already been discussed earlier.

c) Harmonisation

In order that bearing and range information can 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, focussing and transmission power.

8.11 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 ie 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.

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8.12 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'.

8.13 RADAR ANTENNAE

The **microwave horn**, **parabolic reflector** and **slotted planar array (or flat plate antenna)** shown in Figures 8.8 and 8.9 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 8.10 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.

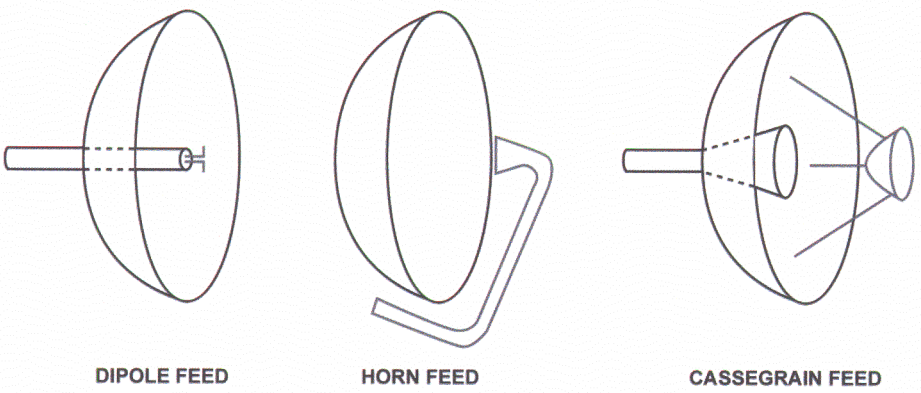

Figure 8.8. Radar Antennae

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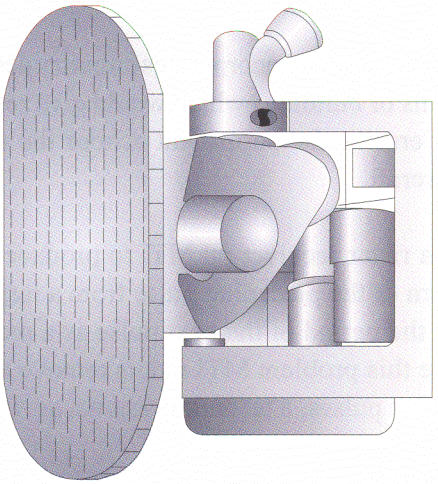

Figure 8.9 Airborne Weather Radar Antenna

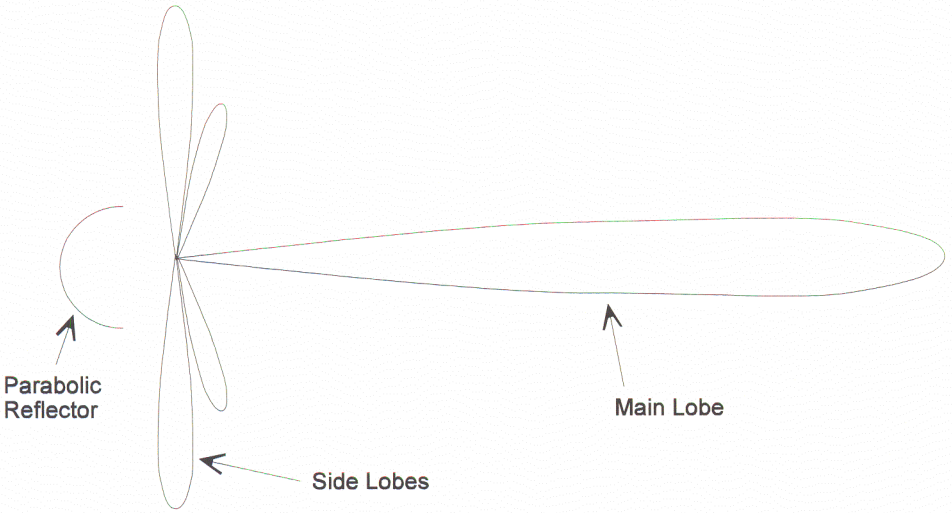

Figure 8.10 Typical Radiation Pattern

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CHAPTER NINE - GROUND RADAR

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9.1 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 :

a) En-Route Surveillance Radar (RSR)

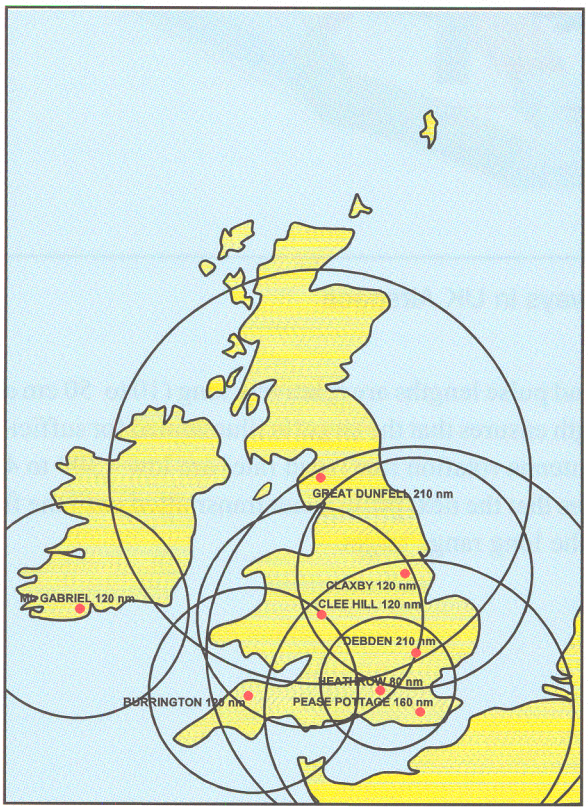
b) Terminal Area Surveillance Radar (TAR)

c) Precision Approach Radar (PAR)

d) Airport Surveillance Detection Equipment (ASDE)

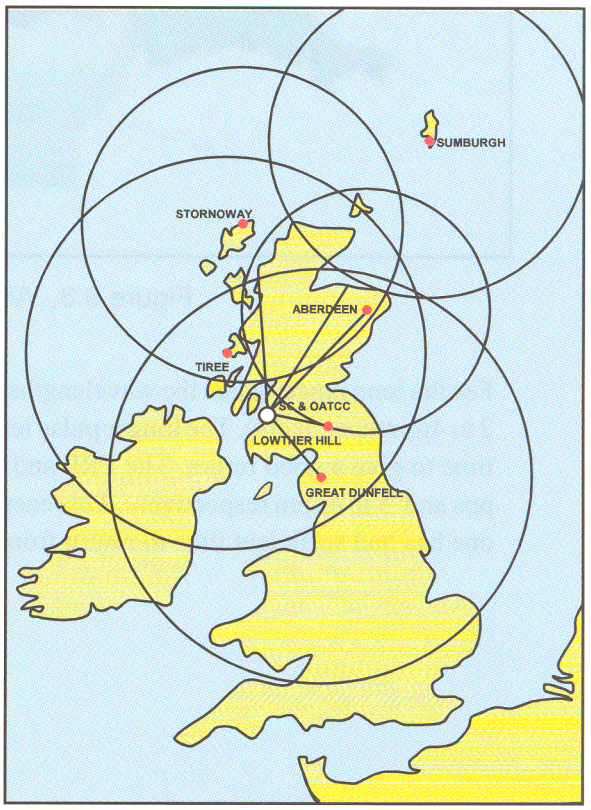
9.2 EN-ROUTE SURVEILLANCE RADARS (RSR)

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 9.1. and 9.2. show the locations and coverage of the London ACC and Scottish ACC radars and Figure 9.3 shows the UK Airways structure .



Courtesy of Airbus Industrie

Figure 9.1. Coverage of LACC Radars.



Courtesy of Airbus Industrie

Figure 9.2. Coverage of SACC Radars.

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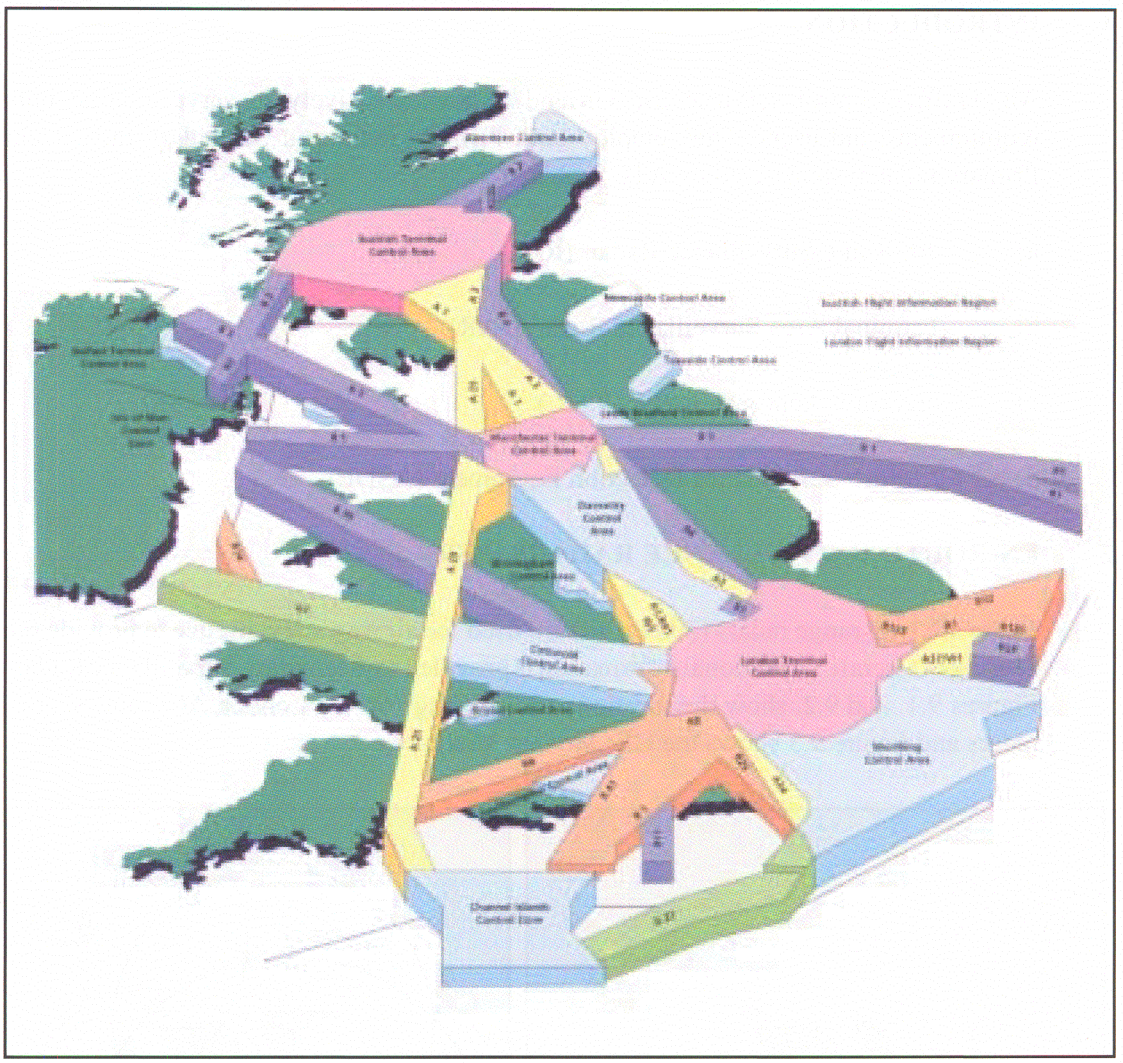

Figure 9.3. Airways in UK Airspace.

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.

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9.3 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.

9.4 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:

a) positional information and control of aircraft in the aerodrome vicinity, Approach radar (RAD)

b) Radar Vectoring to the ILS.

c) Surveillance Radar Approach (SRA)

9.5 RADAR VECTORING TO ILS

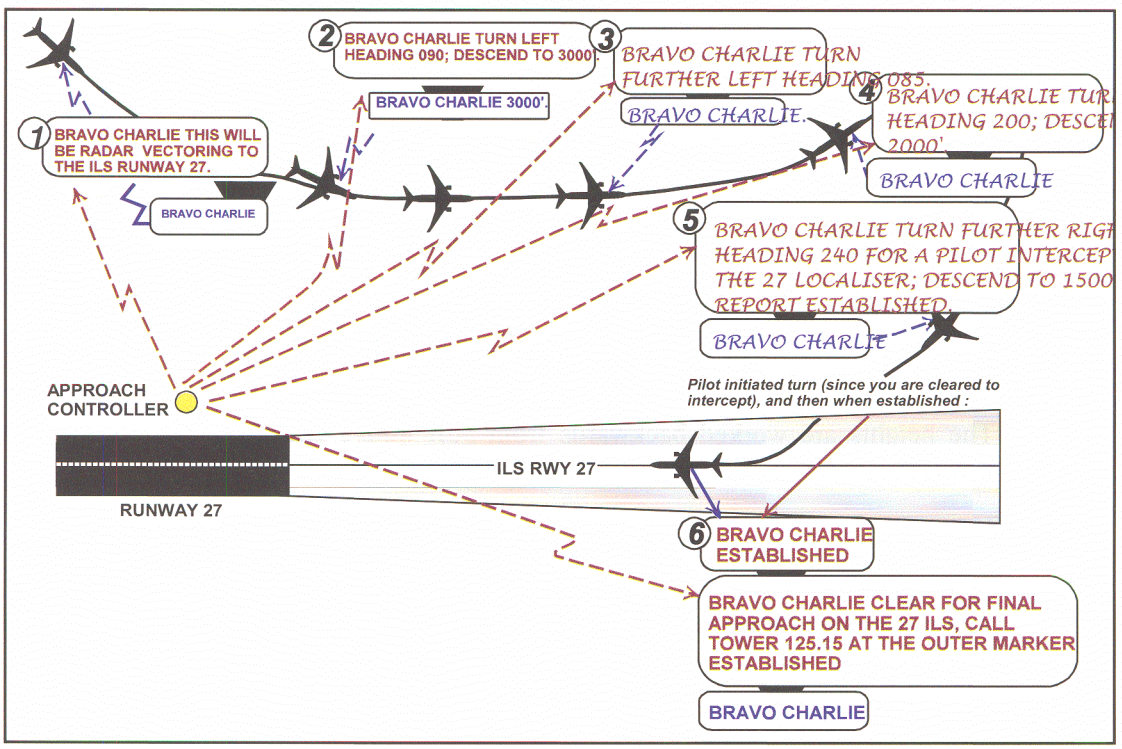

Figure 9.4. Radar Vectoring to ILS

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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.

9.6 SURVEILLANCE RADAR APPROACH (SRA)

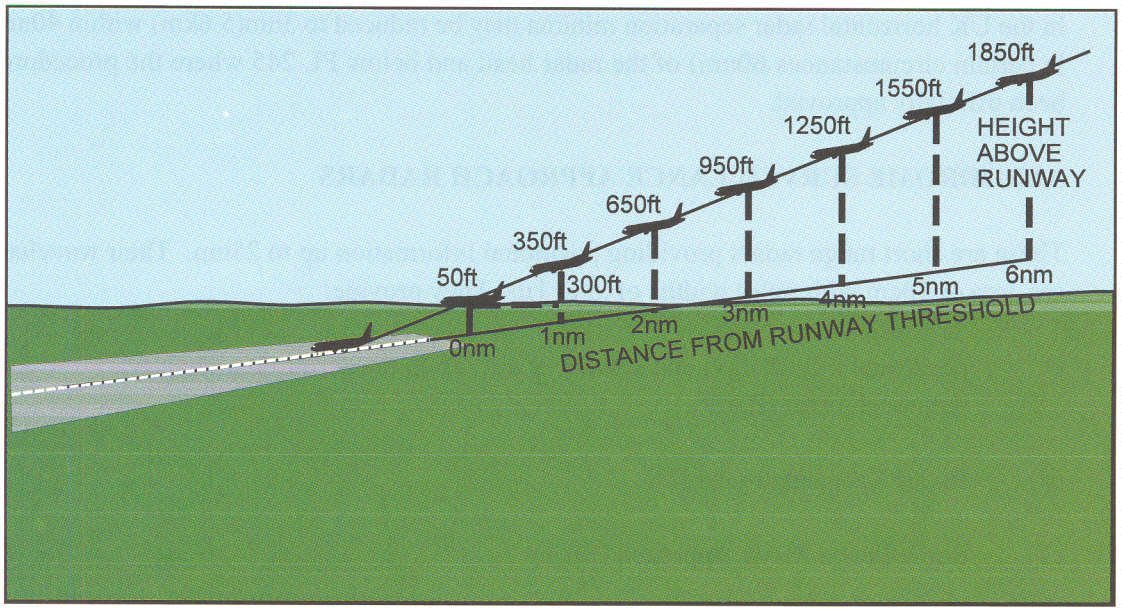

Figure 9.5. SRA Approach

a) Whilst the pilot flies the radar approach the controller passes him:

i) tracking instructions in the form of turns ro make and headings to fly:
"Turn right 5 degrees - Heading 265"

ii) descent instructions in the form of **advisory heights for range:**
"Range 5miles - height should be 1550"

b) The descent slope is usually 3° - approximately 300ft/nm

c) The heights are worked backwards from **50ft above the threshold which is the reference point**.

d) The heights are based upon **QFE**, usually.

e) **A non-high resolution Surveillance Radar Approach** shall be terminated **2nm before touchdown** except where a termination range of 1nm has been specially approved.

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9.7 HIGH RESOLUTION SURVEILLANCE RADAR

Certain approved Surveillance Radar Equipments (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:

a) There is a **continuous talkdown from 4nm** with **ranges and advisory heights** being given **every .5nm.**

b) The approach controller providing final approach guidance is allocated full time to the task.

c) 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.**

9.8 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 9.6. 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 eg."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 9.7.

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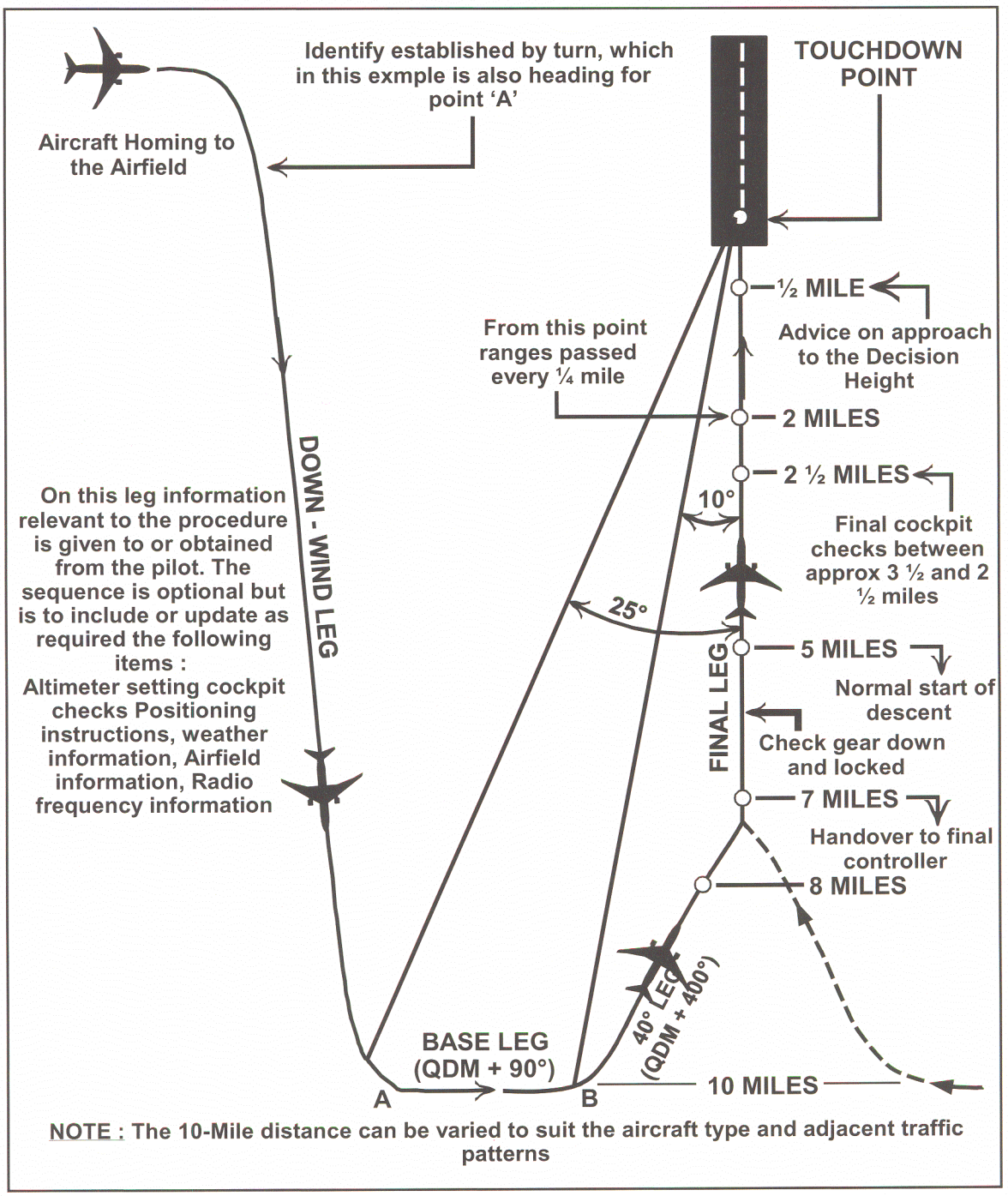

Figure 9.6. The PAR Approach.

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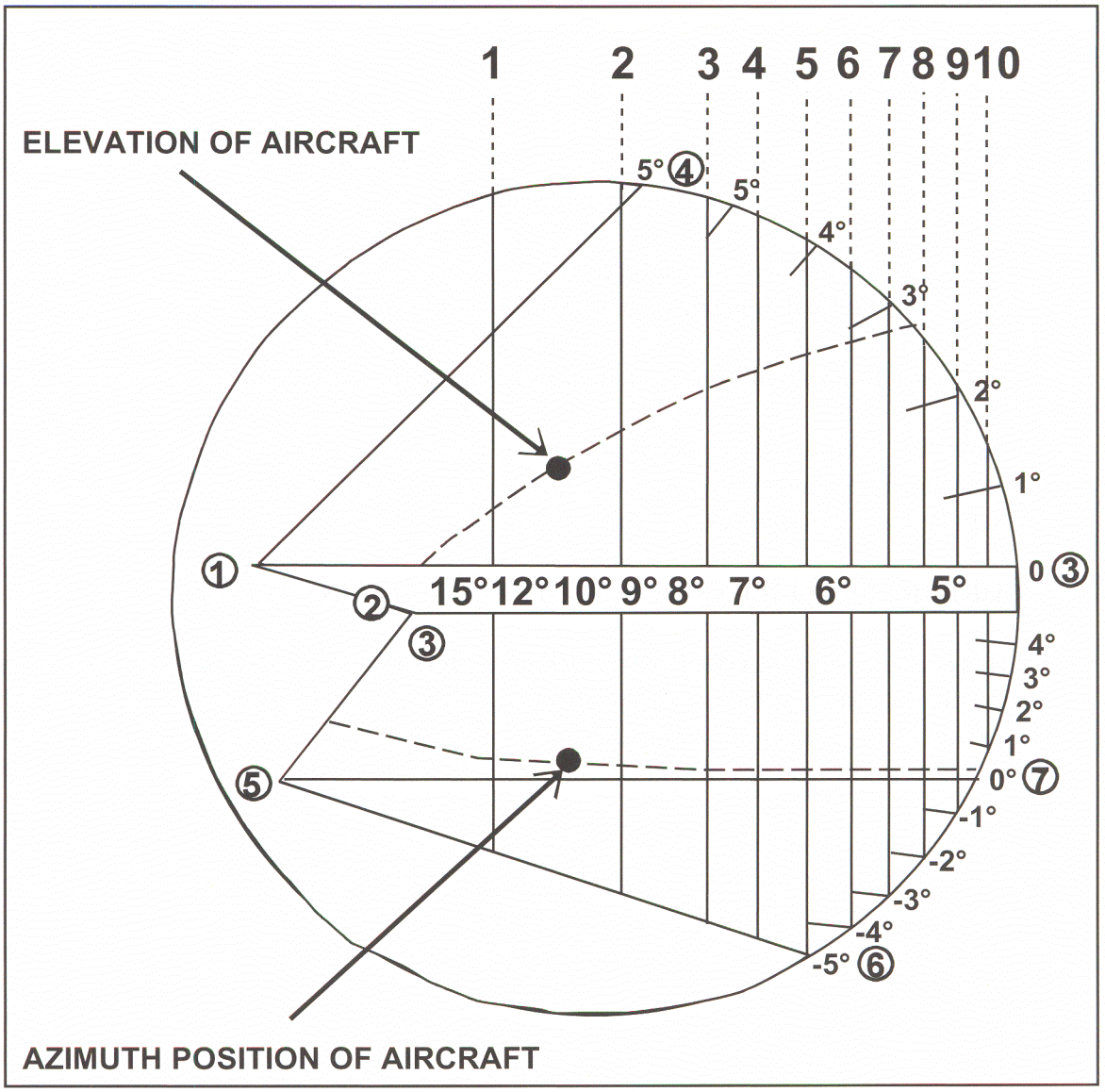

Figure 9.7. The PAR Display

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9.9 USE OF QFE / QNH APPROACH AND LANDING

When an aircraft is descended 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.

9.10 AIRPORT SURVEILLANCE DETECTION EQUIPMENT (ASDE)

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 feature leaving
targets on runways and taxi-ways, etc.,clearly visible. This is shown if Figures 9.8. and 9.9; the aircraft taking-off is a DC9.

The very high definition required by these radars is achieved by designing a radar with:

a) a very narrow beam in the order of .25° to 1°.

b) a scanner rotation rate of 60rpm.

c) a PRF in the order of 4000 to 20000pps.

d) pulse widths in the order of .03 µsec.

e) frequencies of 15 to 17 Ghz (SHF), 2 to 1.76cm wavelengths.

f) ranges of 2.5 to 6nm in light precipitation.

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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.

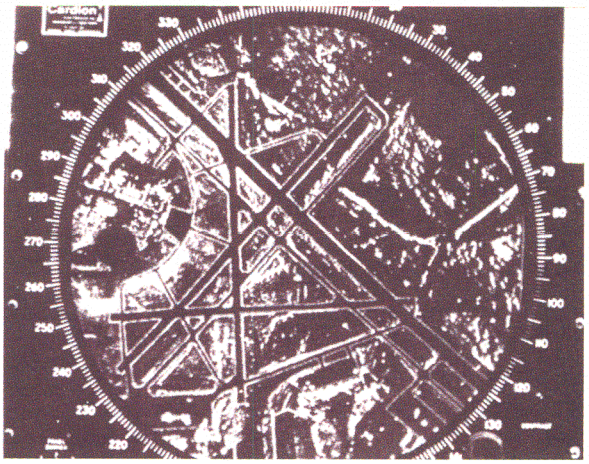

Figure 9.8. ASMI with fixed features.

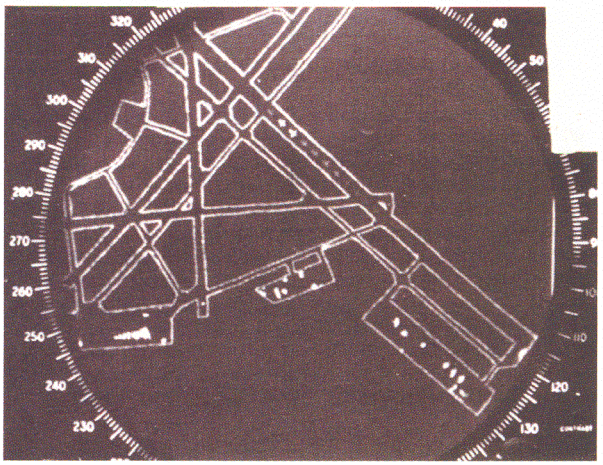

Figure 9.9 Processed ASMI with DC9 taking off.

9.11 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.

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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

9.12 QUESTION PAPER (PRINCIPLES AND GROUND RADAR)

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

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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.

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ANSWER SHEET

QUESTION	ANSWER
01	a
02	b
03	b
04	a
05	a
06	a
07	b

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CHAPTER TEN - AIRBORNE WEATHER RADAR

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10.1 INTRODUCTION

Airborne weather radar (AWR) is used to provide the pilots with information regarding both 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 and red heavy ground returns.

10.2 COMPONENT PARTS

The airborne equipment comprises:

a) Transmitter/receiver. (Figure 10.1.)

b) Antenna, which is **stabilised in pitch and roll**. (Figure 10.1.)

c) Indicator. (Figures 10.1, 10.2, 10.3 and10. 4.)

d) Control unit. (Figure 10.1. and 10.5.)

10.3 AWR FUNCTIONS

The main functions of an AWR are to:

a) **detect the size of water droplets** and hence deduce where the areas of turbulence are within the cloud

b) **determine the height of cloud tops** by tilting the radar beam up or down

c) **map the terrain** below the aircraft to provide navigational information and high ground avoidance

d) **provide a position fix (range and bearing)** from a prominent feature.

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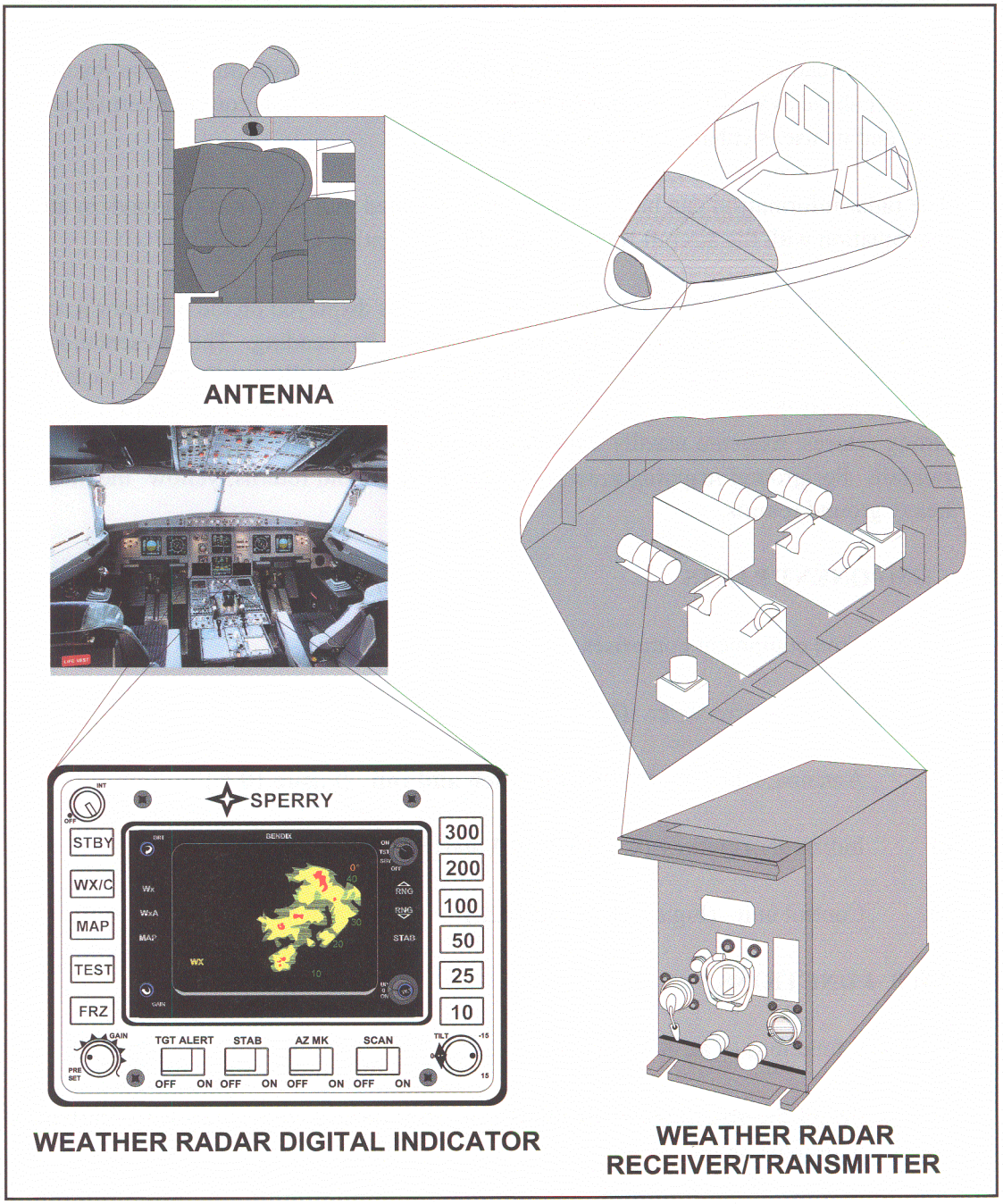

Figure 10.1. AWR Components.

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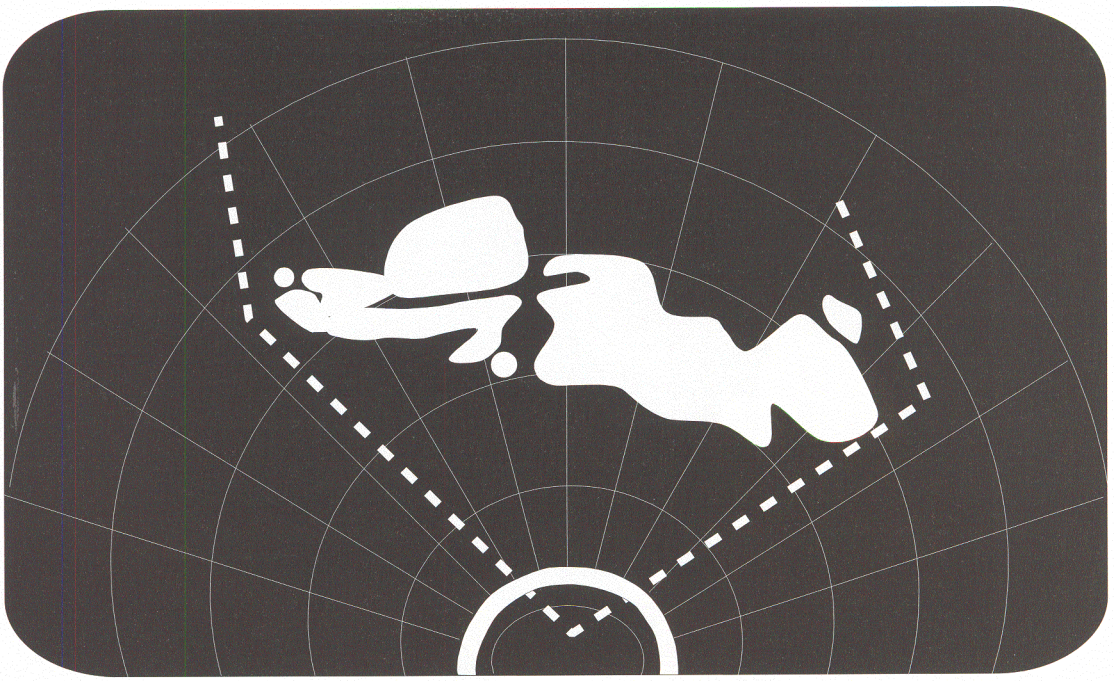

Figure 10.2. Monochrome Cloud Display And Avoidance Courses.

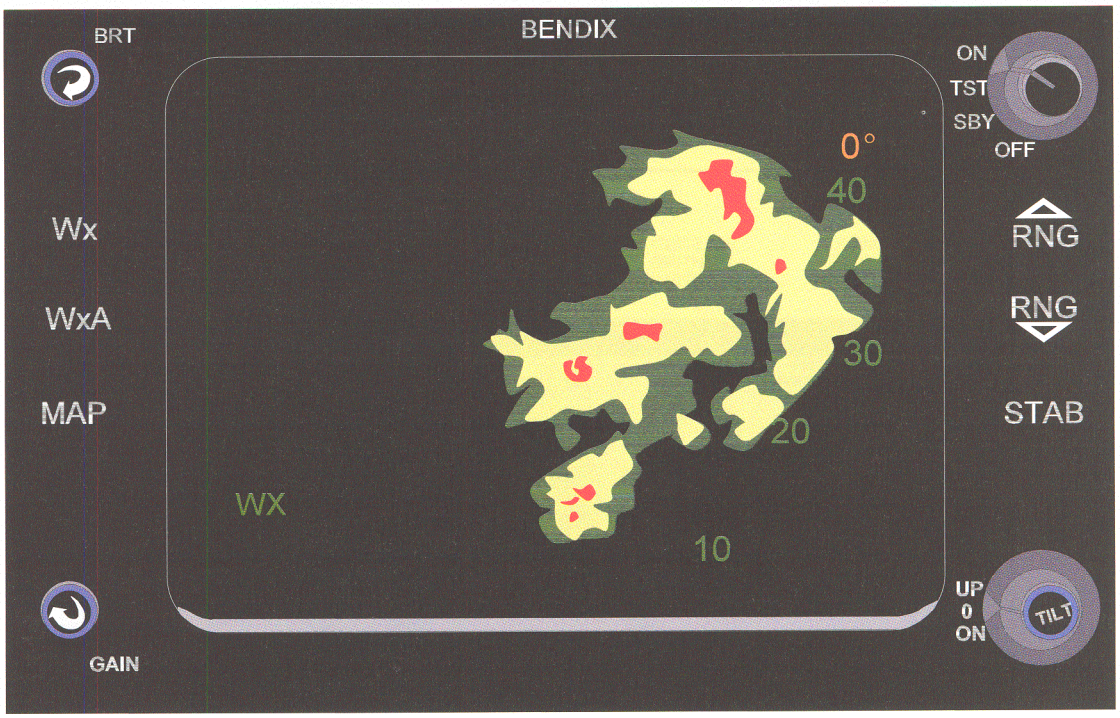

Figure 10.3. Colour Weather Display.

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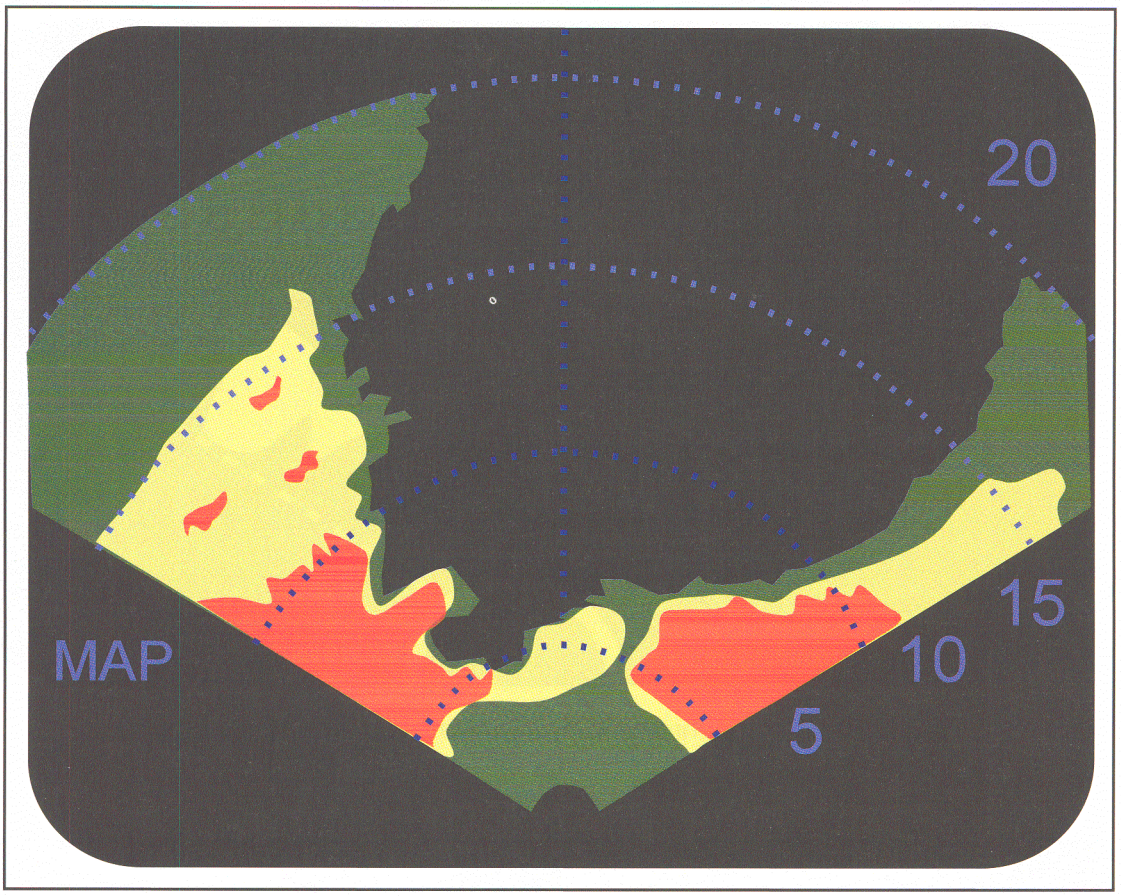

Figure 10.4. Terrain Mapping Display.

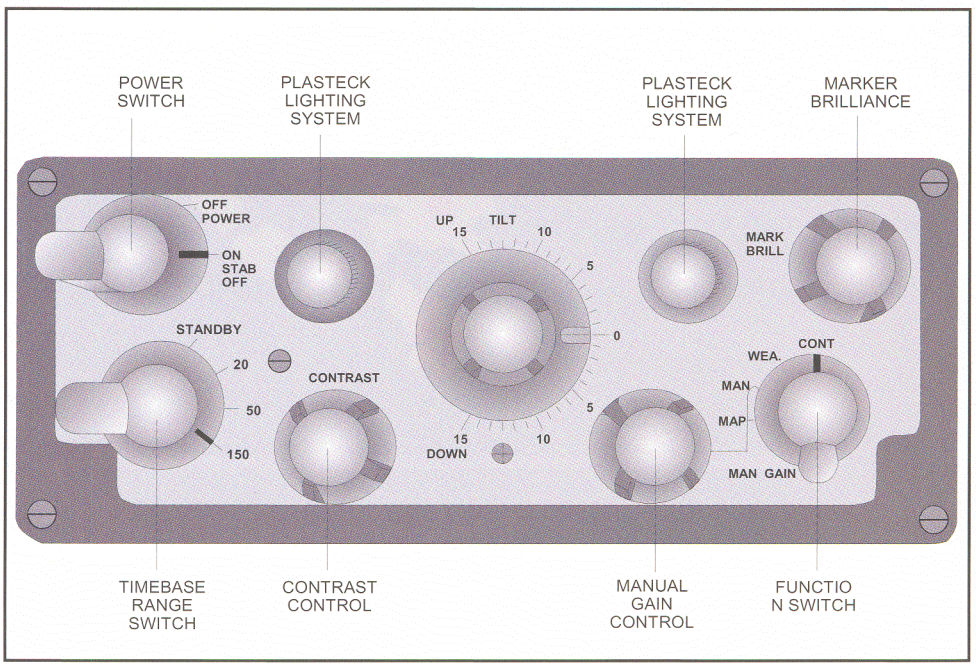

Figure 10.5. Control Unit.

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10.4 PRINCIPLE OF OPERATION

a) 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 10.10). 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.

b) 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 lob-sided during manoeuvres.

c) 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. Two clouds at say 100nm might appear as one large return until, at a closer range, they are shown correctly in figure 10.6, 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**.

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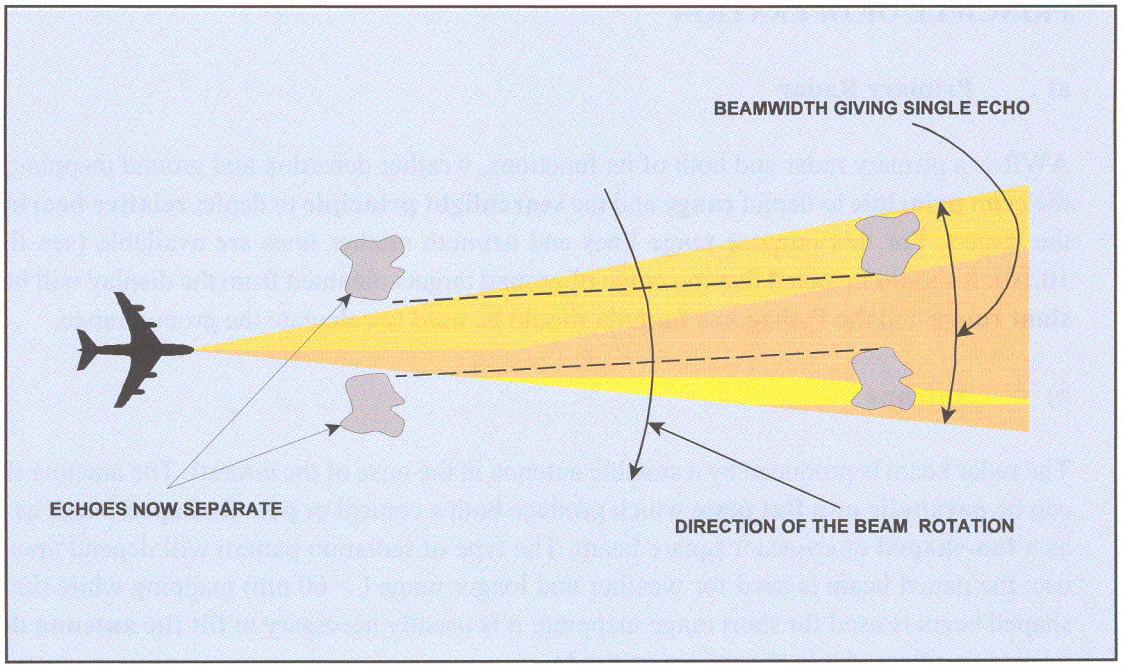

Figure 10.6. Effect Of Beam Width.

d) **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:

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

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 from to highlight the area of turbulence.

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e) **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 10.7. shows the coverage for a 3° beam at various ranges. The area illuminated by the beam increases with range.

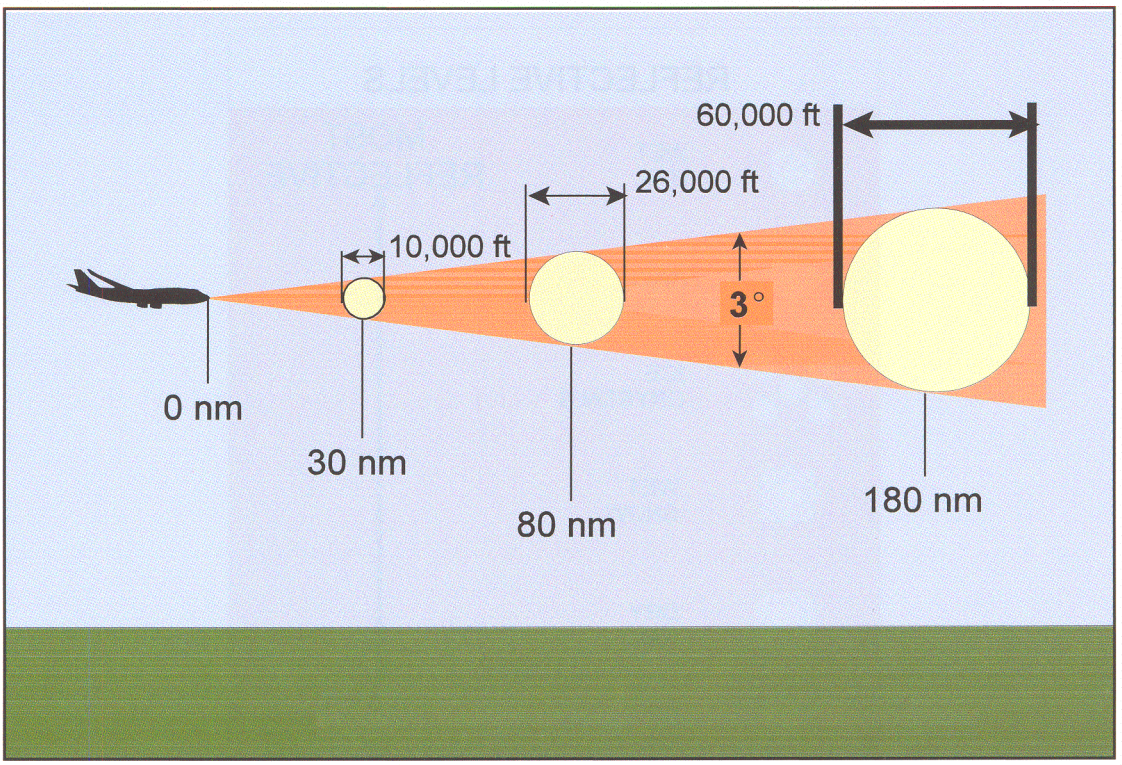

Figure 10.7. Radar Beam Coverage At Varying Ranges.

f) **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.

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10.5 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 10.8. depicts the reflective levels of different precipitation types. For a given transmission power a 3cm wavelength will give the best returns from large water droplets. Wavelengths of **10cm and above produce few weather returns.**

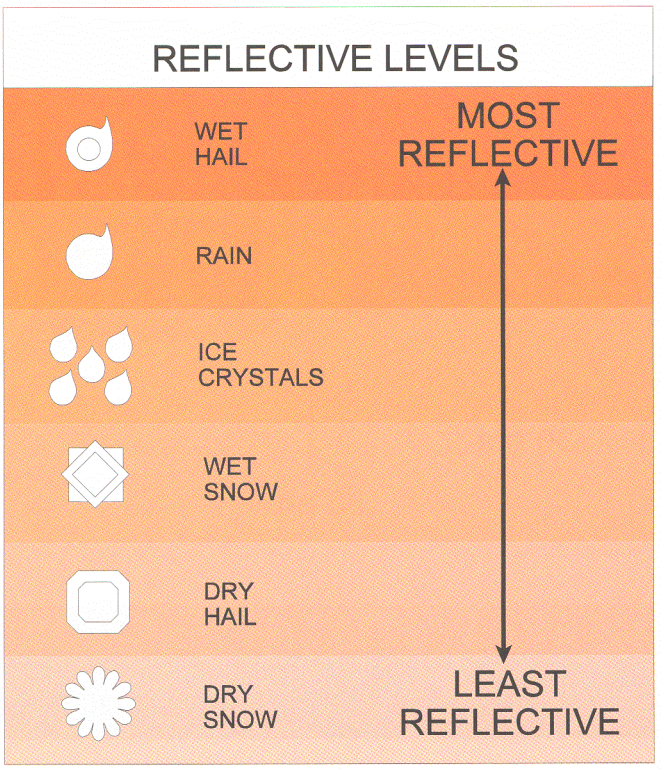

Figure 10.8. Reflective Levels.

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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 10.9 : **U-shapes, Fingers, Scalloped edges and Hooks**. These are areas to avoid.

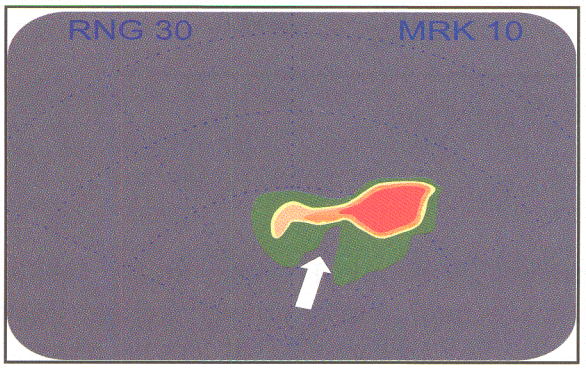

Figure 10.9a. U-Shape indicating Hail Activity.

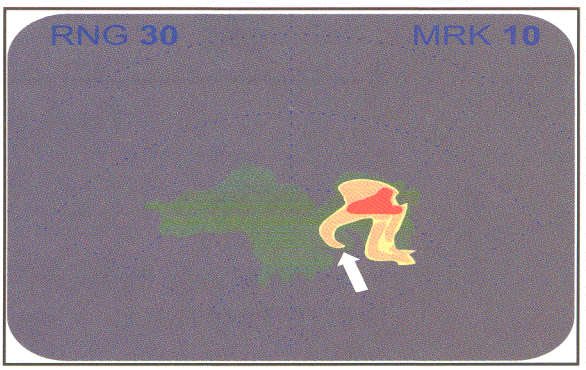

Figure 10.9b. Finger indicating Hail Activity.

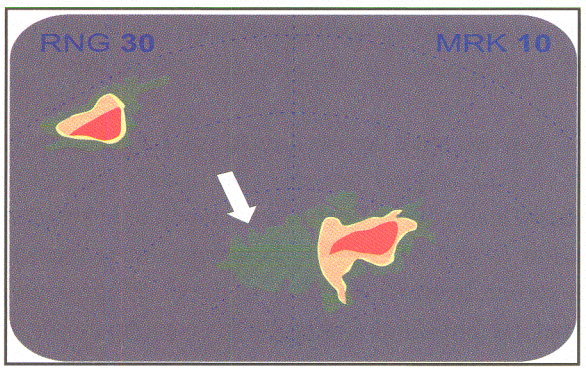

Figure 10.9c. Scalloped Edge indicating Hail Activity.

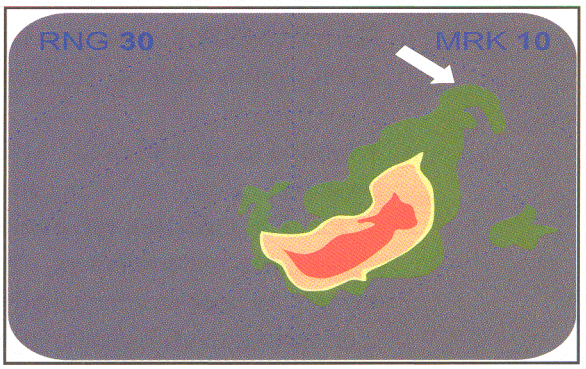

Figure 15.9d. Hook indicating Hail Activity.

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10.6 MONOCHROME CONTROL UNIT

Figure 10.10 illustrates a basic control unit for a monochrome AWR with range scales 20, 50 and 150nm; its various functions are described below.

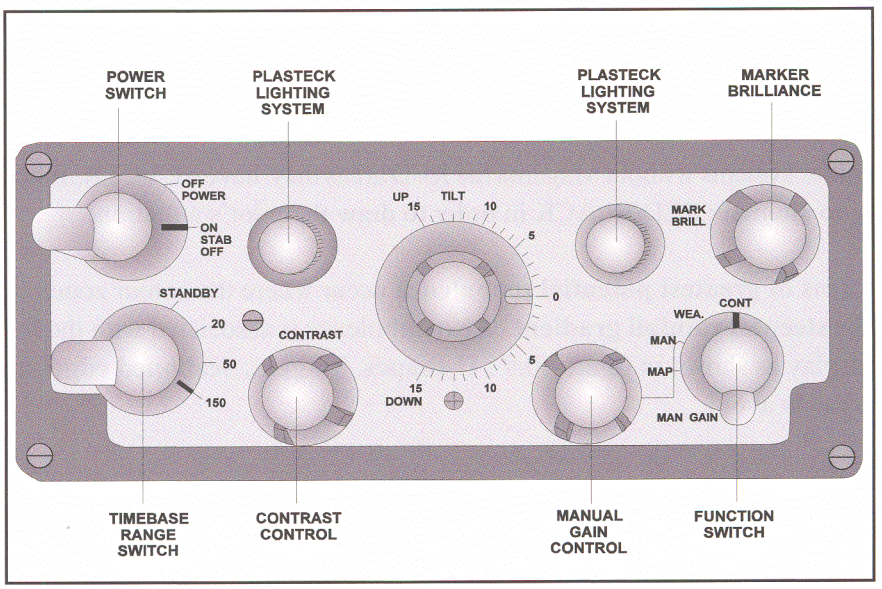

Figure 10.10. Control Unit.

a) **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.**

b) **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.

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c) **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 10.11).

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 10.12.

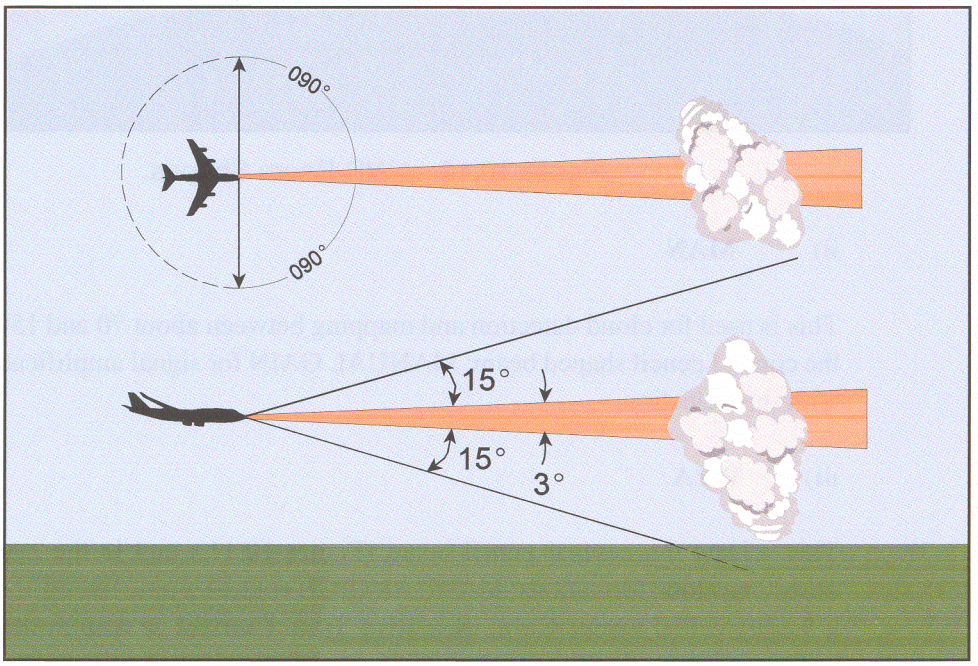

Figure 10.11. Projected Radar Beam and Tilt Angle.

d) **Function Switch**

i) **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.

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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 10.12.

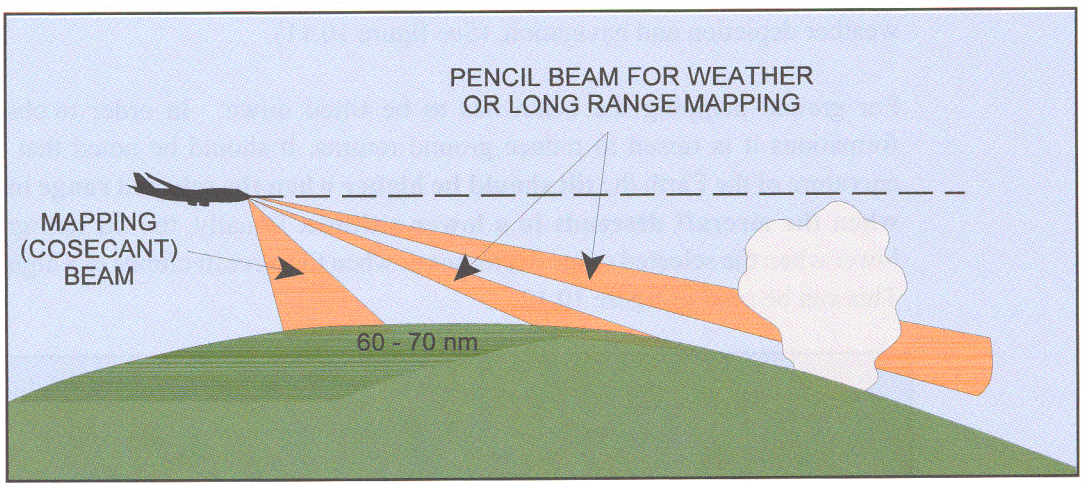

Figure 10.12. AWR Beam Shapes.

ii) **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.

iii) **WEA**

This selects the conical pencil beam (Figure 10.11.) 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.

iv) **CONT**

Figure 10.13. 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 10.14. shows the same cloud formation with CONT deselected. The position, therefore, is used to indicate storm intensity, turbulence and areas to avoid.

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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.

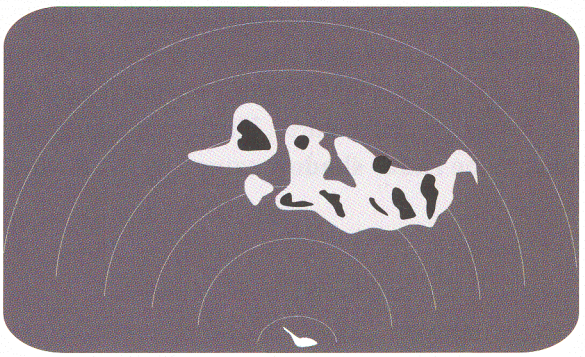

Figure 10.13. Typical Cloud Display With Contour On.

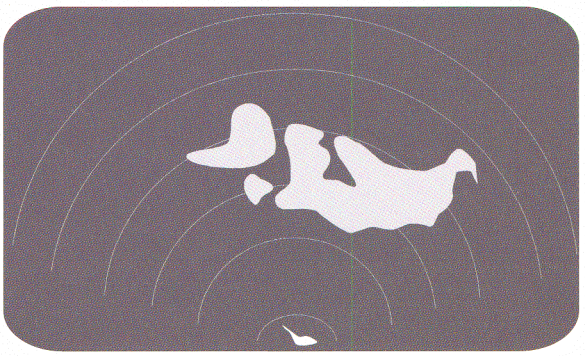

Figure 10.14. Typical Cloud Display With Contour Off.

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10.7 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 10.15).

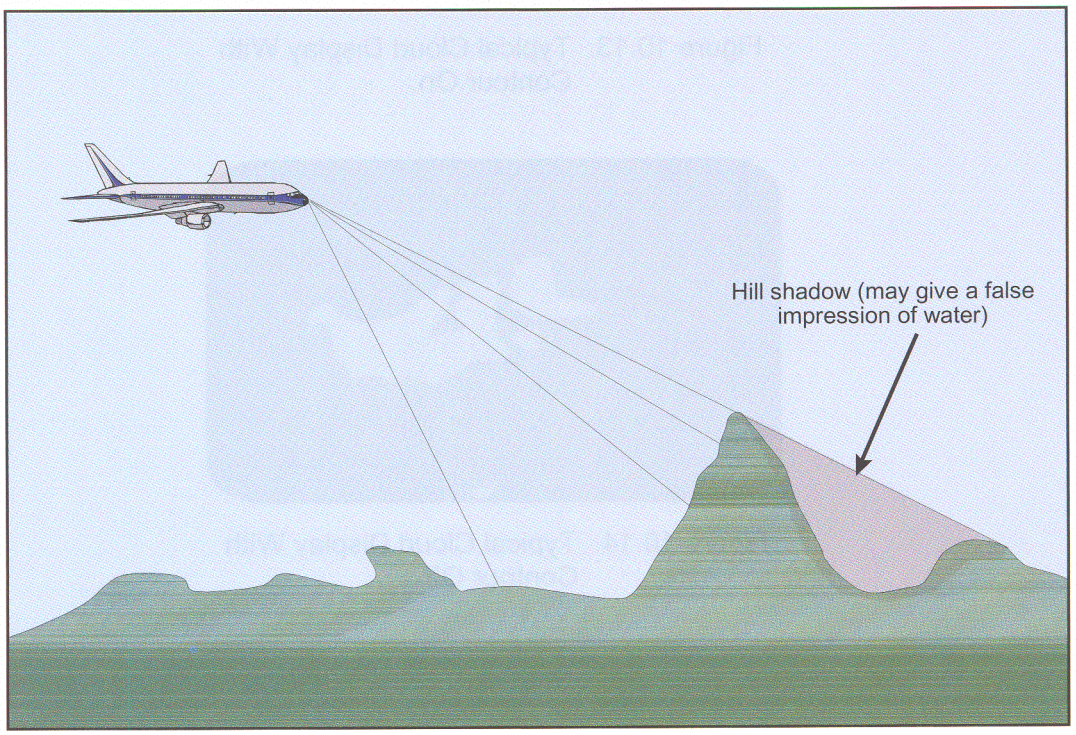

Figure 10.15. Hill Shadow.

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10.8 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 10.16.)

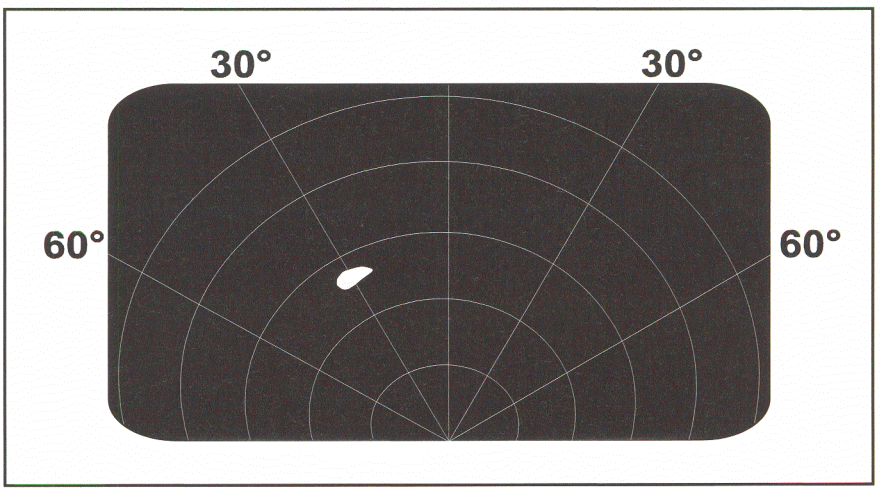

Figure 10.16. 0 - 25 Scale.

An aircraft at 42560' is heading 216°(M); variation is 17° East.

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

True heading =

True bearing TO island =

QTE to plot =

Ground Range (nm) = $\sqrt{(S^2 - H^2)}$

=

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

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10.9 WEATHER OPERATION

a) 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.

b) 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.

c) 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.

d) 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.

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10.10 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:

a) **Test**

This displays the colour pattern for pre-flight serviceability check. (Figure 10.17.)

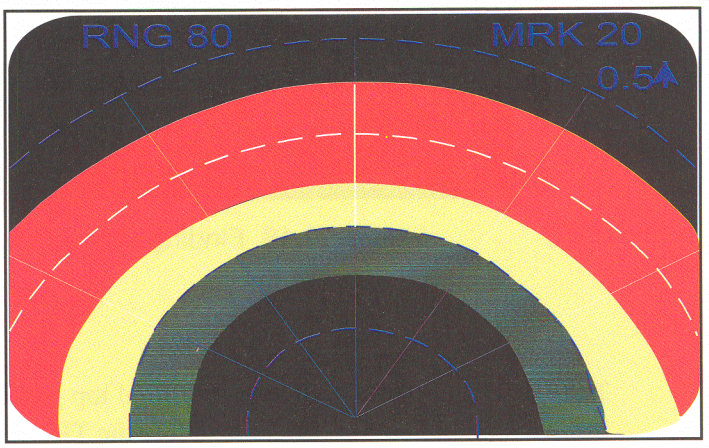

Figure 10.17. Typical Radar System Test Pattern for PP1 Indicators.

b) **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.

c) **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.

d) **Fault**

This is controlled by a fault monitoring circuit and FAULT flashes on the screen if there is a power or transmitter failure.

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10.11 APPENDIX 10A: CALCULATING APPROXIMATE CLOUD HEIGHT

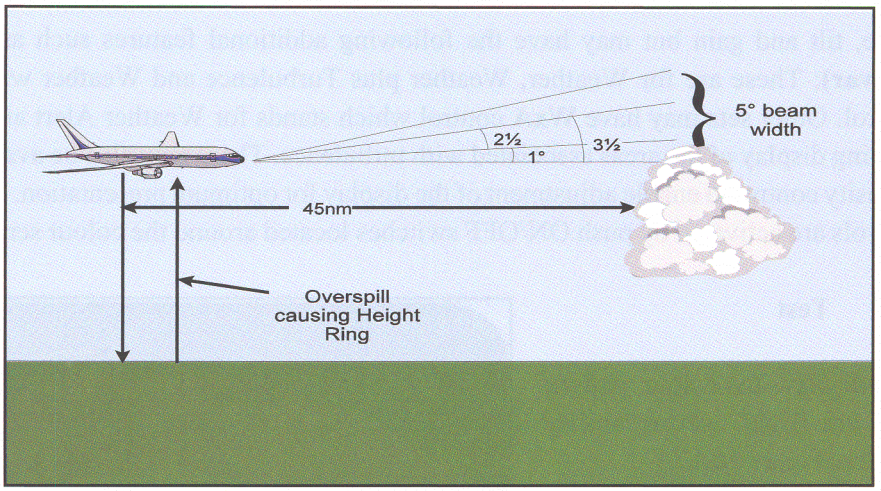

Figure 19.18 Finding Cloud Height using 1 in 60 rule.

Tilt the beam up or down until the cloud top just disappears from the screen; the base of the beam is directly on the cloud top. Note the TILT angle and the range of the cloud.

Example: Tilt angle 3.5°; beam width 5°; range 45nm;

Use the 1 in 60 rule to obtain the height.

From the diagram the cloud top elevation is seen to be 1° relative to the aircraft's horizontal.

$$\therefore \text{ Relative cloud height} = \frac{1 \times 45 \times 6080}{60} = 4560\text{ft.}$$

Depending upon whether QNH or 1013.2mb is set on the aircraft's altimeter the cloud top's relative height may be converted to an altitude or flight level.

Tilt Angle **UP:**

Elevation Angle of Cloud Top = TILT ANGLE - ½ BEAM WIDTH.

If the angle is + then the cloud top is above your level; if - , then the cloud is below you.

Tilt Angle **DOWN:**

Elevation Angle of Cloud Top = TILT ANGLE + ½ BEAM WIDTH.

The cloud will be below your level.

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10.12 AWR SUMMARY

Components	Tx / Rx, antenna, indicator, control unit.
Functions	Turbulence, navigation
Principle of Op.	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

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10.13 QUESTION PAPER

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 30^0 right bearing line and the 10 nm range marker of an airborne weather radar. If the heading is 045^0(T) and the aircraft is at flight level 360 what range and bearing should be plotted in order to obtain a fix?

   a) 10nm 030^0(T)
   b) 10nm 075^0(T)
   c) 8nm 075^0(T)
   d) 8nm 255^0(T)

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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 017^0(T) has a small island showing on the AWR at 45nm range on the 60^0 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 12^0W. 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.

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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 60^0 left bearing line and 15nm range arc of an airborne weather radar. If the aircraft's heading and height are 035^0(M) and 42500ft what QTE and range should be plotted in order to obtain a fix from the island ? (variation is 20^0W)

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.

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16. The beam width of a radar transmitter with a frequency of 9.4 Ghz and an antenna diameter of 15" would be:

a) 5°
b) 6°
c) 7°
d) 8°.

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AWR ANSWERS

QUESTION	ANSWER
01	b
02	a
03	b
04	d
05	d
06	c
07	b
08	d
09	b
10	c
11	a
12	c
13	b
14	c
15	d
16	b

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CHAPTER ELEVEN - SECONDARY SURVEILLANCE RADAR

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11.1 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 has already been discussed in chapter 4.

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.

11.2 ADVANTAGES OF SSR

SSR has the following advantages over primary radar. It :

a) requires much less transmitting power to provide coverage up to 200 to 250nm.

b) is not dependent on an aircraft's echoing area or aspect.

c) gives clutter free responses as it is does not rely on returning reflected pulses.

d) positively identifies an aircraft's primary response by displaying its code and call sign alongside.

e) indicates an aircraft's track history, speed, altitude and destination.

f) 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 11.1 and 11.2.

11.3 SSR DISPLAY

Ths SSR information is displayed in combination with the primary radar information on the same screen as shown in figure 11.3. This includes the callsign or flight number, pressure altitude or flight level, ground speed and destination.

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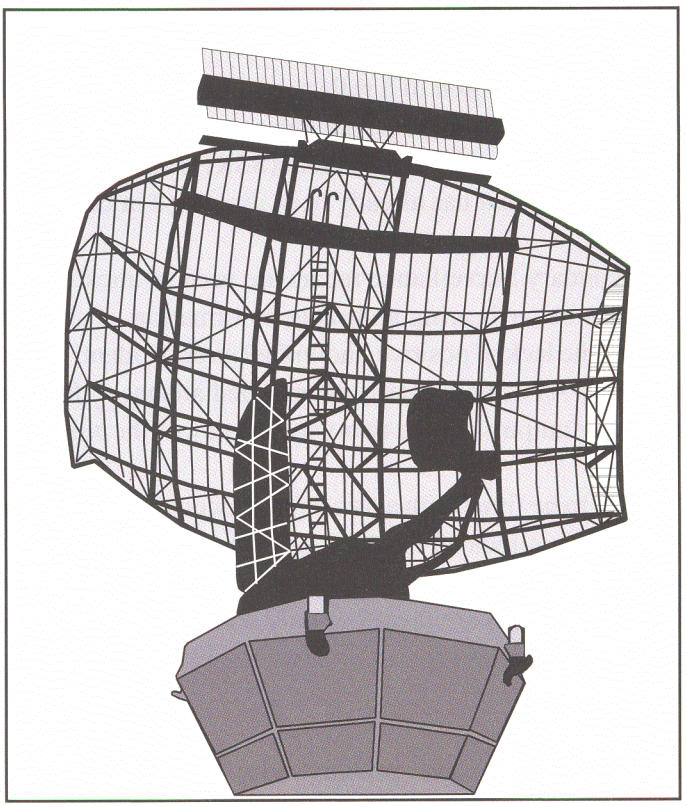

Figure 11.1. SSR aerial mounted on top of a 23cm Primary Radar aerial.

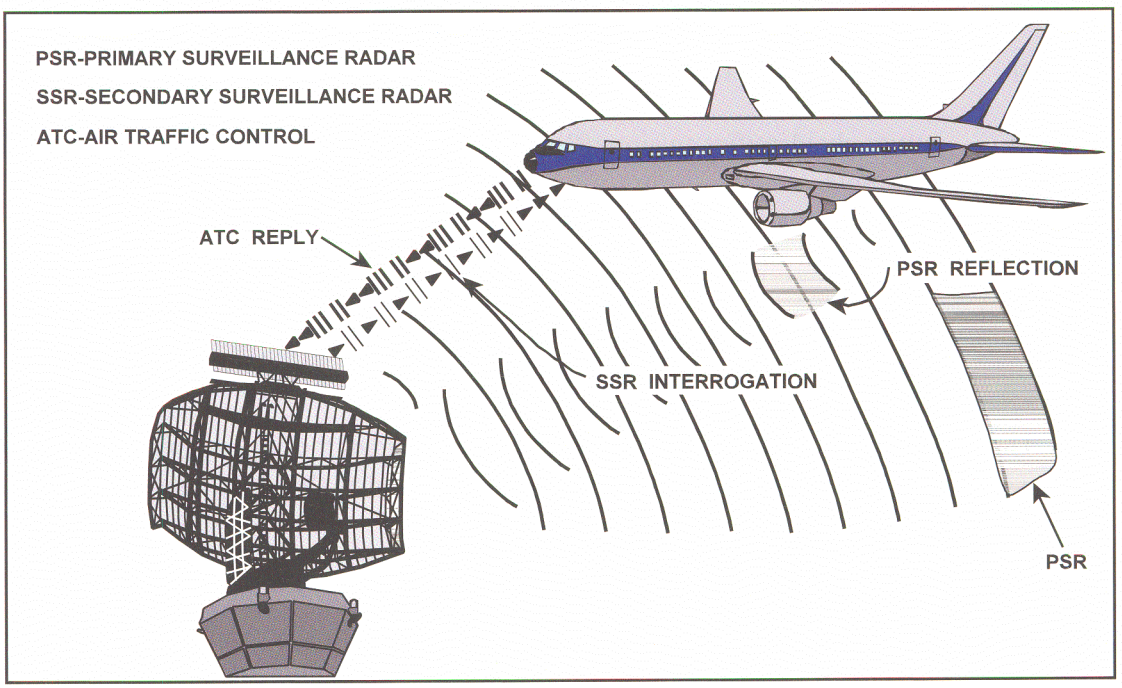

Figure 11.2. Primary and Secondary Radar used for ATC.

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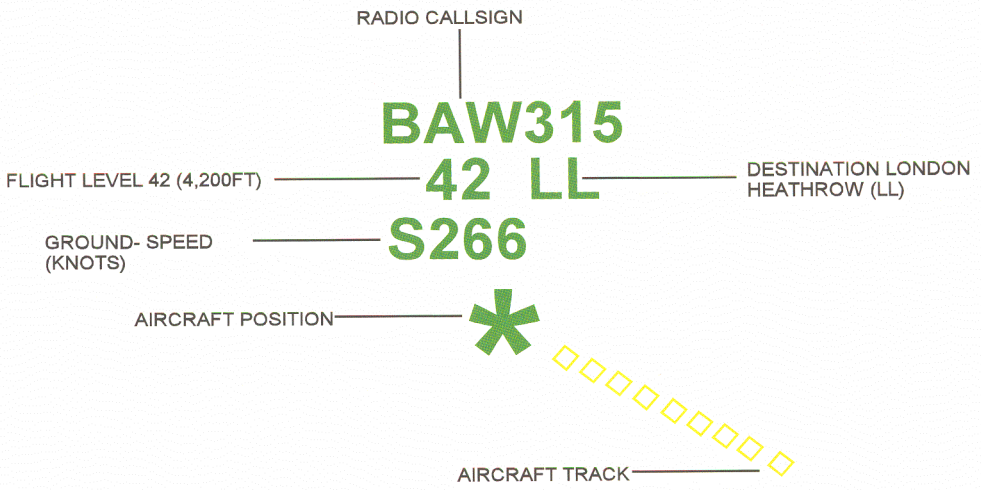

THE CALLSIGN, FLIGHT LEVEL AND DESTINATION OF AN AIRCRAFT AS THEY APPEAR ON THE RADAR DISPLAY.

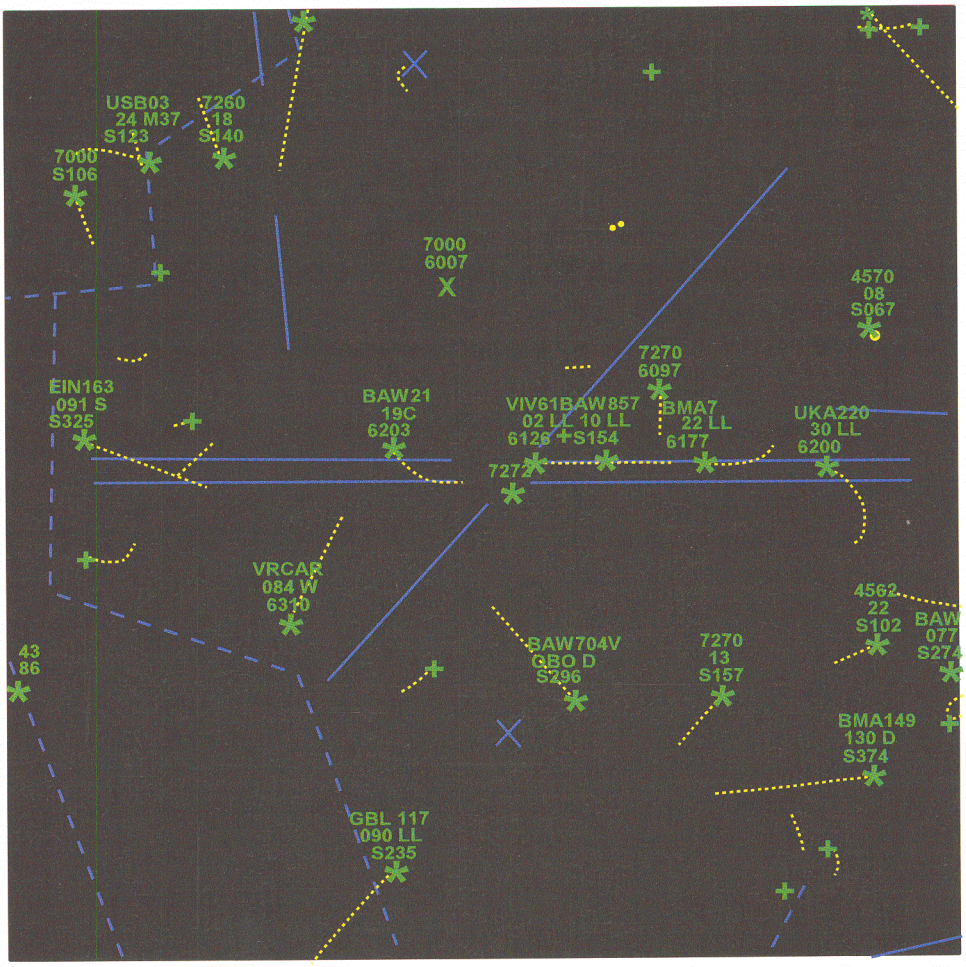

Figure 11.3. A Radar Display Showing Positions of Aircraft in the London TMA.

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11.4 SSR FREQUENCIES AND TRANSMISSIONS

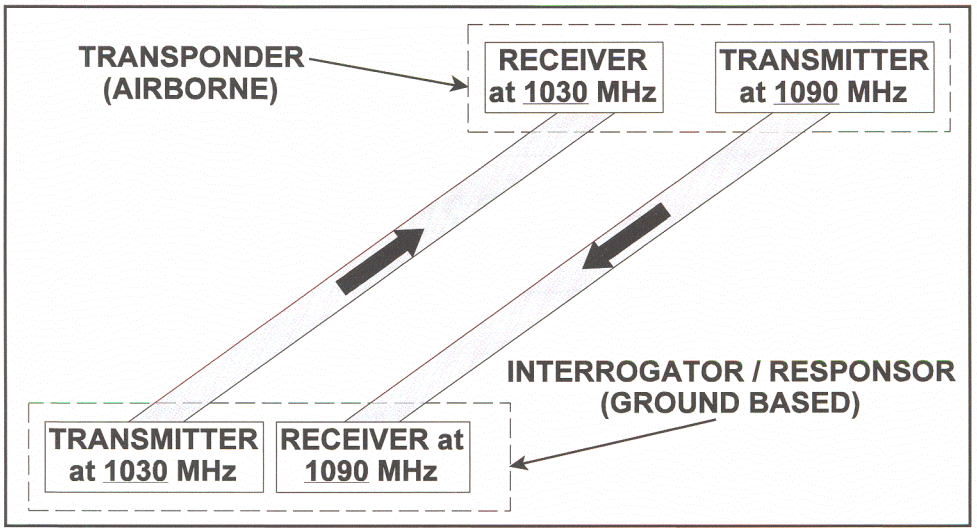

Figure 11.4. SSR operates in the UHF Band.

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.

11.5 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:

a) **Mode A** - an interrogation to **identify** an aircraft

b) **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.

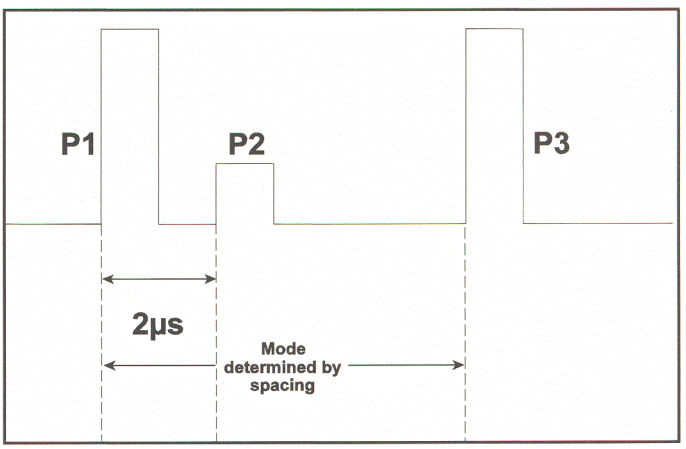

Figure 11.5. Modes.

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11.6 REPLY PROCESS

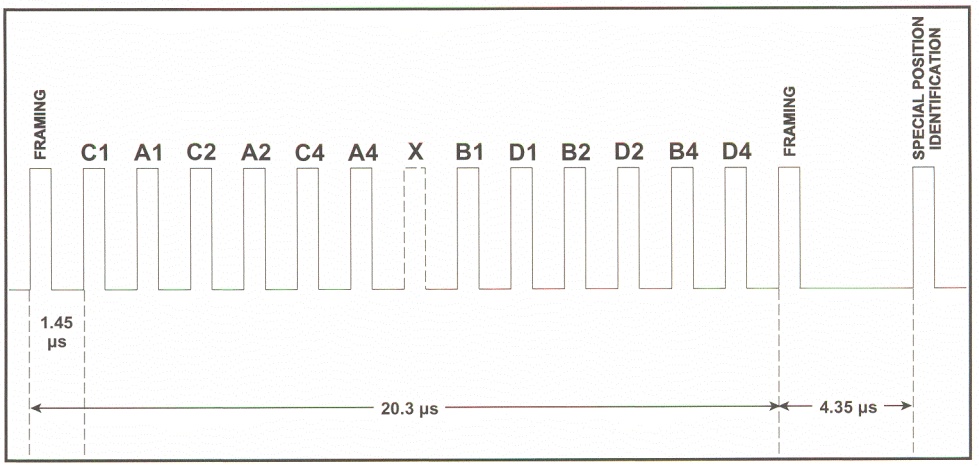

Figure 11.6. SSR Reply Pulse Patterns.

The aircraft transponder will reply correctly to an Mode A or C interrogation provided the pilot has selected correctly the mode and code allocated by ATC. On receiving a valid interrogation the aircraft transponder transmits **two framing pulses**, F_1 and F_2, 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 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**".

A transponder is shown at Figure 11.7.

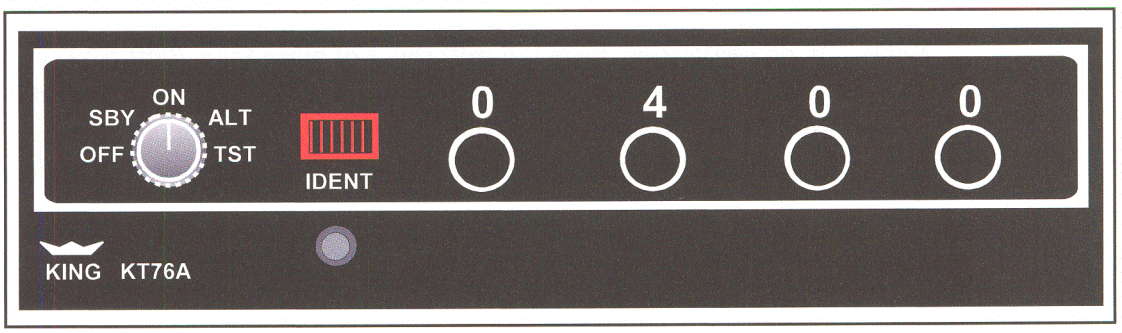

Figure 11.7. Transponder Controls and Indicators.

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11.7 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 50' 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 drifts now downwards, then, as it passes from 6450' to 6445' the coded transmission changes and results in 064 being indicated at the controller's consol.

11.8 SSR OPERATING PROCEDURE

Pilots **shall**:

a) 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

b) select or reselect codes, or switch off the equipment when airborne only when instructed by an ATS Unit

c) acknowledge code setting instructions by reading back the code to be set

d) select Mode C simultaneously with Mode A unless otherwise instructed by an ATS unit

e) 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: If, on verification, there is **a difference of more than 200ft** 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.

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11.9 SPECIAL CODES

a) Special Purpose Codes

Some codes are reserved internationally for special purposes and should be selected as follows:

i) **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.

ii) **7600.** To indicate a radio failure.

iii) **7500.** To indicate unlawful interference with the planned operation of the flight, unless circumstances warrant the operation of code 7700

iv) **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.

MODE C should be operated with all of the above codes.

b) Conspicuity Code in the UK

When operating at and **above FL100** pilots shall select code **7000** and Mode C except:

i) when given a different setting by an ATS unit

ii) 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.

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11.10 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:

a) **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 under1.7 nm in terms of radar miles.]

b) **Fruiting**

This is interference at one interrogator caused by replies from a transponder responding to interrogations from another.

c) **Availability of codes**

Only **4096** identification codes are available in Mode A.

d) **Ghost targets**

These are due to reflections from obstacles or high terrain.

e) **Shielding**

When the aircraft is banked the antenna is shielded, resulting in loss of signals.

11.11 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. Current planning envisages **1 January 2001** as the earliest date for which the carriage and operation of Mode S is required for the Initial Implementation in Europe.

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The main features of the new **mode S** are:

a) **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.

b) **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.**

c) **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.

d) **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.

e) **Interrogation Modes**

Mode S operates in the following modes:

i) **All Call** - to elicit replies for acquisition of mode S transponders

ii) **Broadcast** - to transmit information to all mode S transponders (no replies are elicited).

iii) **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.

iv) **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.

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11.12 BENEFITS OF MODE S

a) **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.

b) **Improved Integrity of Surveillance Data**

The superior resolution ability of Mode S plus selective interrogation will:

i) eliminate synchronous garble.
ii) resolve the effects of over interrogation.
iii) simplify aircraft identification in the case of radar reflections.

c) **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.

d) **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.

e) **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.

f) **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.

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11.13 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)

a) **Basic Functionality**

i) Automatic reporting of Flight Identity(callsign used in flight).

ii) Transponder Capability Report.

iii) Altitude reporting in 25ft intervals (subject to aircraft availability).

iv) Flight Status (airborne/on the ground)

b) **Enhanced Functionality**

i) Magnetic heading.

ii) Speed (IAS/TAS/Mach No).

iii) Roll Angle (system acquisition of start and stop of turn).

iv) Track Angle rate (system acquisition of start and stop of turn).

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v) Vertical Rate (barometric rate of climb/descent or, preferably baro-inertial).

vi) 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:

a) Selected Flight Level/Altitude.

b) Selected Magnetic Heading.

c) Selected course.

d) Selected IAS/Mach No.

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11.14 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 1060 MHz and receives at 1090 MHz.. Aircraft receives at 1060 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 100' (±50' from given level) Switch off if difference > 200'
Special codes	7700 - emergency, 7600 - radio failure, 7500 - hijacking 2000 - when no instructions given, 7000 - conspicuity code in UK.
Disadvantages of SSR	Garbling - overlapping replies if aircraft <1.7nm apart 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 25'.
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.

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11.15 QUESTION PAPER

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 feet Regional QNH
   b) 200 feet 1013 mb
   c) 300 feet 1013 mb
   d) 400 feet QNE

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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.

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SSR ANSWERS

QUESTION	ANSWER
01	a
02	d
03	d
04	b
05	d
06	c

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CHAPTER TWELVE - DISTANCE MEASURING EQUIPMENT

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12.1 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)

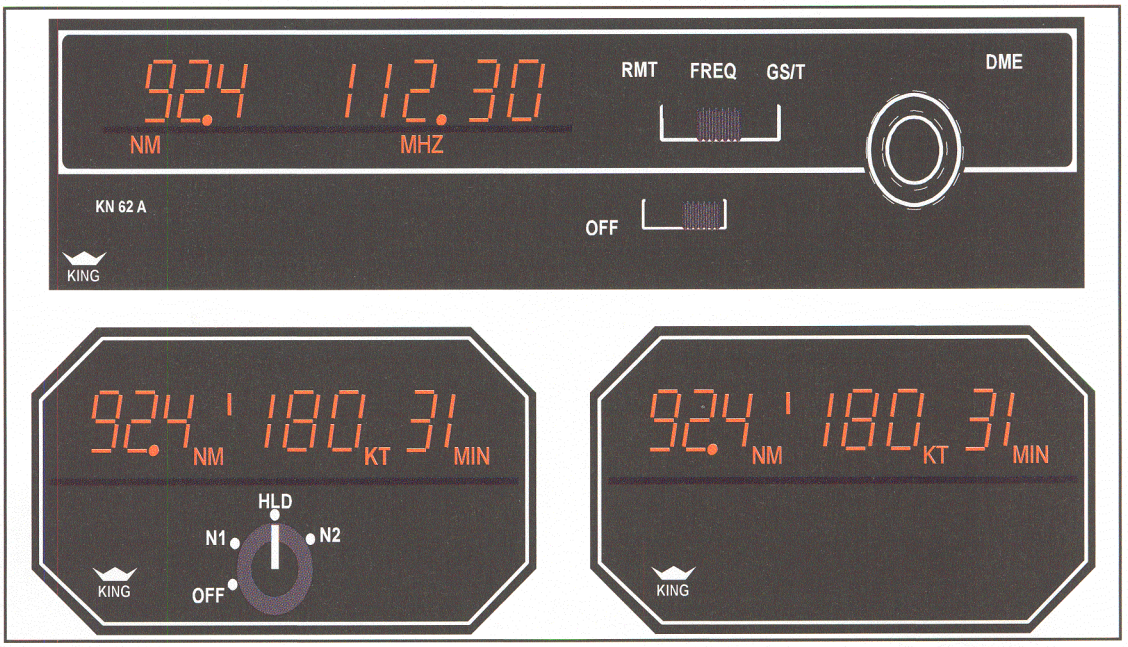

Figure 12.1. Distance Measuring Equipment.

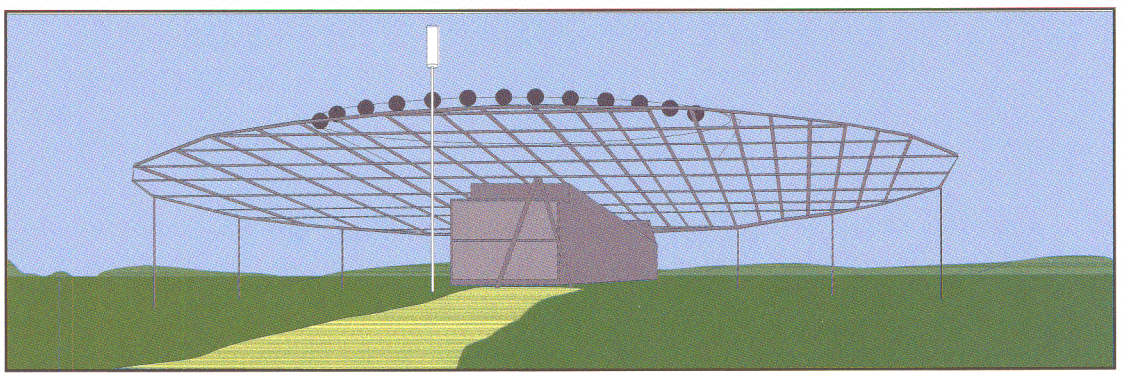

Figure 12.2. A Combined Doppler VOR/DME.

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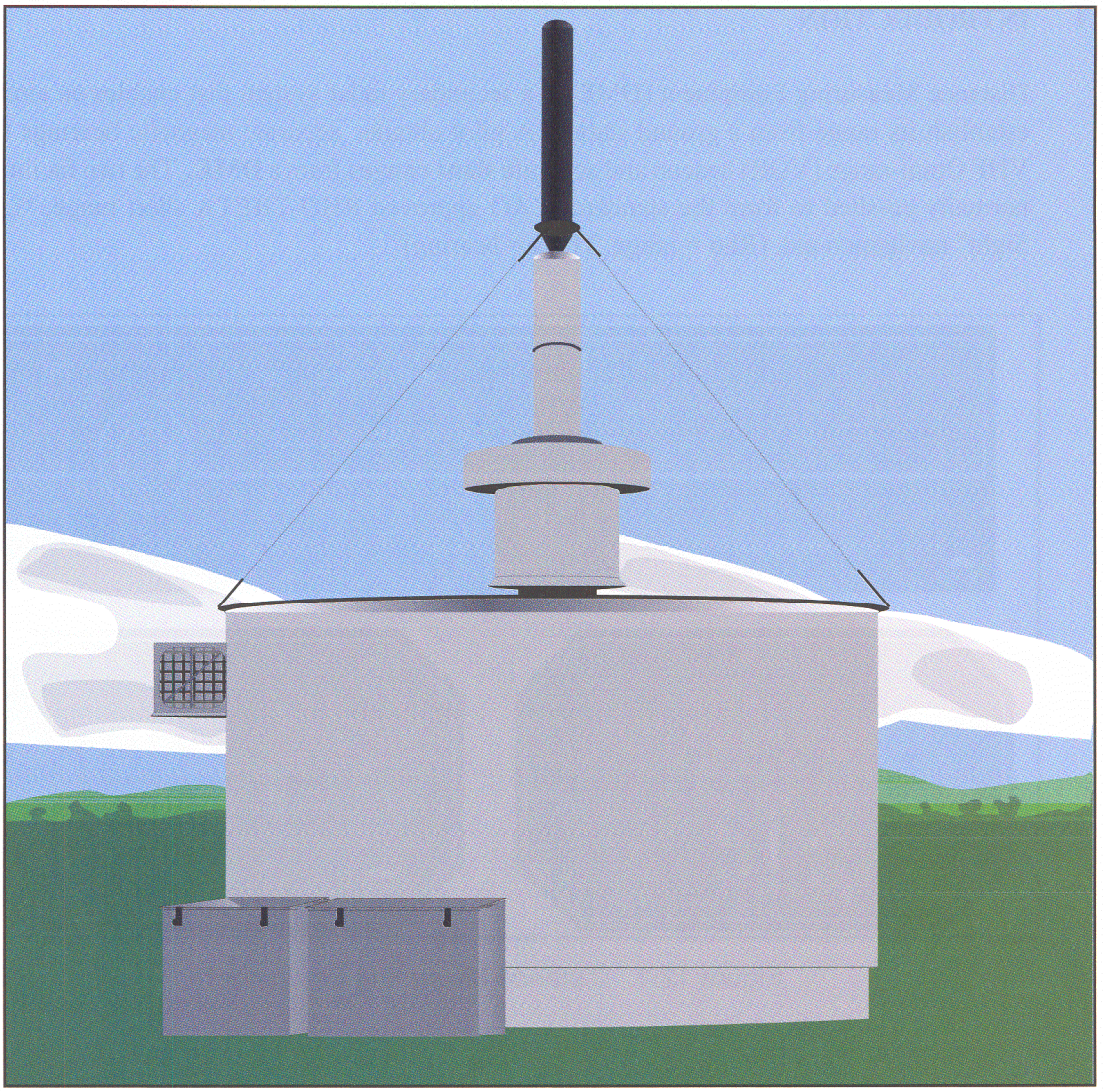

Figure 12.3. A Conventional VOR Installation Surmounted by a DME Antenna.

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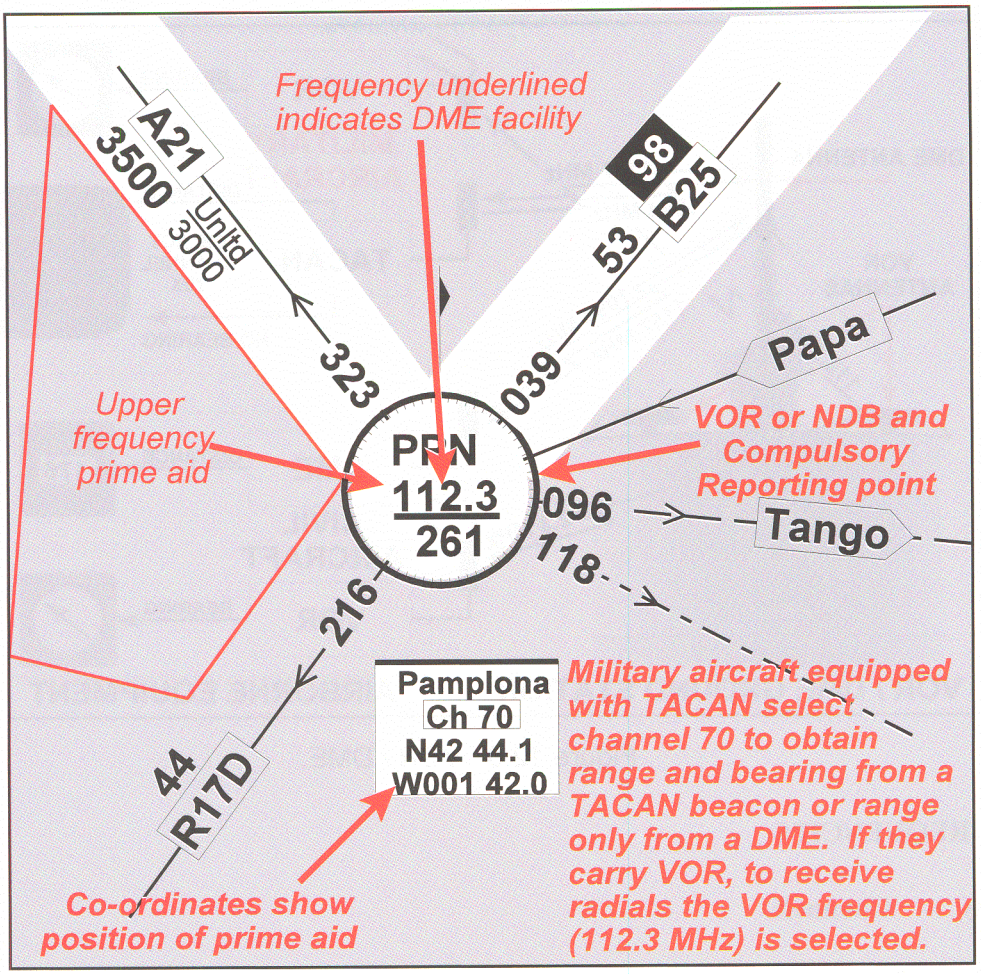

Figure 12.4. DME and VOR Presentation - AERAD Airways High Level Chart.

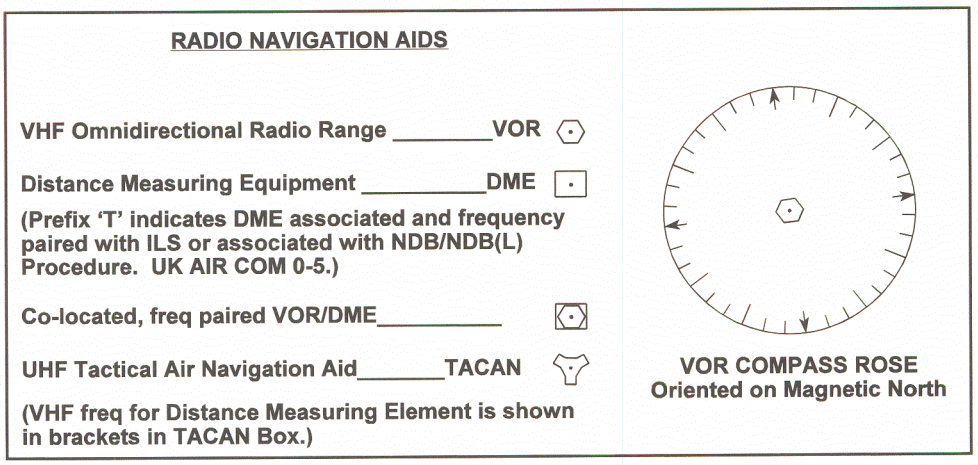

Figure 12.5. DME, VOR and Tacan Presentation- Topographical Chart.

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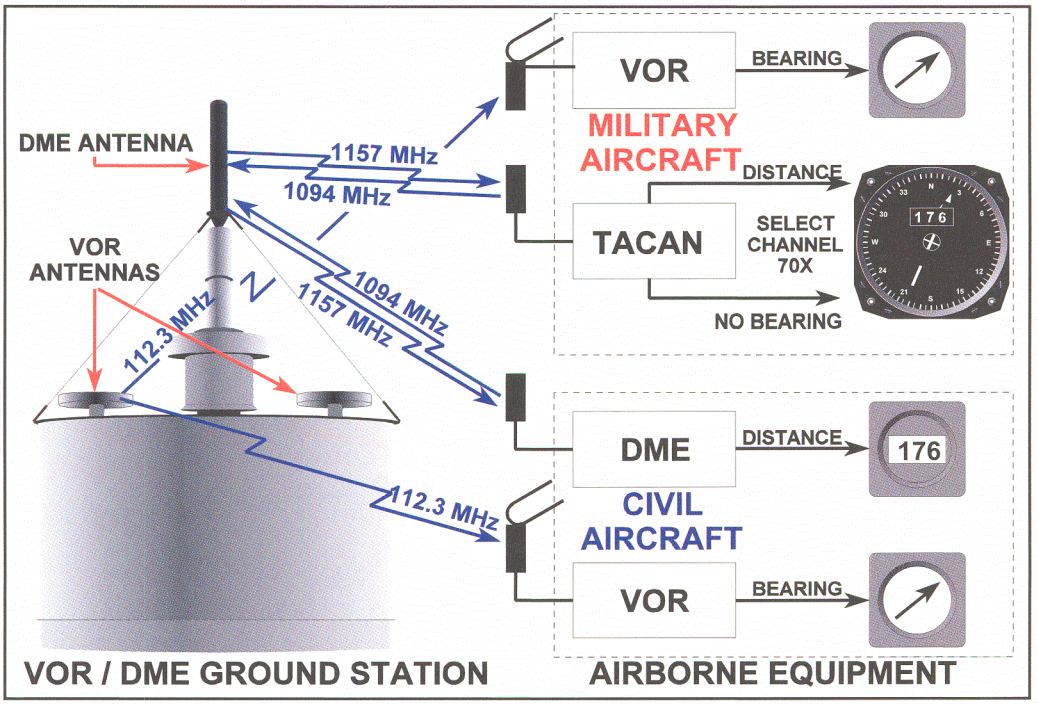

Figure 12.6. VOR / DME.

12.2 FREQUENCIES

a) 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.

b) 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

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c) 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.

12.3 USES OF DME

A DME:

a) provides very accurate slant range a **circular position line** and in conjunction with another DME, or a co-sited VOR, two position line fixes.

b) integrates the change of slant range into **groundspeed** and **elapsed times** when the aircraft is fitted with an appropriate computer.

c) permits more accurate flying of holding patterns and **DME arcs**.

d) provides **range and height checks** when flying non-precision approach procedures. e.g. Locator only and VOR let-downs.

e) indicates accurate **ranges to the runway threshold**, and heights for range, when flying an ILS/DME procedure.

f) **facilitates radar identification** when the pilot reports his VOR/DME position.

g) facilitates the separation and control of aircraft in **non-radar airspace,** based upon a VOR/DME fix reported by individual aircraft

h) is the basis for a simple **Area Navigation** (RNAV) system when the appropriate computerisation is fitted.

i) provides accurate range inputs into the more complex and **accurate RNAV systems**; twin, self selecting DME/DME are used.

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12.4 PRINCIPLE OF OPERATION

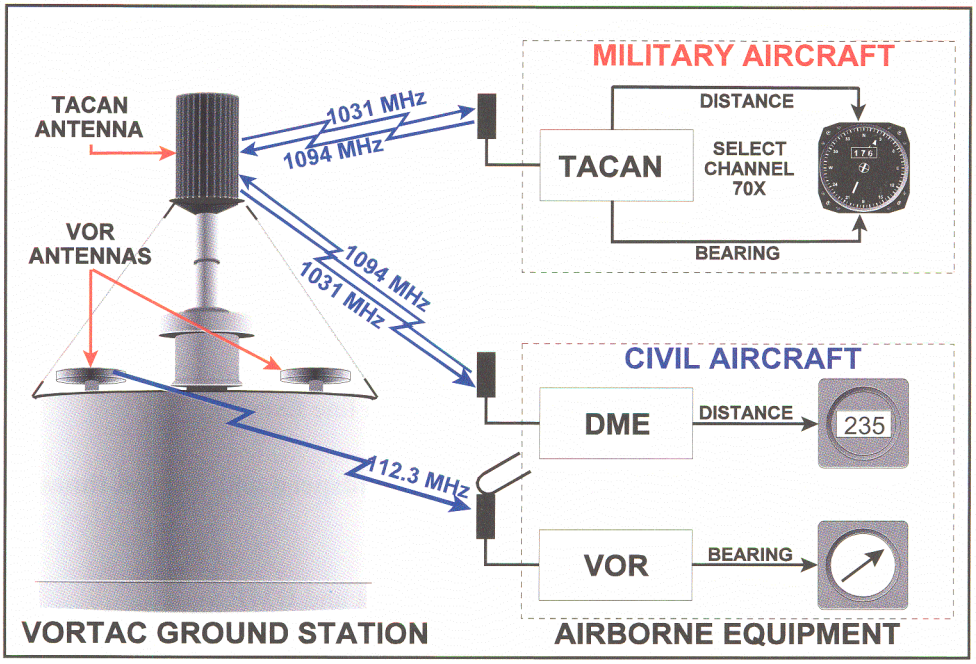

Figure 12.7. VORTAC.

a) 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 hundred 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)

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b) **Aircraft Range Determination**

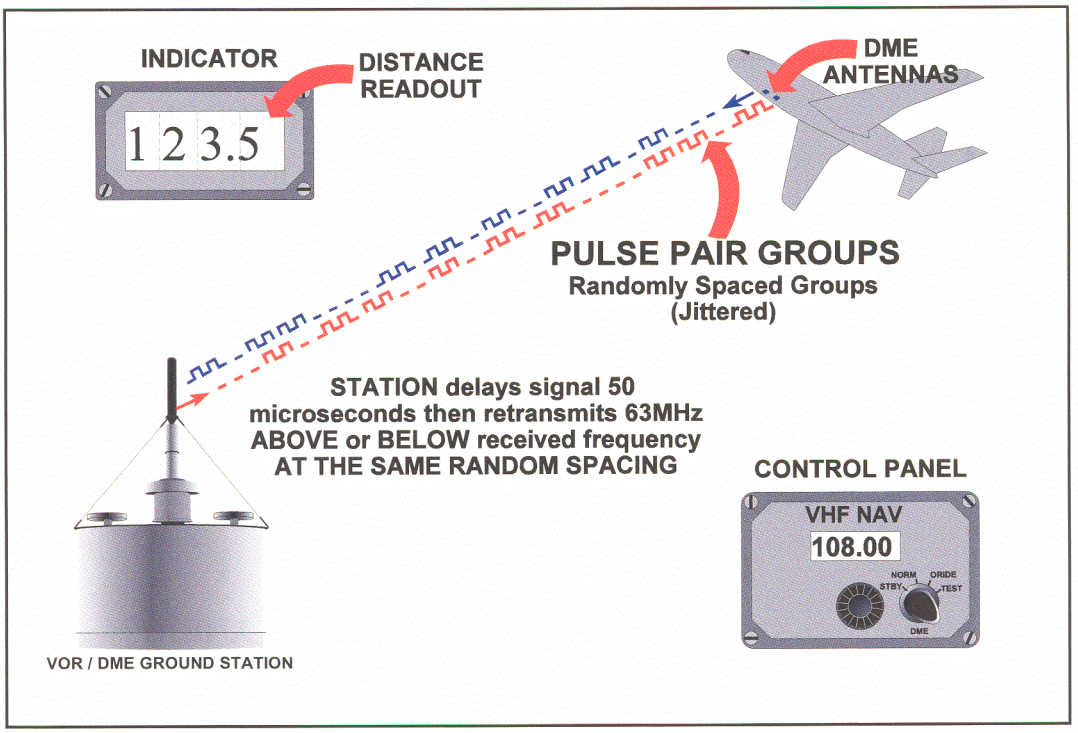

Figure 12.8. The Principle of Range Measurement.

For an individual aircraft to achieve an unambiguous slant range measurement and overcome the problem of identification:

i) 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.

ii) At the instant of transmission the receiver of an interrogator sets up **gates** to match the random PRF of the transmitted twin pulses.

iii) The responses, on the transponder's carrier frequency, include an **individual aircraft's** paired pulses **plus** those from **other aircraft**.

iv) 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.

v) 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.

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vi) The off-set in time between transmission and reception is the measure of the aircraft's slant range from the DME transponder.

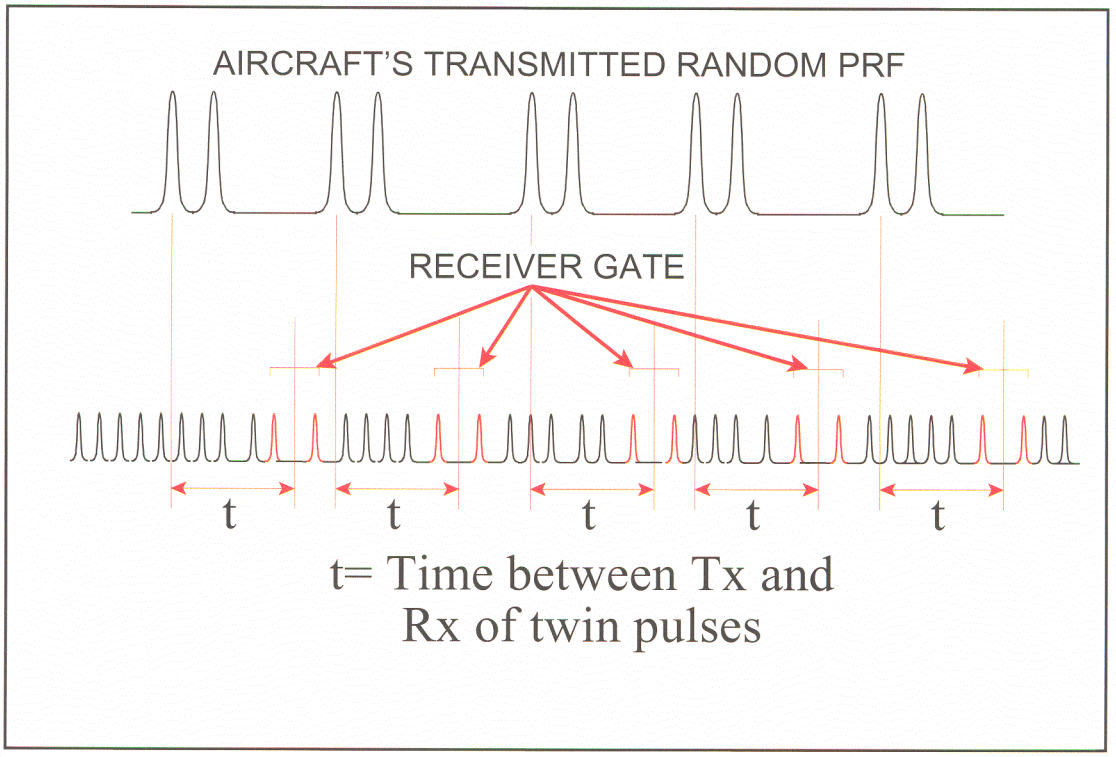

Figure 12.9. Acceptance of Own Pulses.

12.5 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.

12.6 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 equipments 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.

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12.7 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 with 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.

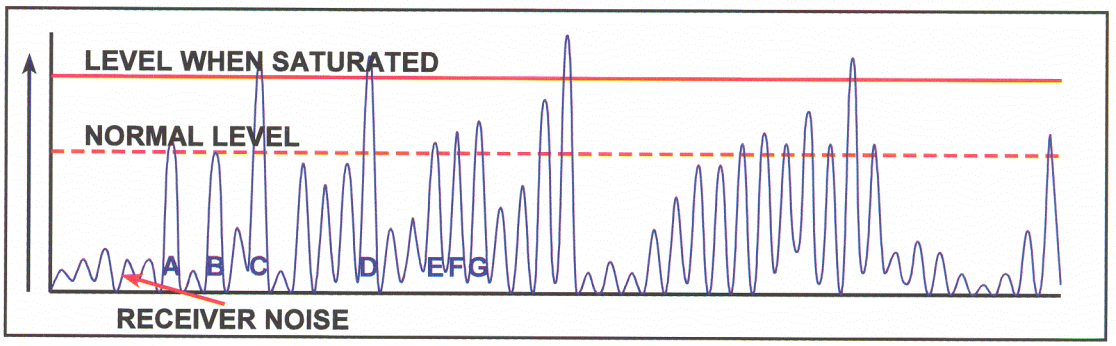

Figure 12.10. Beacon Saturation.

In Figure 12.10. 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.

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12.8 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).

12.9 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 30m/100' IN TMAs, or	**PAIRED**	**THE VOR TRANSMITS 3 OF THE FOUR**
(Iii) THE MAXIMUM DISTANCE BETWEEN BOTH TRANSMITTERS IS 600m/2000', FOR USE ELSEWHERE	**PAIRED**	**THE DME 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**

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12.9A 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, such 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.

12.10 RANGE AND COVERAGE

a) DME transmissions obey the **'line of sight'** rule. Thus the higher the aircraft, and the ground beacon, the greater the theoretical reception distance.

b) Intervening high ground will block the line of sight range.

c) 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.

d) 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.

e) 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.

12.11 ACCURACY

a) System Accuracy

Based on a 95% probability the system accuracy for DME used for navigation (DME/N) should give a total system error of not more than **+/- 0.2 nm (370 m)**. [For aircraft first registered before 1 Jan 89 this accuracy is +/- 0.25 nm plus 1.25% of distance measured.]

The total system limits include errors from causes such as those arising from airborne equipment, ground equipment, propagation and random pulse interference effects.

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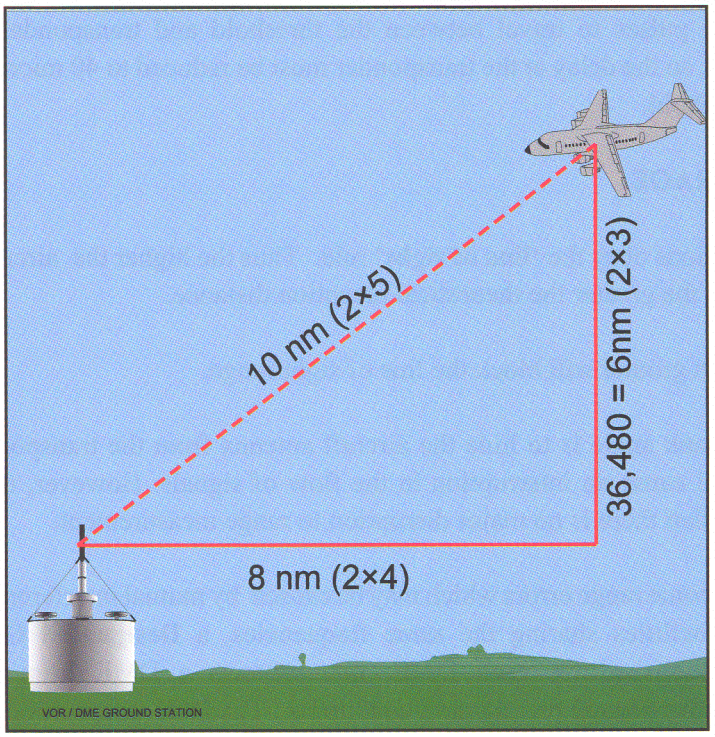
b) Slant Range / Ground Range Accuracy.

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. e.g. When the aircraft is directly over the DME (0 nm ground distance) it will indicate the aircraft's height in nautical miles. e.g. (There is a small cone of confusion over a DME, plus range indications continue to be computed as the equipment has a 10s memory circuit).



Aircraft at 36480 feet:

$$\frac{36480}{6080} = 6 \text{ nm}$$

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

x $= \sqrt{100 - 36}$

$=$ **8nm ground range**

Figure 12.11.

Applying the ICAO system accuracy limitations, the ground range is 7.5nm to 8.5nm.

c) 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.

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12.12 DME SUMMARY

Frequency: UHF band; 962 o 1213 MHz; I 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 pp's
- 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: 0.2 nm; (0.25 nm + 1.25 % of range for older aircraft)
Slant range error significant when aircraft range < 3 x height;
Groundspeed error increases as aircraft goes higher and closer to station.

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12.13 QUESTION PAPER

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	1214 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.

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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) 0.2 nm

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 using multiple DMEs in the RNAV configuration errors in navigation can occur because:

a) the aircraft is below their line of sight reception ranges.
b) the aircraft is outside their Promulgated Ranges.
c) it is difficult, if not impossible, to make a positive identification of the beacon being used and thus confirm its DOC.
d) the ground beacon may be saturated by the number of aircraft interrogating it.

9. An aircraft flying at flight level 250 wishes to interrogate a DME beacon situated 400' above mean sea level. What is the maximum range likely to be achieved ?

a) 210 nm
b) 198 nm
c) 175 nm
d) 220 nm

10. For a DME and a VOR to be said to be associated it is necessary for:

a) 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'.

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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) + or - 0.2 nm

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

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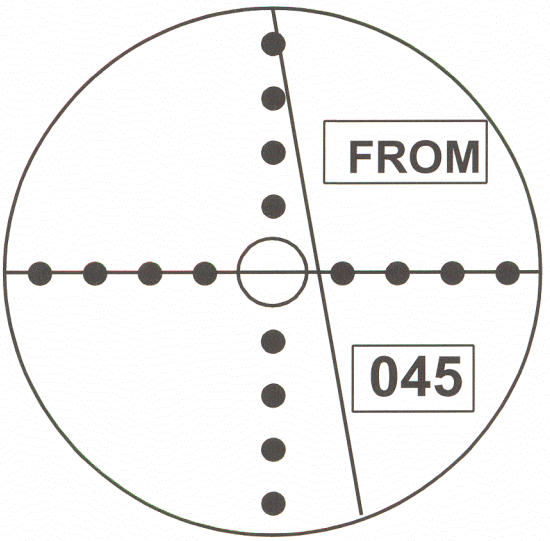
15. The receiver of airborne DME equipment is able to "lock on" to its own "reply pulses" because:

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 below. 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 2^0



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 045^0
b) right onto 048^0
c) left onto 225^0
d) right onto 225^0

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

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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 - 63Mhz from the interrogation frequency.

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DME ANSWERS

QUESTION	ANSWER
01	c
02	c
03	c
04	c
05	c
06	d
07	c
08	c
09	d
10	b
11	b
12	d
13	c
14	b
15	c
16	a
17	a
18	b
19	b
20	c
21	c

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CHAPTER THIRTEEN - AREA NAVIGATION (RNAV) SYSTEMS

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13.1 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

13.2 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.

13.3 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 has yet to be implemented.

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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**.

13.4 A SIMPLE 2D RNAV SYSTEM

The flight deck of a simple 2D RNAV system includes the following components:

a Navigation Computer Unit

Control Display Unit (CDU)

an Indicator in the form of a:

CDI (course deviation indicator) or
HSI (horizontal situation indicator).

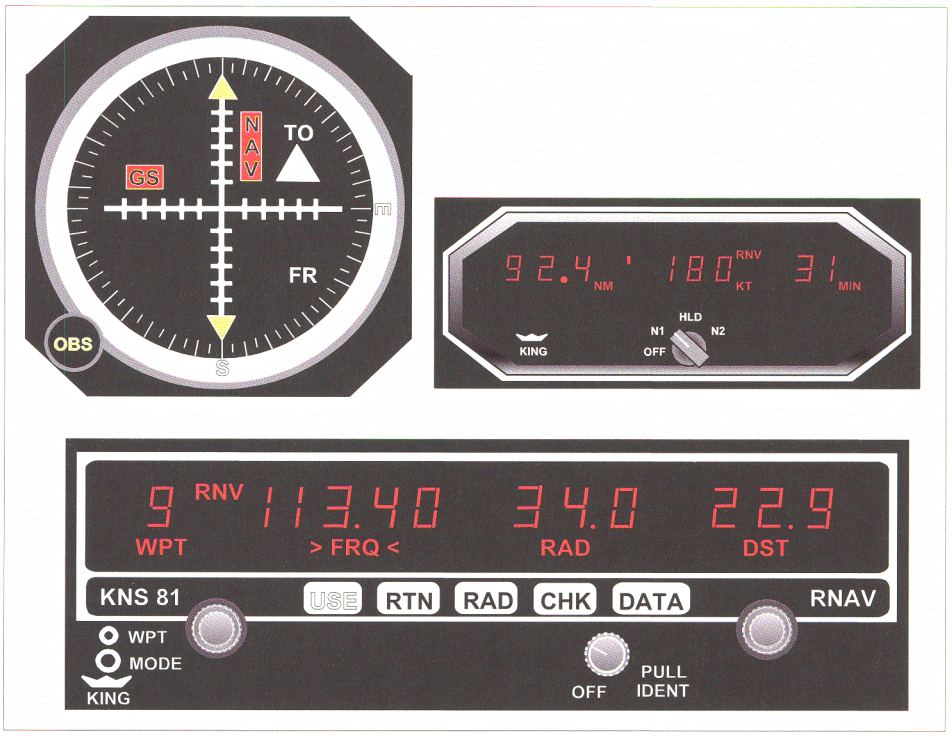

Figure 13.1 VOR/DME RNAV Integrated Nav System

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13.5 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.

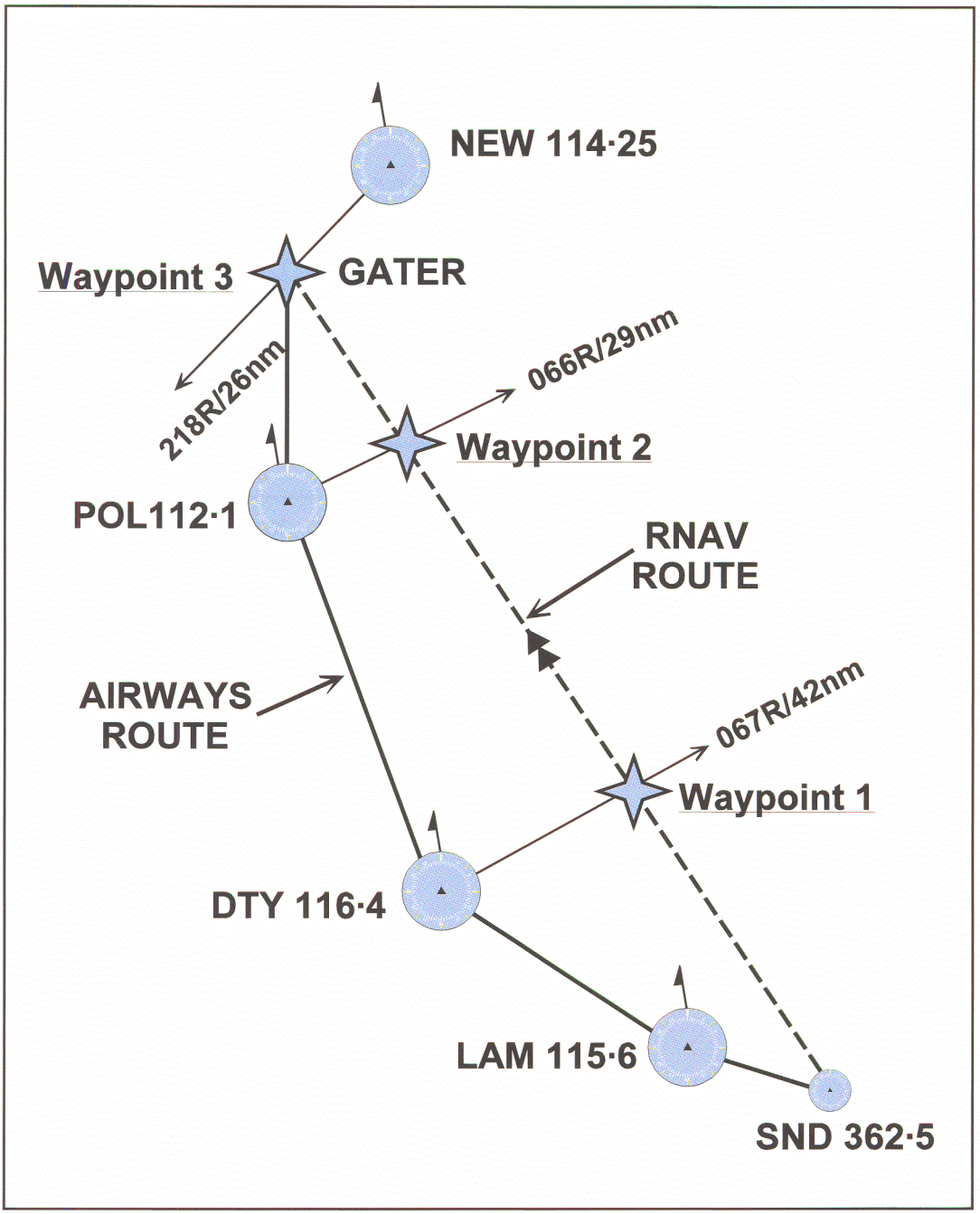

Figure 13.2 An RNAV Route and Waypoints

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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	N/A	N/A	ILS

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13.6 PRINCIPLE OF OPERATION OF A SIMPLE 2D RNAV SYSTEM

Refer to figure 13.3 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 so the computer can now compute the track and distance from WP1 to WP2 (340(M)/102 nm) since it has two sides and 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 a continuous range readout to WP2. It should be noted that on such a system the indications of deviation from track are in nms.

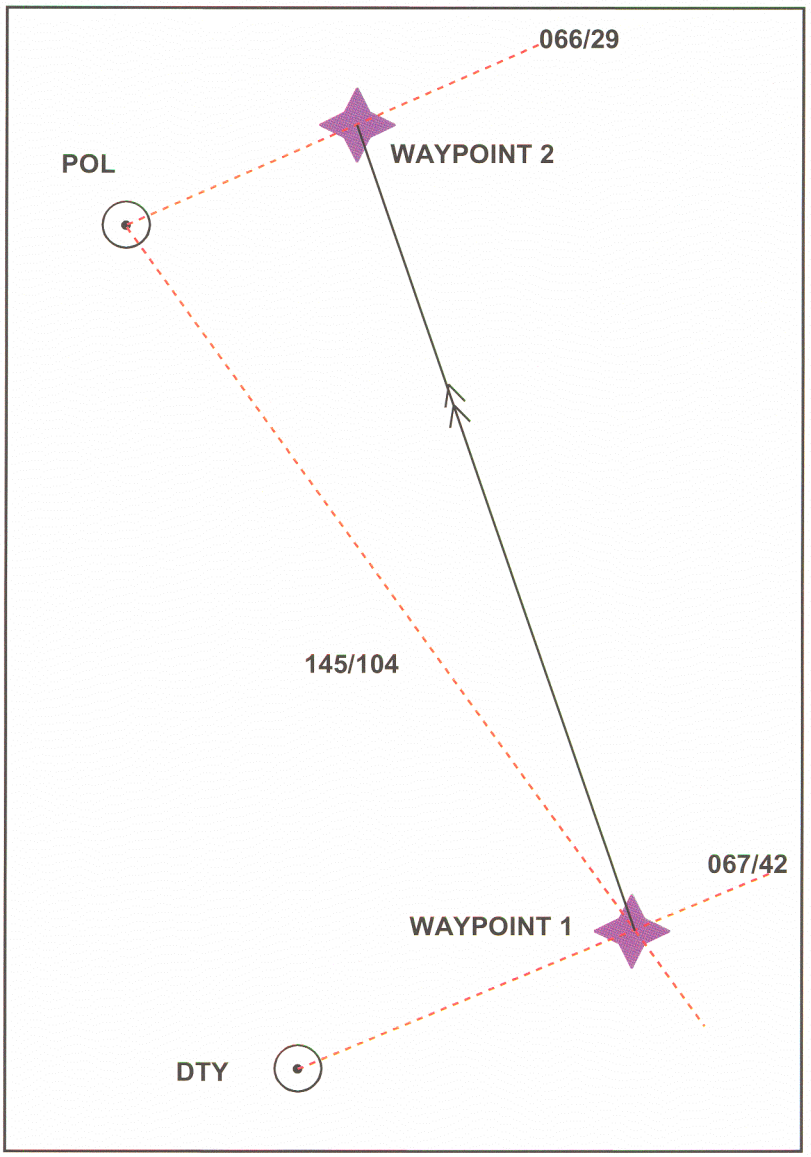

Figure 13.3

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13.7 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, then the along track element will be most accurate. If the VOR/DME designating the way point is perpendicular to the track; then across track will be most accurate.

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13.8 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.

OPERATION OF THE FLIGHT MANAGEMENT SYSTEM (FMS)

13.9 OVERVIEW OF 737-800 FMS OPERATION

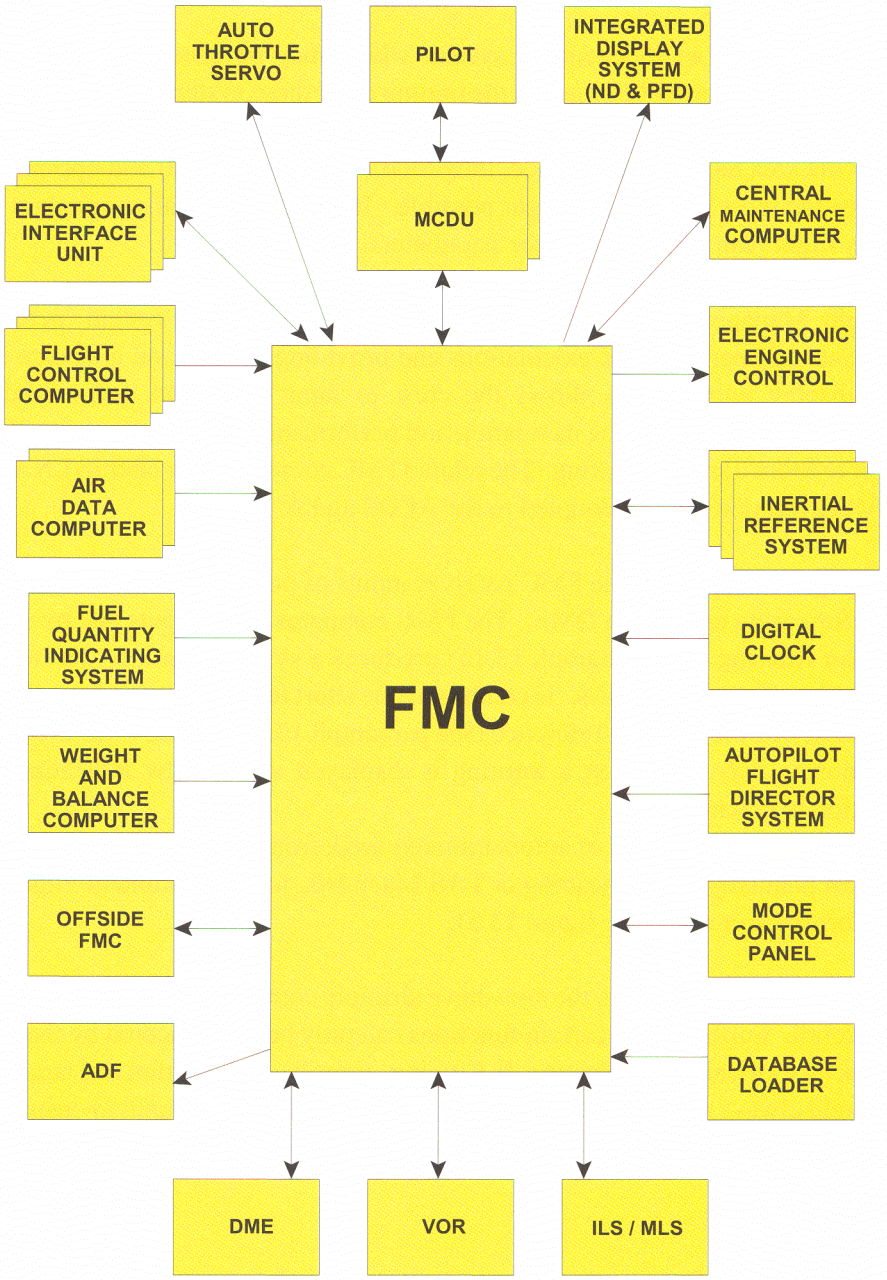

Figure 13.4 - FMS Schematic

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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 paragraph 13.15) 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 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, eg for heading or TAS/Mach No., to fully automatic flight path guidance and performance control (see figure 13.5).

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, eg. 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.

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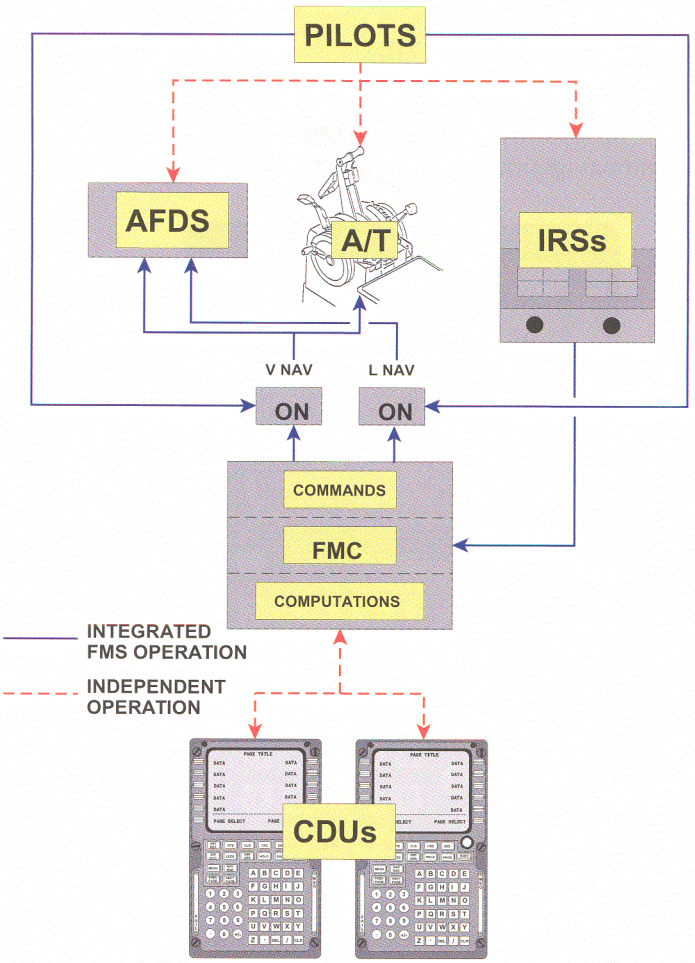

CONDITION: L NAV AND V NAV ENGAGED

Figure 13.5 - B737 - 400 FMS

The FMC contains a performance data base and a navigation data base. The performance database contains all parameters of the aircraft performance and the company's cost index strategy. The navigation data base 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.

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13.10 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.

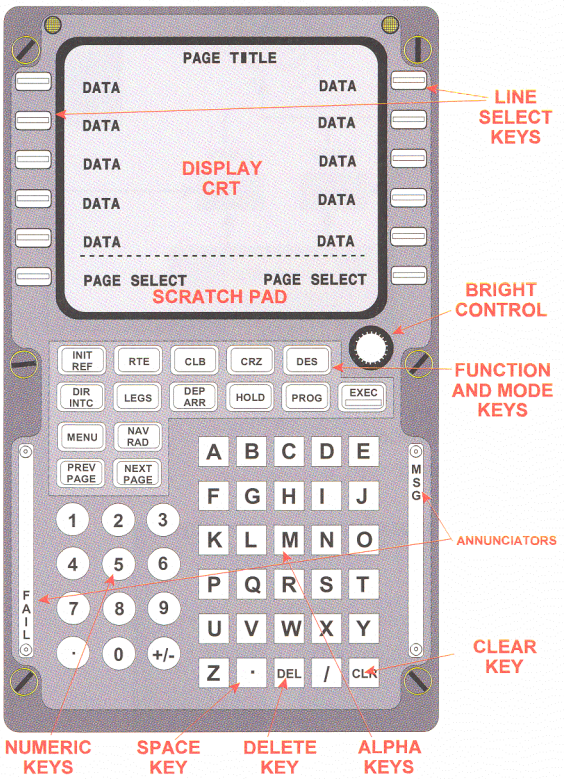

Figure 13.6 - Control Display Unit

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 (eg 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.

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PRE-FLIGHT

The pre-flight initialization of the FMC in the navigation mode require 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

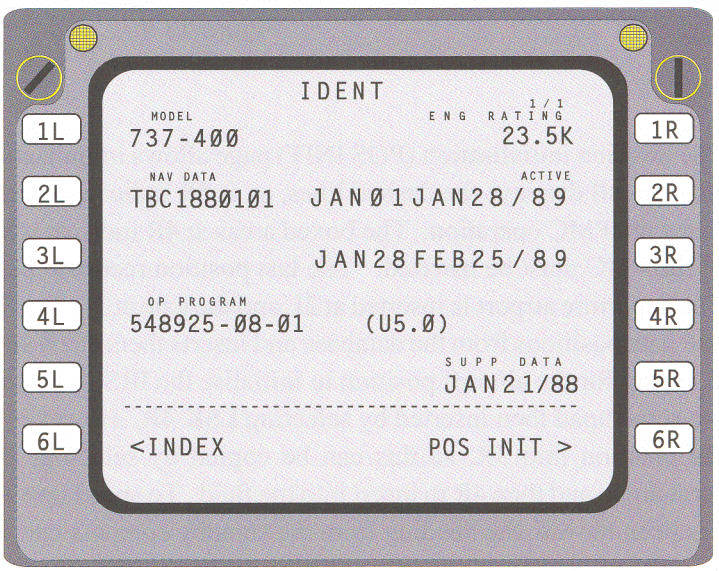

Figure 13.7

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.

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POS INIT page

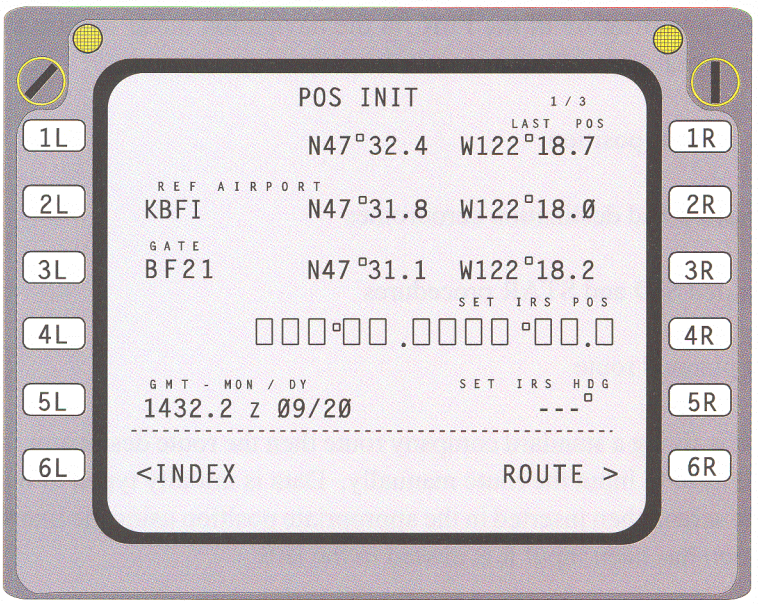

Figure 13.8

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.

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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.

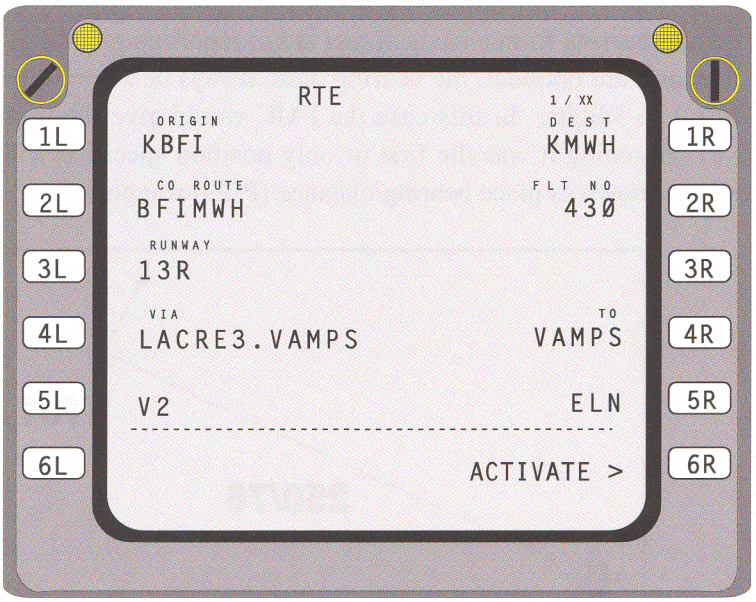

Figure 13.9

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 is now complete, but the performance initialisation is yet to be actioned, this is dealt with elsewhere in the course, suffice to remind that 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 the 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 (eg. N05W010) or a 15 group (eg. N0926.3W00504.7), note the leading zeros must be entered for the FMC to accept the position.

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Up to 5 alphanumerics for reporting points, navigation facilities and airway designators (eg. KODAP, A23 etc)

Up to 7alphanumerics for SID and STAR (eg. 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 3or 5digit group, the distance may be 1 to 5digits. 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.

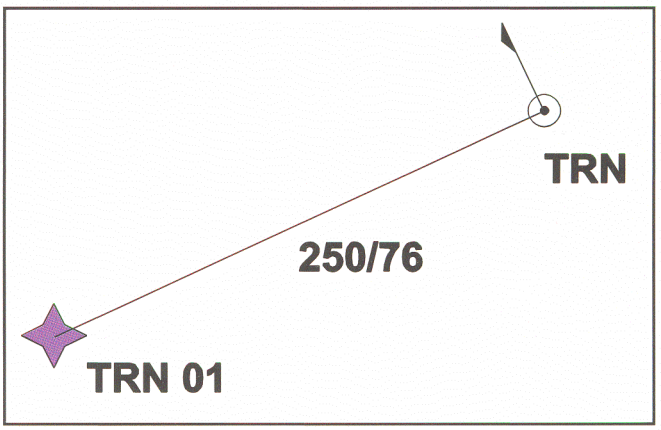

Figure 13.10 - Range/Bearing Waypoint

Course interception waypoints are positions defined where the bearing from any valid database position intersects with a course (eg an airway) or the bearing from another database defined position. The format for input is eg. 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.

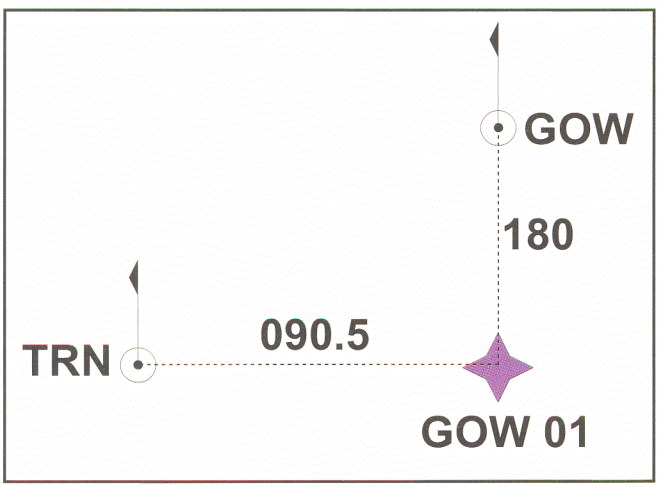

Figure 13.11 - Bearing/Bearing Waypoint

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13.11 CLIMB

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

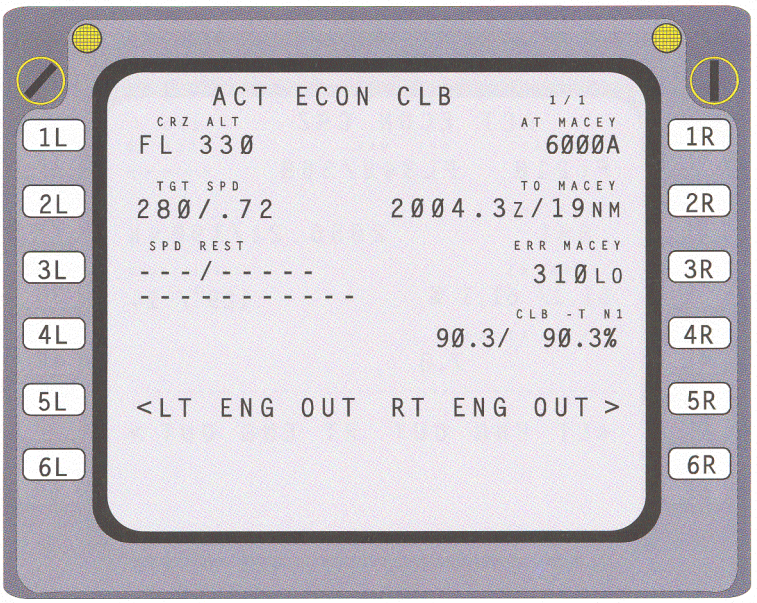

Figure 13.12

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 at 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)

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13.12 CRUISE

In the cruise all three modes will normally be active.

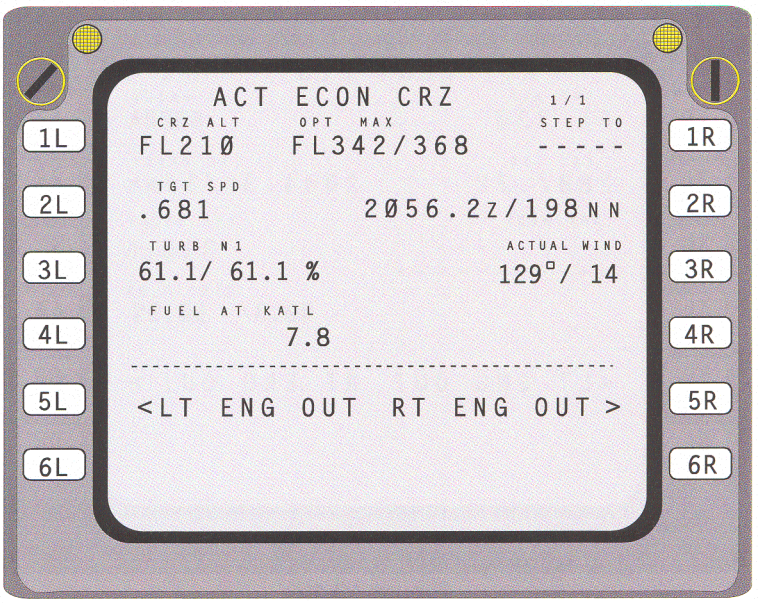

Figure 13.13

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 4R. At 1C is the optimum and maximum cruising levels 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.

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13.13 DESCENT

As in the climb the LNAV, VNAV and timing modes are all operative.

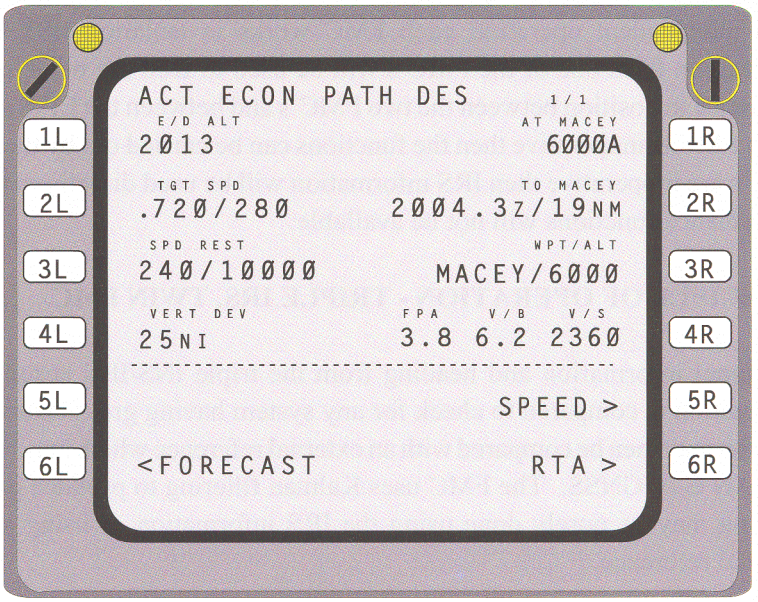

Figure 13.14

With the active economy path descent (ACT ECON PATH DES) page selected, the target Mach number and CAS are at 2L, at 1L is the end of descent altitude. At 1R is the next descent position and altitude, the suffix A indicates at or above.. Position 3L contains the speed transition, which is 10 kt less than that stored in the database, and the transition altitude, if none is defined then it defaults to 240/10000, no input is permitted to this field, but the data can be removed. The next waypoint and altitude is shown at 3R with the expected deviation from this required height is 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 ie 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.

13.14 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, 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 (see 13.15 and 13.16).

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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 FMC's will be used to feed the other systems and their will be a difference in position between the two FMC's 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 FMC's are inoperative then IRS information will be used directly in the EFIS but the automatic performance functions will not be available.

13.15 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 purely done 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 (eg sec86°00'=14.3356, sec86°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.

13.16 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 will become more biassed 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 (ie the more factors are included) the better will be the quality of the system position and velocity.

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13.17 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 range and the cut of the position lines. The second problem is solved by the computer selecting DMEs positioned such 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 so after several hours, since the DME error is constant, the DME fixing will be significantly more accurate than the IRS.

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13.18 EXAMPLE QUESTIONS

1. The accuracy required of a precision area navigation system is:

   a. 0.25 nm
   b. 2 nm
   c. 1 nm
   d. 0.5 nm

2. A basic 2D RNAV system will determine tracking information from:

   a. twin DME
   b. VOR/DME
   c. Twin VOR
   d. Any of the above

3. An aircraft using a basic 2D RNAV system is on a section between WP1 and WP2 a distance of 45 nm. The aircraft is 20 nm from the phantom station; which is 270/30 nm from the VOR/DME. The aircraft is 15 nm from the VOR/DME. The range 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

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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

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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

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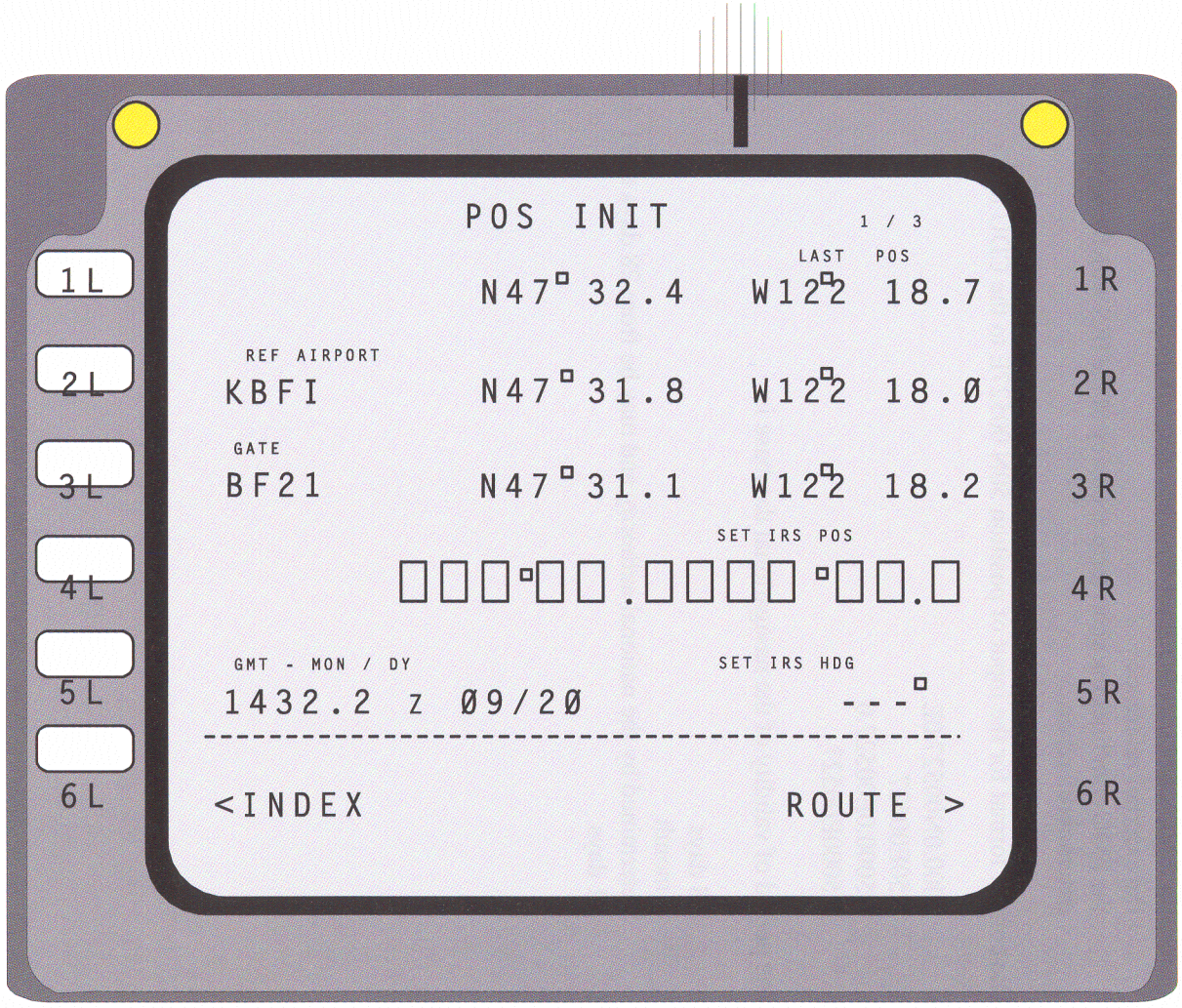
APPENDIX A


POS INIT
1 / 3
LAST POS
N47° 32.4 W122 18.7
REF AIRPORT
KBFI N47° 31.8 W122 18.0
GATE
BF21 N47° 31.1 W122 18.2
SET IRS POS
□□□°□□.□□□□ °□□.□
GMT - MON / DY
1432.2 Z 09/20
SET IRS HDG
---°
<INDEX
ROUTE >
1L
2L
3L
4L
5L
6L
1R
2R
3R
4R
5R
6R

13.19 ANSWERS

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

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CHAPTER FOURTEEN - ELECTRONIC HORIZONTAL SITUATION INDICATOR (EHSI) - BOEING 737-800

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14.1 INTRODUCTION

(JAR25) 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 14.12), and the requirement on manufacturers to ensure there can be no confusion between colours or symbols. It also defines the probabilities that essential information (eg attitude, altitude, heading etc) will not be lost or inaccurately displayed.

Detailed knowledge of the JAR25 specifications is not required for the examination. Such knowledge as is needed has been reproduced in this chapter.

14.2 EHSI CONTROLLER

The EHSI displays navigational information, radar information and TCAS information. For the Radio Navigation examination a 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 sources is fed to the port and starboard EHSI through the respective symbol generator, 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.

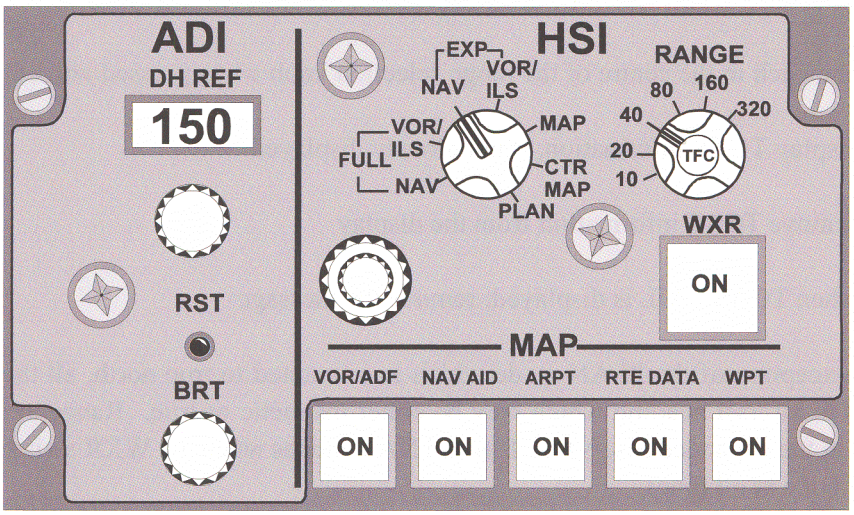

Figure 14.01

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The display modes available are:

Full rose Navigation (FULL 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.

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DISPLAY MODES

14.3 EXPANDED NAVIGATION MODE

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

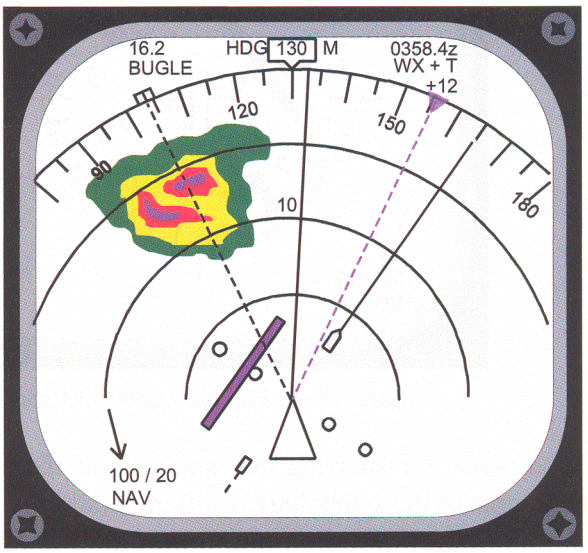

Figure 14.02 Expanded Navigation Mode

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 146°M. The aircraft is just over 2 nm right of the required track. The heading bug is selected to 104°M, the 20 nm 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 16 nm. The wind is 100°M/20 kt.

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14.4 FULL NAVIGATION MODE

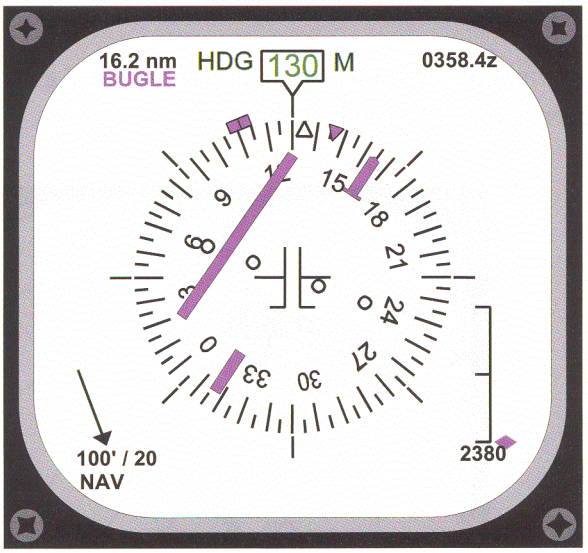

Figure 14.03 Full Navigation Mode

The full navigation mode is displaying the same data as the expanded navigation mode (at 14.02), 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.

14.5 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 14.04 Expanded VOR Mode

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The display shows that VOR2 is in use on a frequency of 116.80 MHz, the aircraft is outbound from the beacon at a range of 13.3 nm (DME) and is 7.5° right of the required track (165°M). The heading is 130°M and the present track 133°M . The pilot has selected the heading bug to 104°M. WXR is selected and the radar is in WX+T mode with 12° uptilt and the display is showing a contouring cloud centred on 105°M between 8 and 17 nm. The selected scale is 20 nm and the wind is 126°M/20 kt.

14.6 FULL ROSE VOR MODE

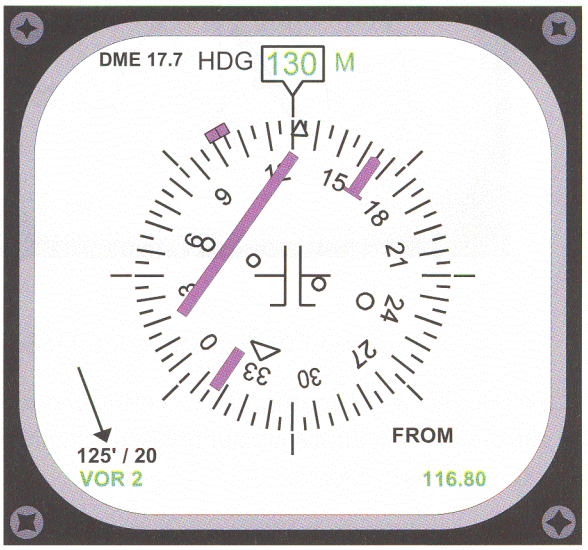

Figure 14.05 Full Rose VOR Mode

The full rose VOR mode is showing the same information as diagram 14.04, 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).

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14.7 EXPANDED ILS MODE

Figure 14.06 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.

14.8 FULL ROSE ILS MODE

Figure 14.07 Full Rose ILS Mode

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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.

14.9 MAP MODE

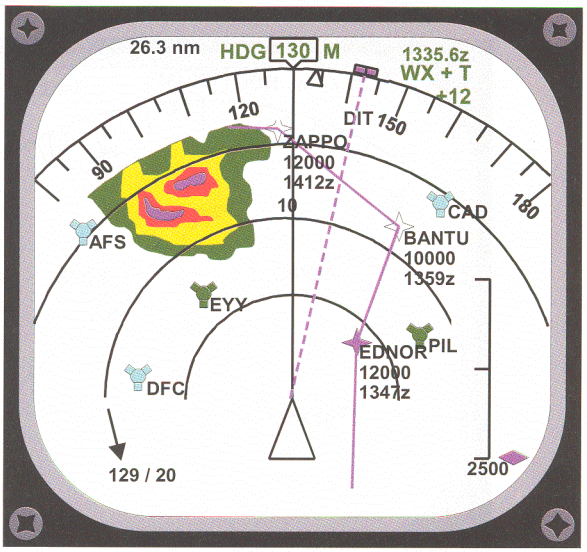

Figure 14.08 Map Mode

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

14.10 CENTRE MAP MODE

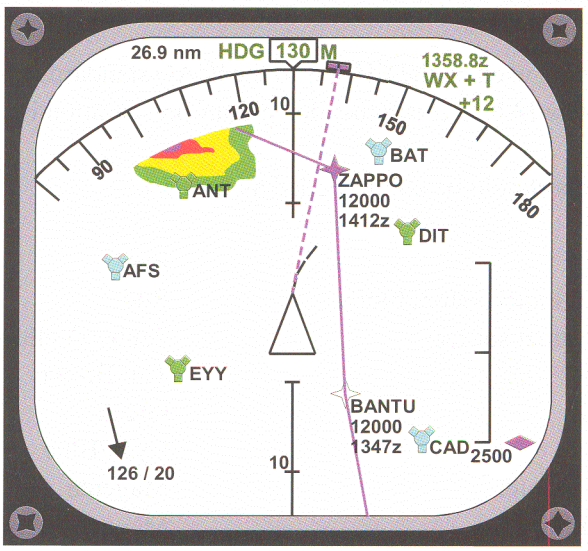

Figure 14.09 Centre Map Mode

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The centre map mode is 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.

14.11 PLAN MODE

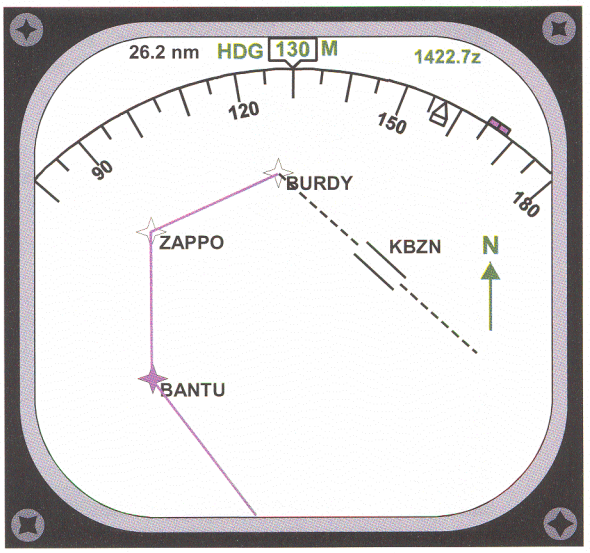

Figure 14.10 Plan Mode

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.

14.12 EHSI COLOUR CODING

The colour coding used on the EHSI is to the ICAO standard, which is also the standard adopted by the JAA. The JAR25 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

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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

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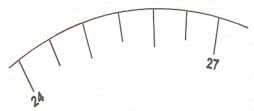
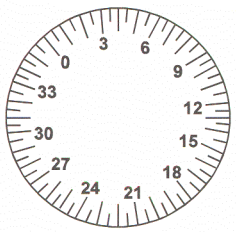
14.13 EHSI SYMBOLOGY

The symbology used in the B737-800 is depicted in the following table, which should be used in conjunction with the display diagrams at 14.3 to 14.11:

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 100 nm tenths of a nm will be displayed
HDG 263 M	HEADING Orientation(G) Indicator(W) Reference(G)	ALL	Indicates number under pointer is a heading - box indicates actual heading. Referenced to Magnetic (M) or true (TRU) North.
0835.4z	ETA Display (W)	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 (360deg available but approximately 70deg 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.
AMBOY	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.

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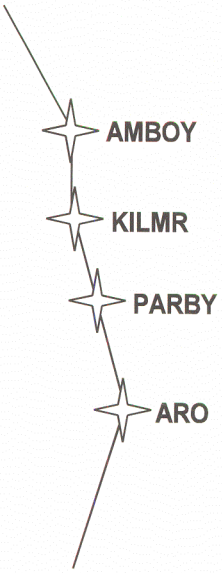
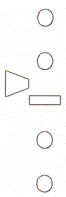
	Trend Vector	MAP	Predicts aeroplane directional trend at the end of 30, 60 and 90 second intervals. Based on bank angle and ground speed. Three segments are displayed when selected range scale is greater than 20nm, two on the 20nm and one segment when on the 10nm scale.
	Active Route(M) Active Route Mod's(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.

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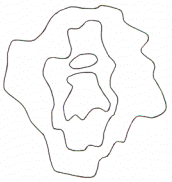
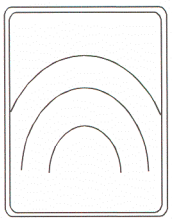
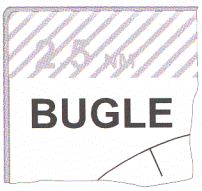
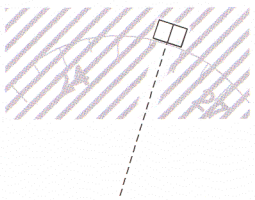
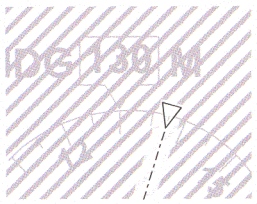
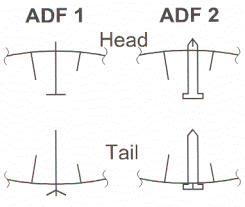
	Altitude Profile Point and Identifier(G)	MAP	Represents an FMC calculated point and is labelled on the flight plan path as" T/C" (top of climb), "T/D" (top of descent), "E/D" (end of descent) and "S/C" (step climb).
	Weather Radar Returns Mapping Radar Returns (both G,A,R,M)	EXP NAV, EXP VOR/ILS, MAP	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

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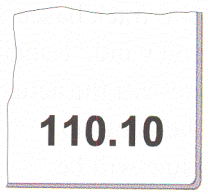
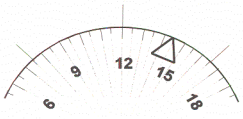
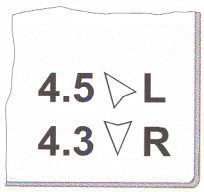
	VOR / ILS Frequency Display (G)	VOR, ILS	Displays frequency of manually tuned navaid. The word 'AUTO' is displayed in place of the frequency if the VHF Nav radio is in the auto tune mode
	Drift Angle Pointer (W)	FULL NAV, FULL VOR/ILS	Indicates airplane's present track. Replaces track line when a Full 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.

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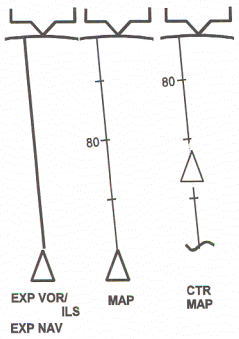
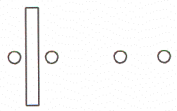
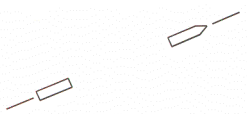
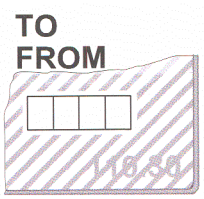
	Present Track Line (W) and Range Scale (W)	EXP NAV, EXP VOR, EXP ILS, MAP	Displays present ground track based on airplane heading and wind. Range numeric values are one-half the actual selected range. With heading-up orientation, the track line will be rotated left or right at an angle equal to the drift 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 data base waypoints not used in the selected flight plan route are dispalyed. Displayed only for HSI ranges of 10, 20, or 40 NM.

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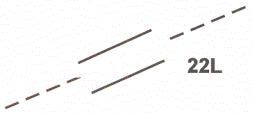
	Airport (C)	MAP, PLAN	**ARPT switch - OFF** Only origin and destination are displayed. **ARPT switch - ON** All FMC data base airports within the MAP area are displayed.
	Airport Identifier and Runway (W)	MAP, PLAN	Available when the EHSI display range is 80, 160, or 320 NM. Displayed if the airport 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.
T/C S/C T/D E/D	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 NDB's) are displayed in green. **NAV AID switch - ON** All appropriate navaids in the FMC data base 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)

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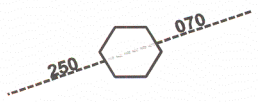
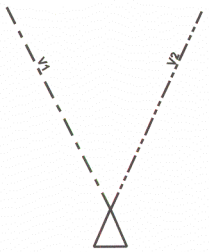
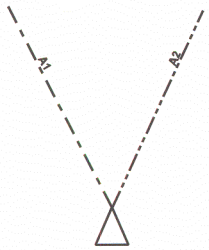
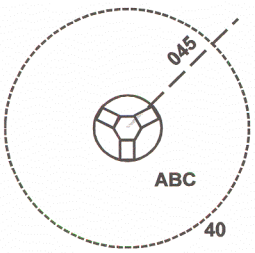
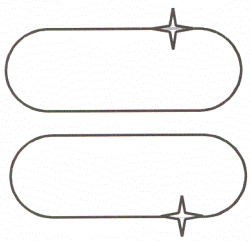
	Manually Tuned VOR Radials (G)	MAP, PLAN	When a VOR navaid is manually tuned, the associated MCP selected course and its reciprocal are displayed.
	VOR Radials (G)	MAP	The VOR/ADF switch on the EFIS control panel must be ON and a valid VOR signal must be received. Displays relative
	ADF Bearings (G)	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..

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14.14 EXAMPLE 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 JAR25 colour code for ILS deviation pointer is:

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

7. The JAR25 colour code for selected heading is:

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

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8. The JAR25 colour code for precipitation rate in excess of 50 mm/hr is:

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

9. The JAR25 colour code for the active route is:

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

10. The JAR25 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 & CTR MAP
b. EXP ILS/VOR, MAP & CTR MAP
c. PLAN, 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)

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

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

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14.15 ANSWERS

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

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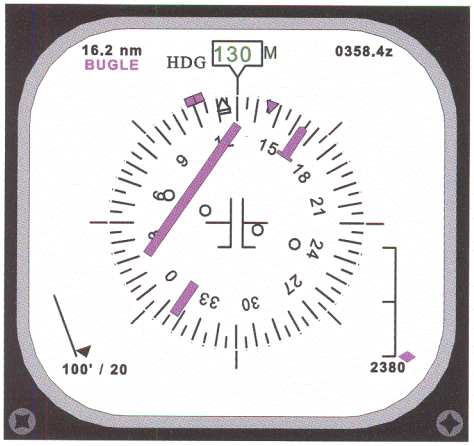
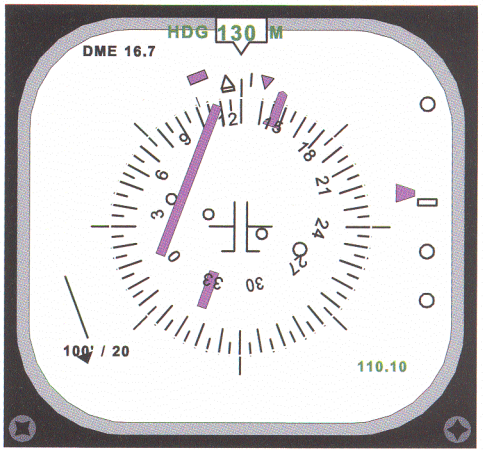
APPENDIX A

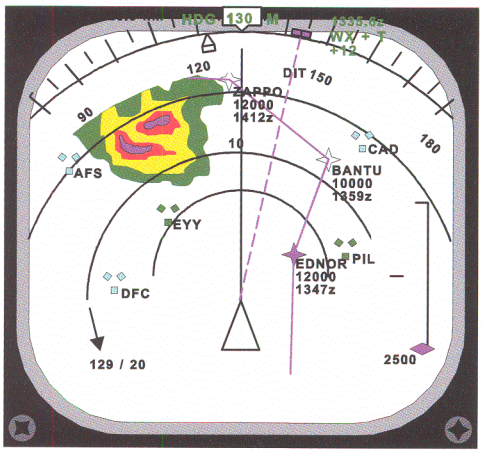
A



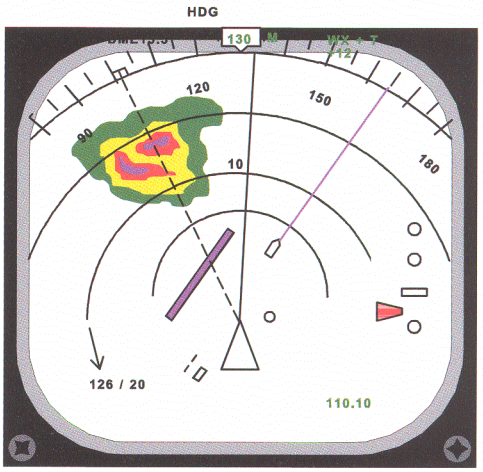
B



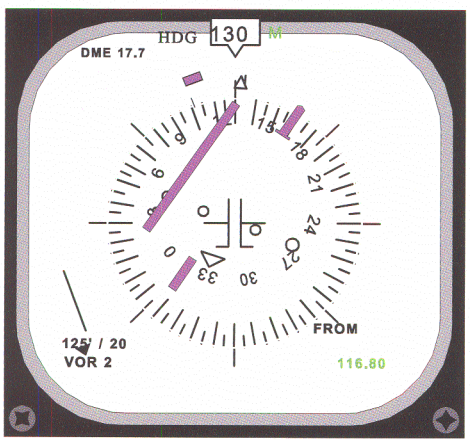
C



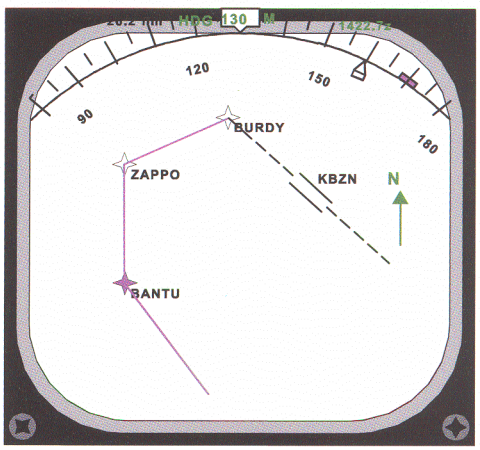
D



E



F



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CHAPTER FIFTEEN - GLOBAL NAVIGATION SATELLITE SYSTEMS

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15.1 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 a precision measured in metres, and where special differential techniques are used the potential is for accuracies substantially less than one metre.

At present (July 2000) 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 Project**, which is, at present, a feasibility study, but is intended to start becoming operational in 2008. 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.

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15.2 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.

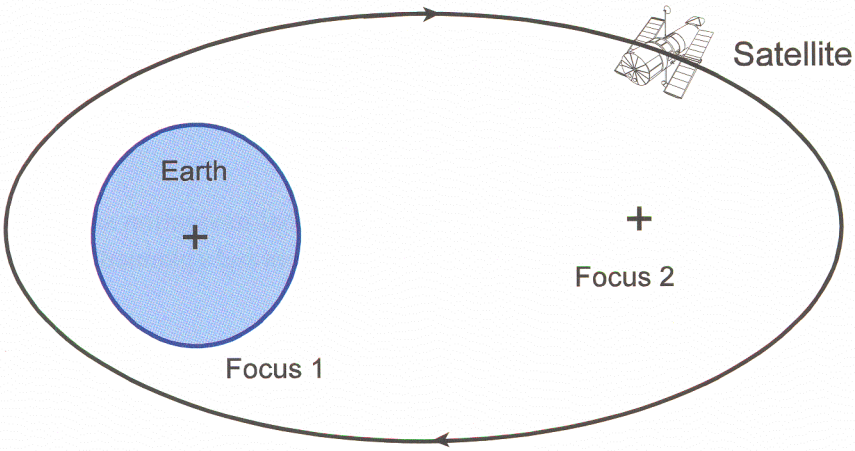

Fig 15.1

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

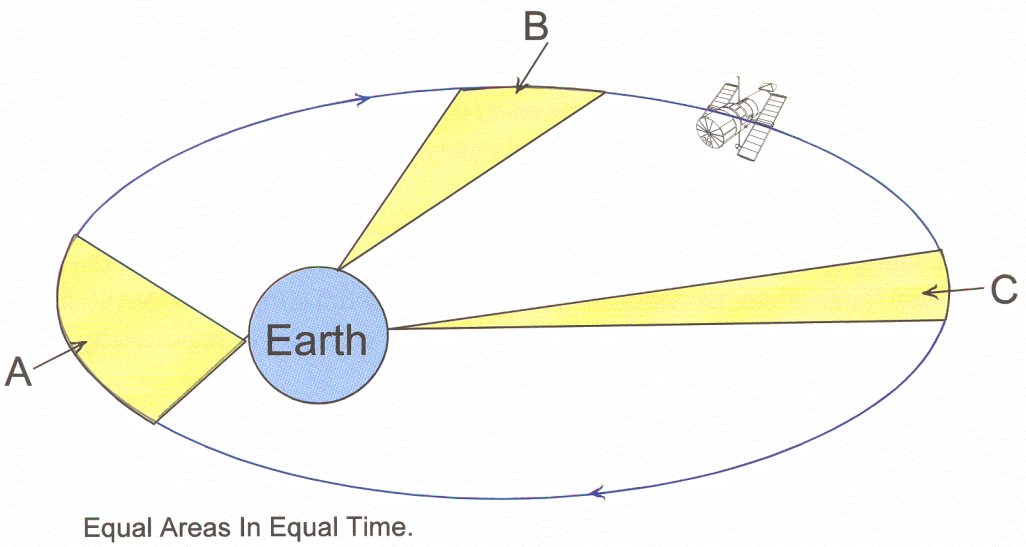

Fig 15.2

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.**

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15.3 POSITION REFERENCE SYSTEM

GNSS use an Earth referenced three dimensional Cartesian coordinate system with its origin at the centre of the earth.

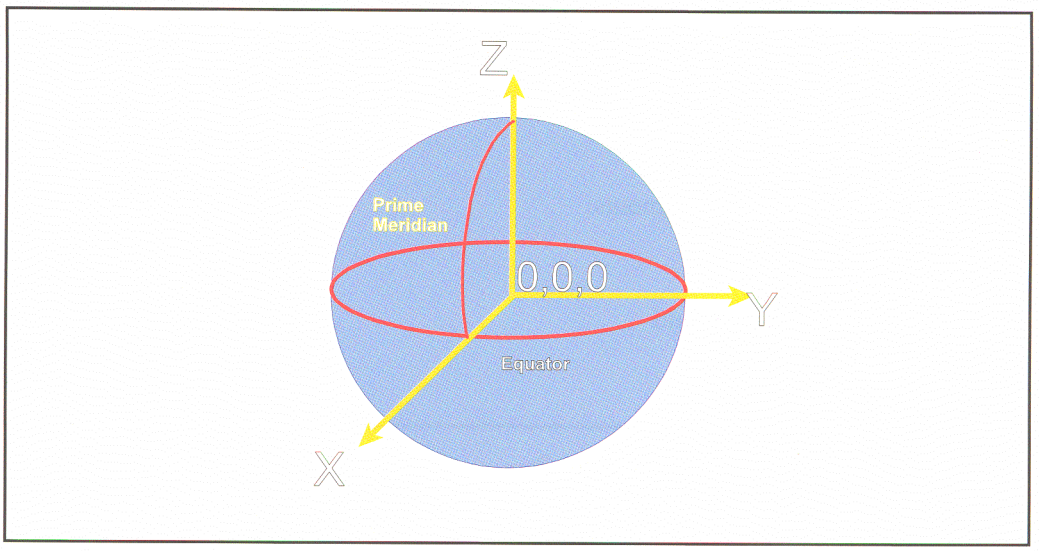

Fig 15.3

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. All maps and charts for aviation in Europe and North America and, no doubt elsewhere, are constructed from the WGS84 model. 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). The Russian model for GLONASS is known as Parameters of the Earth 1990 (PZ90).

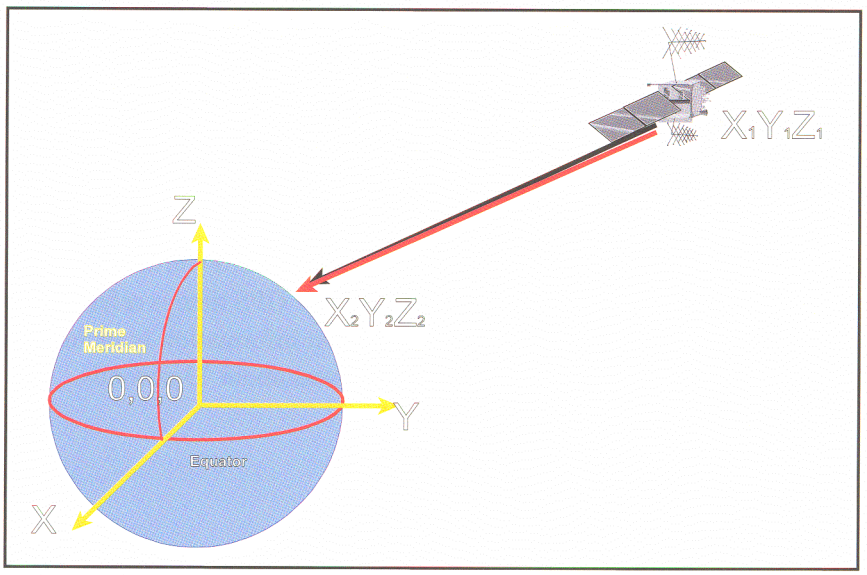

Fig 15.4

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Any model of the earth represents the basic shape of the mean sea level over the planet, known as a geoid. The model cannot be a perfect representation, nor can it represent geographical features, eg mountains and land depressions. 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.

15.4 THE GPS SEGMENTS

GPS comprises three segments:

The Space Segment
The Control Segment and
The User Segment

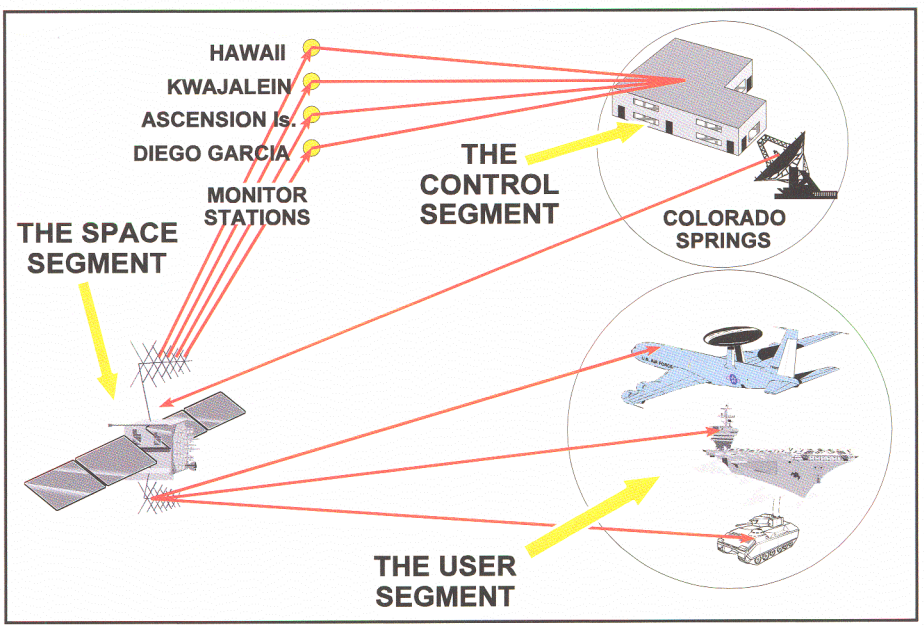

Figure 15.5. The Three Segments of the GPS Operational Control System.

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 section15.8). In July 2000 the difference was about 13 seconds.

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15.5 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 10,898 nm (20,180 km) and have an orbital period of 12 hours. The orbital planes have an inclination of 55° and are equally spaced around the Equator. The spacing of the SVs in their orbits is such that an observer on, or close to the surface of the Earth will have between five and eight SVs in view, at least 5° above the horizon. The SVs have 4 atomic clocks (2 each of caesium and 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.

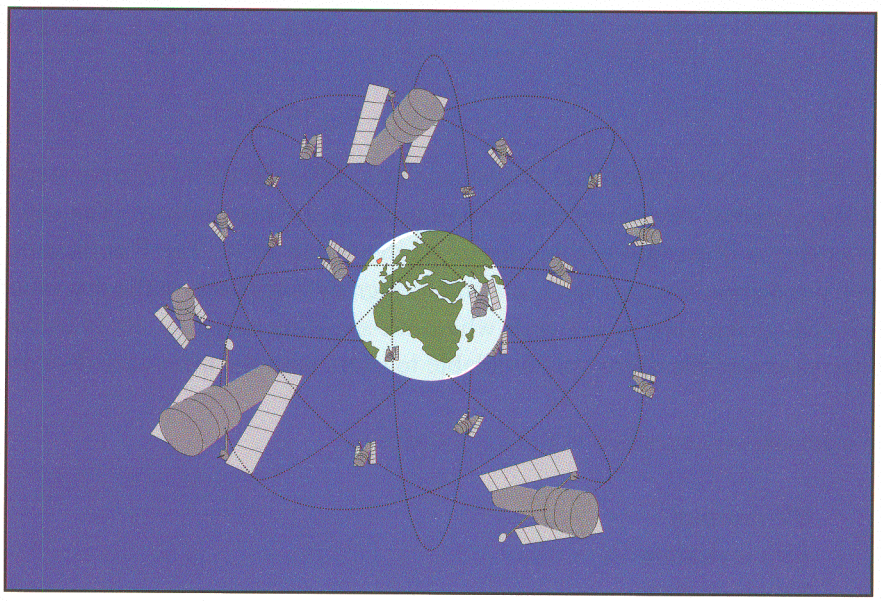

Figure 15.6. The GPS Satellite Constellation (21 active, 3 spares, in 6 orbital planes)

The SVs broadcast **pseudo-random noise (PRN)** codes of one millisecond duration on two frequencies in the UHF band. 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.

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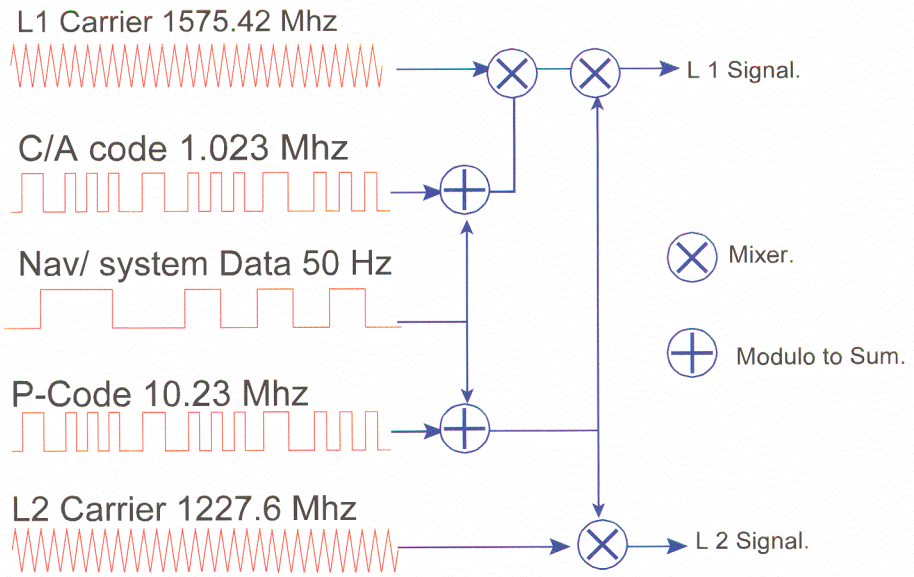

Fig 15.7

Only the C/A code is available to civilian users, although the USA have stated their intention to provide a second frequency for civilian users in the near future. The reason the use of two frequencies is important will be discussed in section 15.9. 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 replaced by a 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 information contained in the PRN codes is:

SV position
SV clock time
SV clock error
Information on ionospheric conditions
Supplementary information

The two services provided are:

The standard positioning service (SPS) using the C/A code
The precise positioning service (PPS) using the P code

GLONASS is intended to have 24 SVs (21 operational and 3 in-space spares) in three orbital planes inclined at 65° to the Equator, at present (July 2000) only 8 are operational. 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.

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15.6 THE CONTROL SEGMENT

The GPS control segment comprises:

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

Figure 15.8 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 15.8).

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15.7 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.

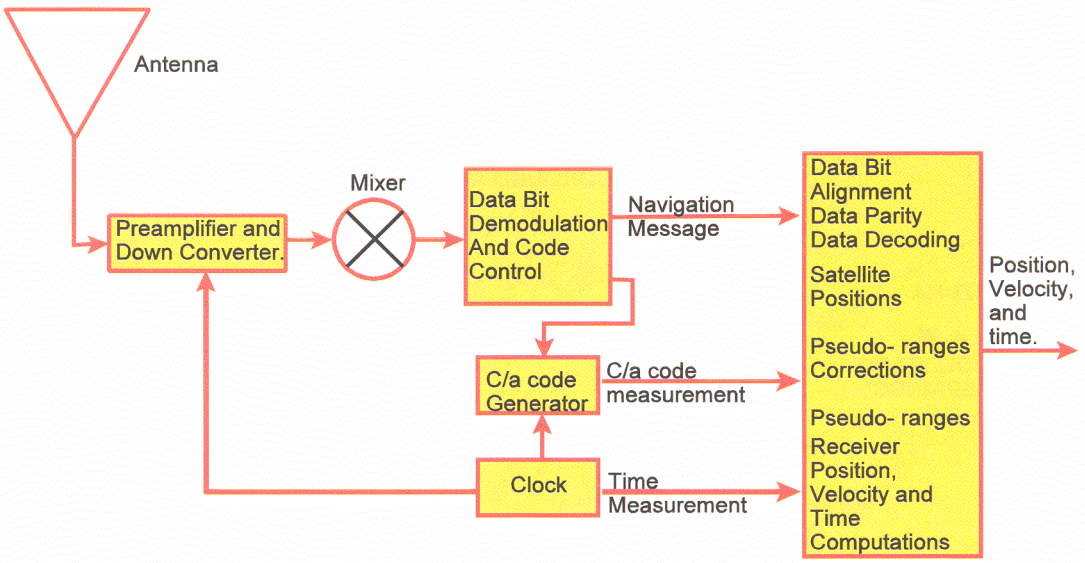

Fig 15.9 GPS Receiver Block Schematic

There are several types of receiver:

Sequential receivers which use one or two channels and scan the SVs sequentially to determine the pseudo-ranges (see paragraph 15.8).

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.

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Figure 15.10a GPS Receiver, Control Unit

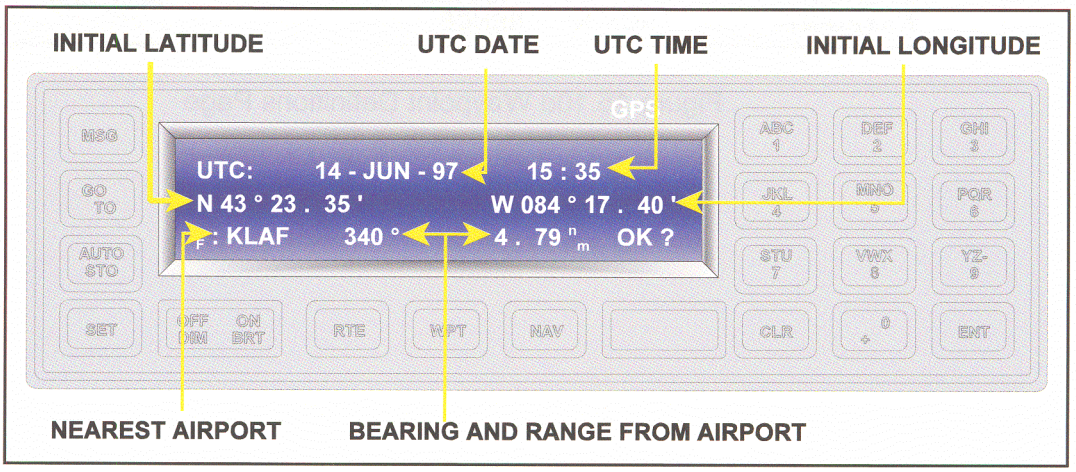

Figure 15.10b Initialisation Page

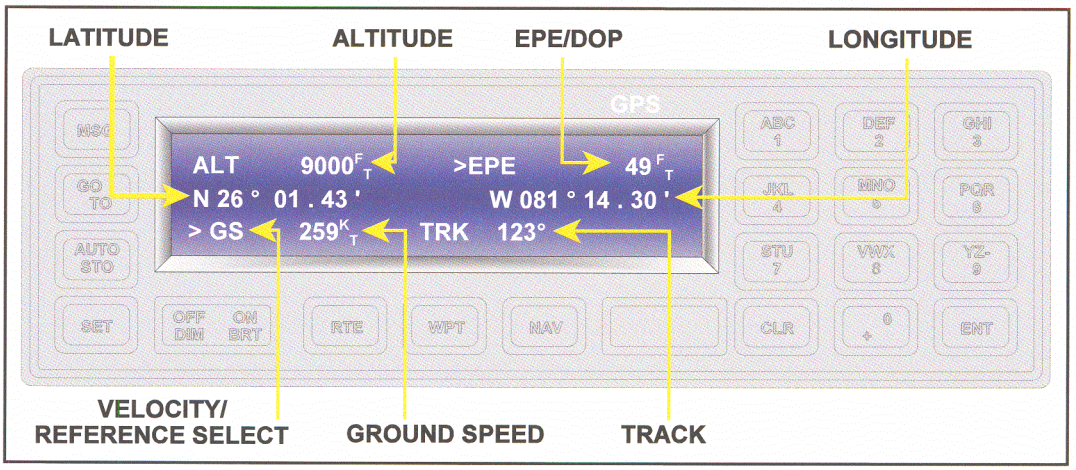

Figure 15.10c Position Page

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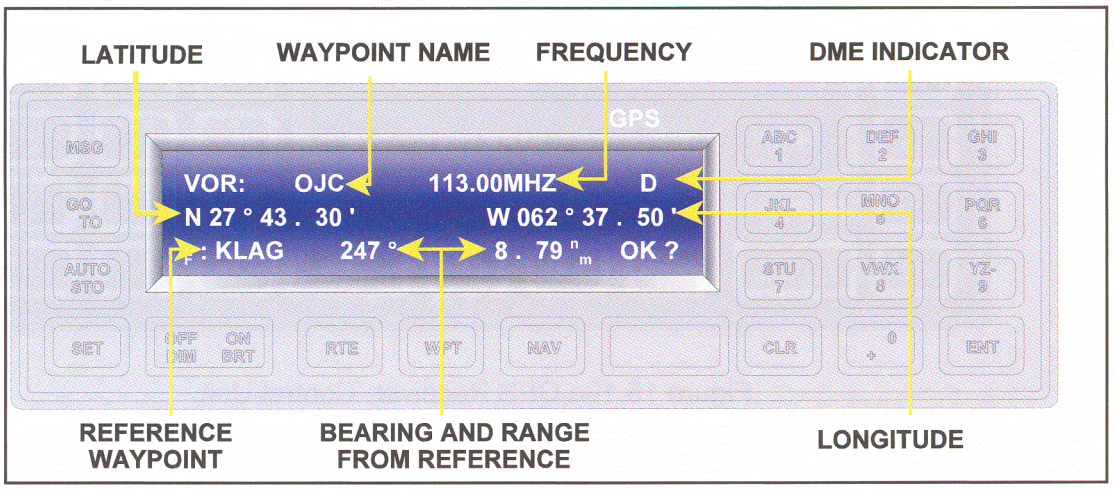

Figure 15.10d Waypoint Definitions Page

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15.8 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.

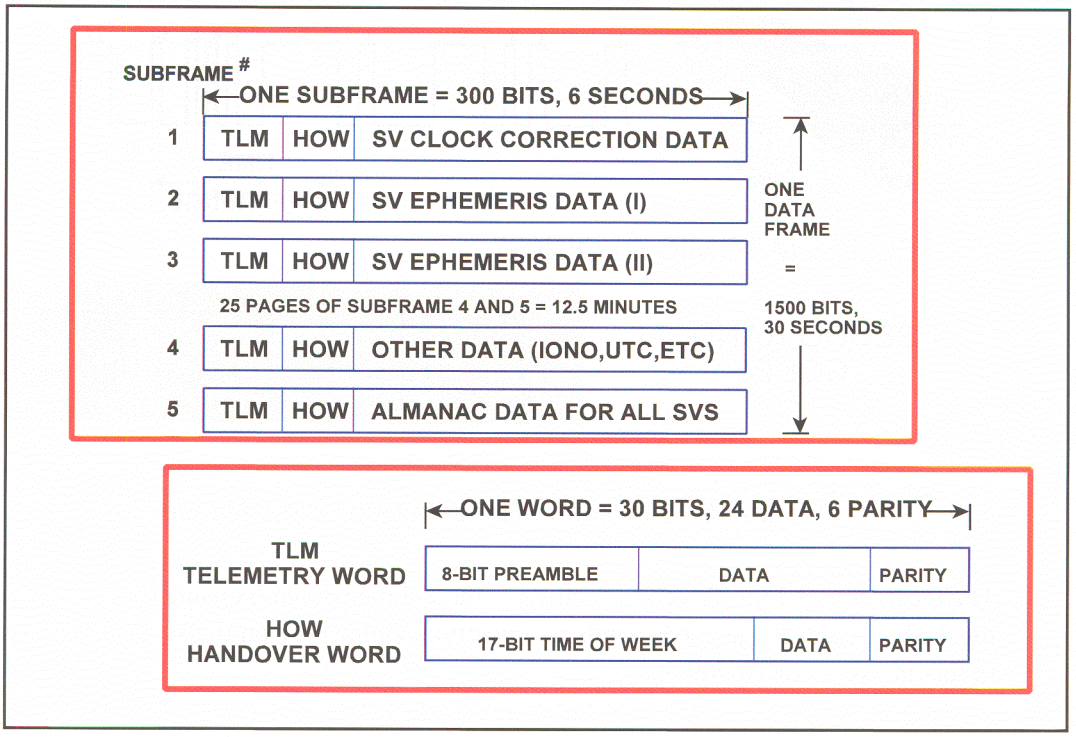

Figure 15.11 GPS Navigation Data Format

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, providing 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 it takes 12.5 minutes to download from the SVs. When the receiver position is significantly in error it will not detect the expected SVs. In this case it will carry out a systematic search to determine which SVs are in view, this search is known as **skysearch**. Similarly, when the receiver does not know its position it will carry out this search. Skysearch may include download of the almanac.

The time to first fix is determined by presence of an up to date almanac and the accuracy of position and time in the receiver. If the receiver has all three then the first fix, on initialisation, will be obtained within about 30 seconds. If any are missing then the time to first fix will be up to 15 minutes.

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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.

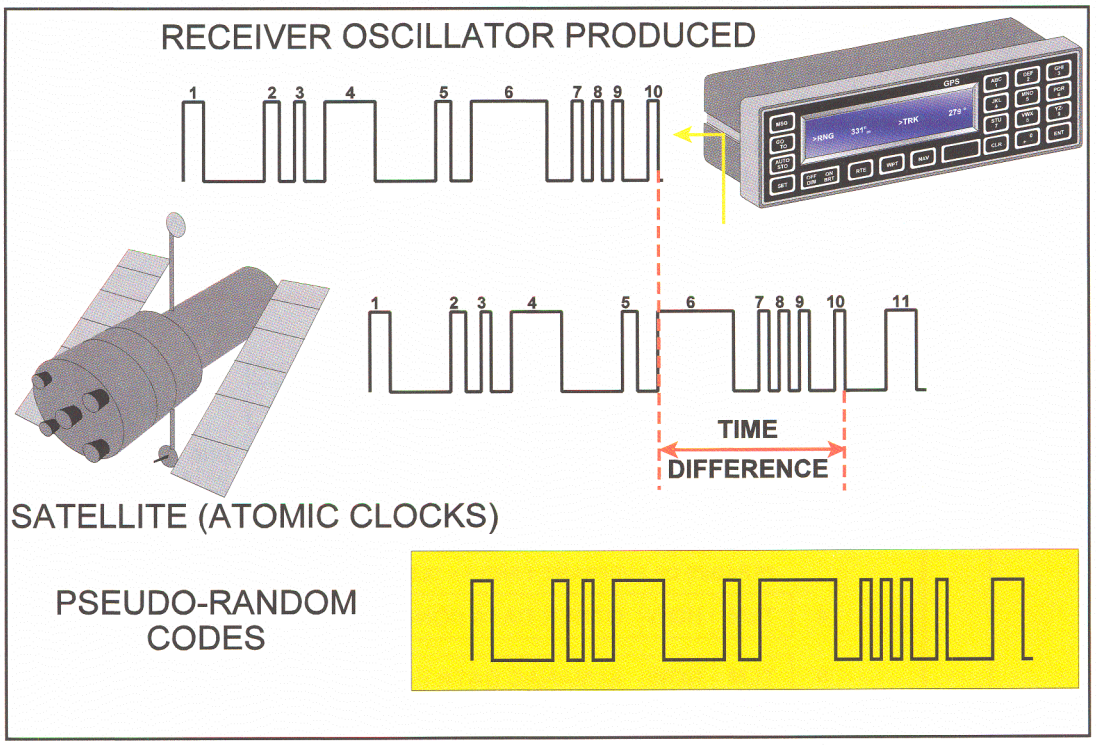

Figure 15.12. Pseudo-Random Code Time Measurement

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 10,900 nm.

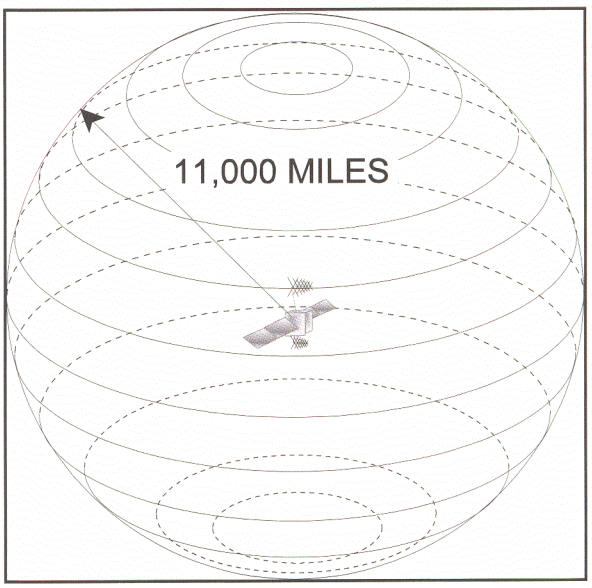

Figure 15.13.

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

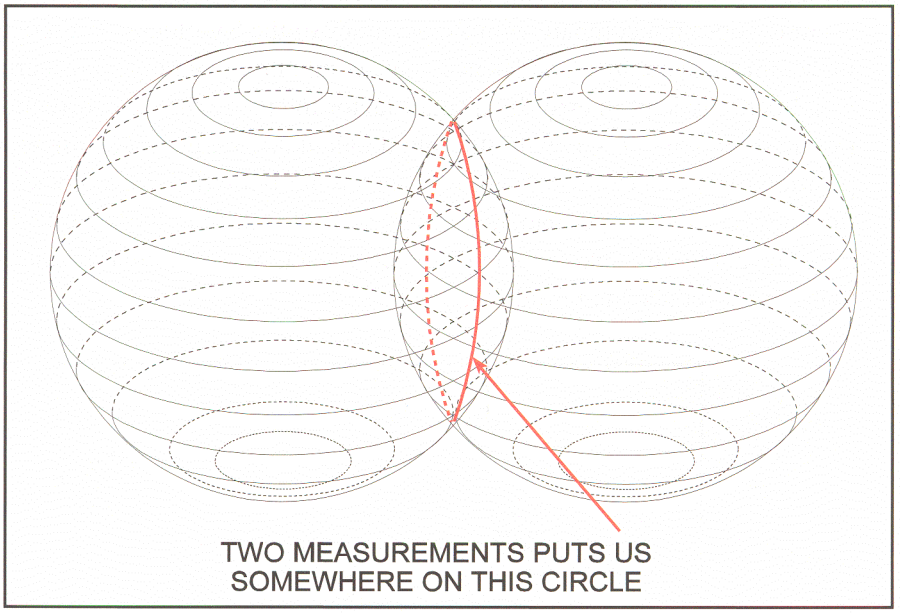

Figure 15.14.

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.

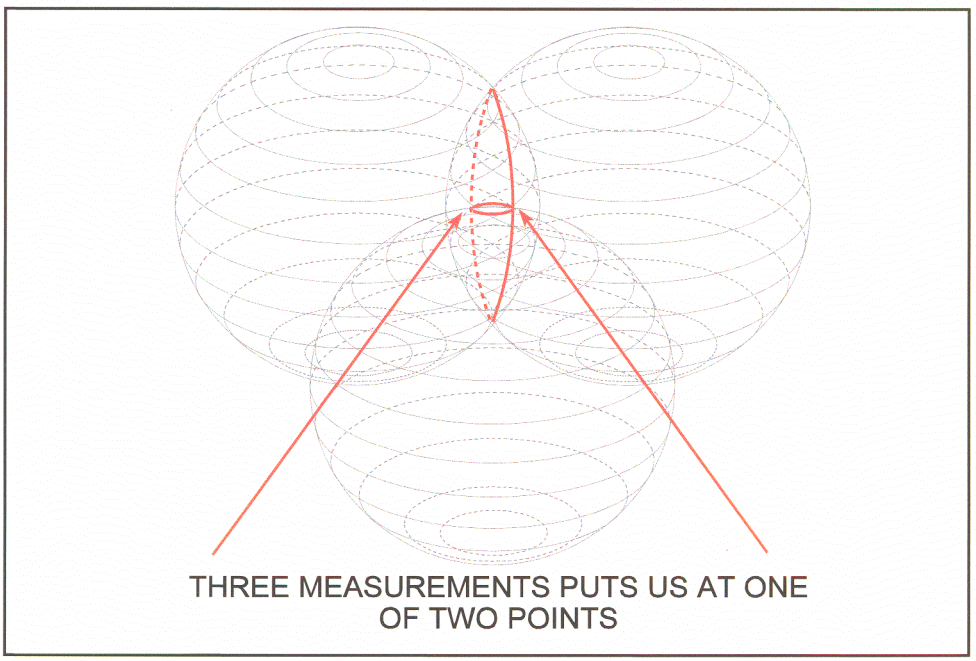

Figure 15.15.

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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**. The position lines as a result 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.

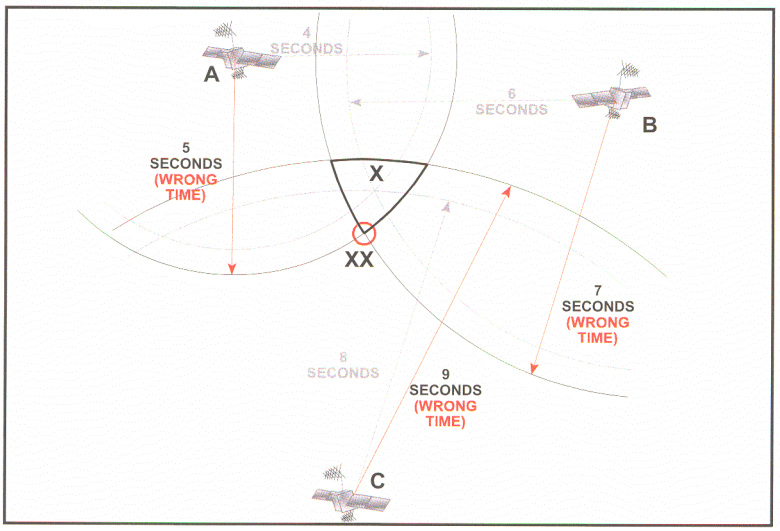

Figure 15.16a

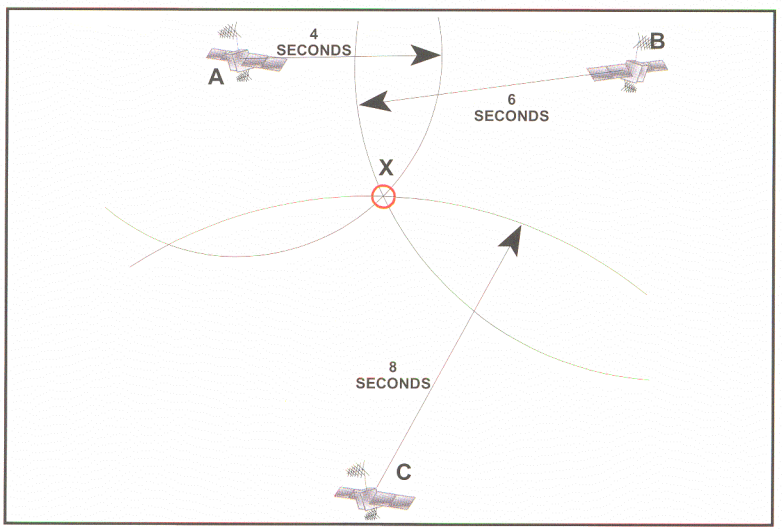

Figure 15.16b.

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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, ie 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 (eg the UK Ordnance Survey grid) and altitude.

Note: some receiver 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.

15.9 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 and planets and solar radiation. As discussed in 15.6 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 passed to the SV to be included in the broadcast. Maximum error 1.5 m.

Ionospheric propagation error. The ionosphere affects radio waves of all frequencies, the actual effect being dependent on the frequency. The SV broadcast contains a 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 model is updated to the SVs at least every 12 hours.
This is the most significant of the errors in SV navigation systems.
If two different frequencies are available then the SV can deduce the ionospheric effect on the transit of the signals and make appropriate adjustments to the observed times, thereby minimising the error.
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, for example a change in transit time of one nanosecond would give an error of 0.3 m. Maximum 0.5 m. 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 0.3 m.

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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.

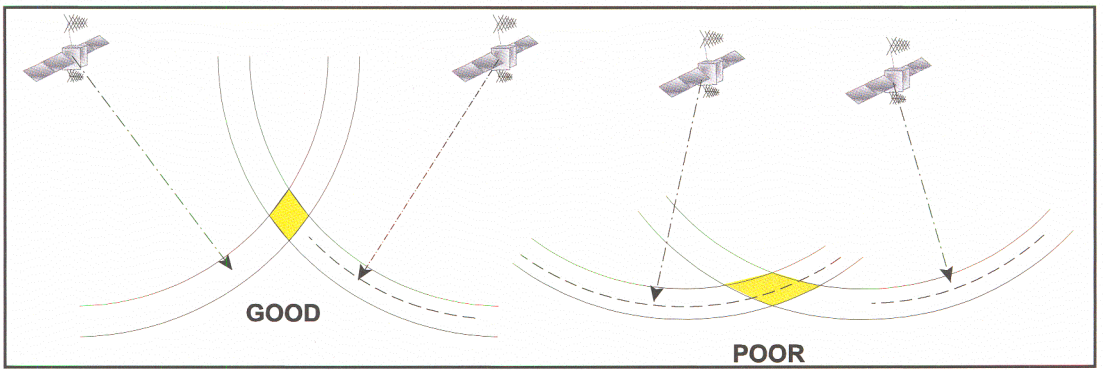

Figure 15.17. GDOP.

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.

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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 (ie 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 is achieved by introducing random errors in the SV clock time, known as *dithering the SV clock time*.

15.10 SYSTEM ACCURACY

The accuracy of the SPS is 15 m spherical error probable and believed to be better than 3 m for the PPS. In practice the accuracy of the SPS has been observed to be of the order of 5 m or better.

15.11 INTEGRITY MONITORING

The ICAO specification for radio navigation systems, requires a 2 second warning of failure for precision systems (eg 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.

15.12 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)

Space based augmentation systems (SBAS)

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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, so 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 there to be 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).

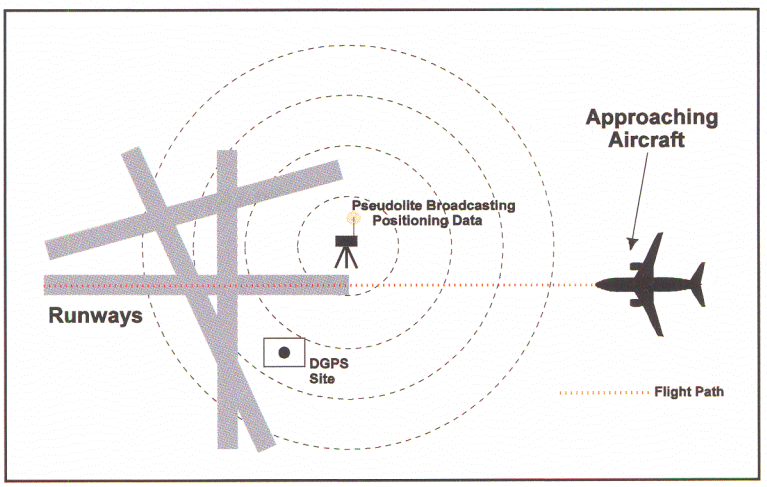

Figure 15.18 - LAAS

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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.

Space 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)**

The USA **WAAS**

The Japanese **MSAS**

The objectives of these systems are more or less identical, that is 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 (ie 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 2 segments making up SBAS:

The space segment which comprises the GPS and GLONASS constellations and the INMARSAT geo-stationary SVs

The ground segment, comprising reference stations (RS), regional control stations (RCS) and master control stations (MCS) or navigation earth stations (NES)

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.

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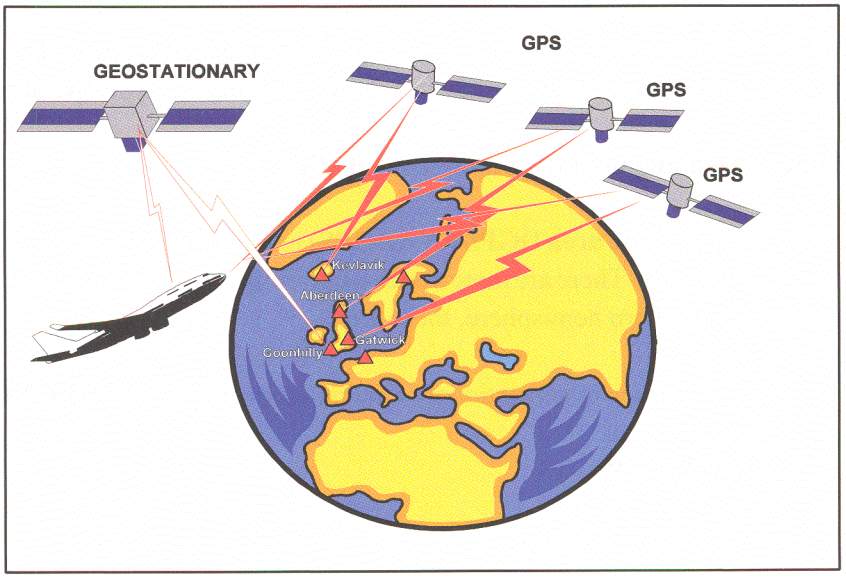

Figure 15.19 EGNOS Segments

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)

15.13 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.

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15.14 EXAMPLE QUESTIONS

1. NAVSTAR/GPS operates in the …… band and 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 and 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 …… satellites

   a. 12
   b. 21
   c. 24
   d. 30

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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. selective availability, satellite ephemeris and clock
c. GDOP, selective availability and propagation
d. receiver clock, GDOP, satellite ephemeris and clock

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14. The most accurate satellite fixing information will be obtained from:

a. NAVSTAR/GPS & GLONASS
a. TRANSIT & NAVSTAR/GPS
b. COSPAS/SARSAT & GLONASS
c. 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

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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

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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

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15.15 ANSWERS

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

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CHAPTER SIXTEEN - LORAN C

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16.1 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.

16.2 LORAN COVERAGE

Figures 16.1and 16.2 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 16.3 A LORAN chain

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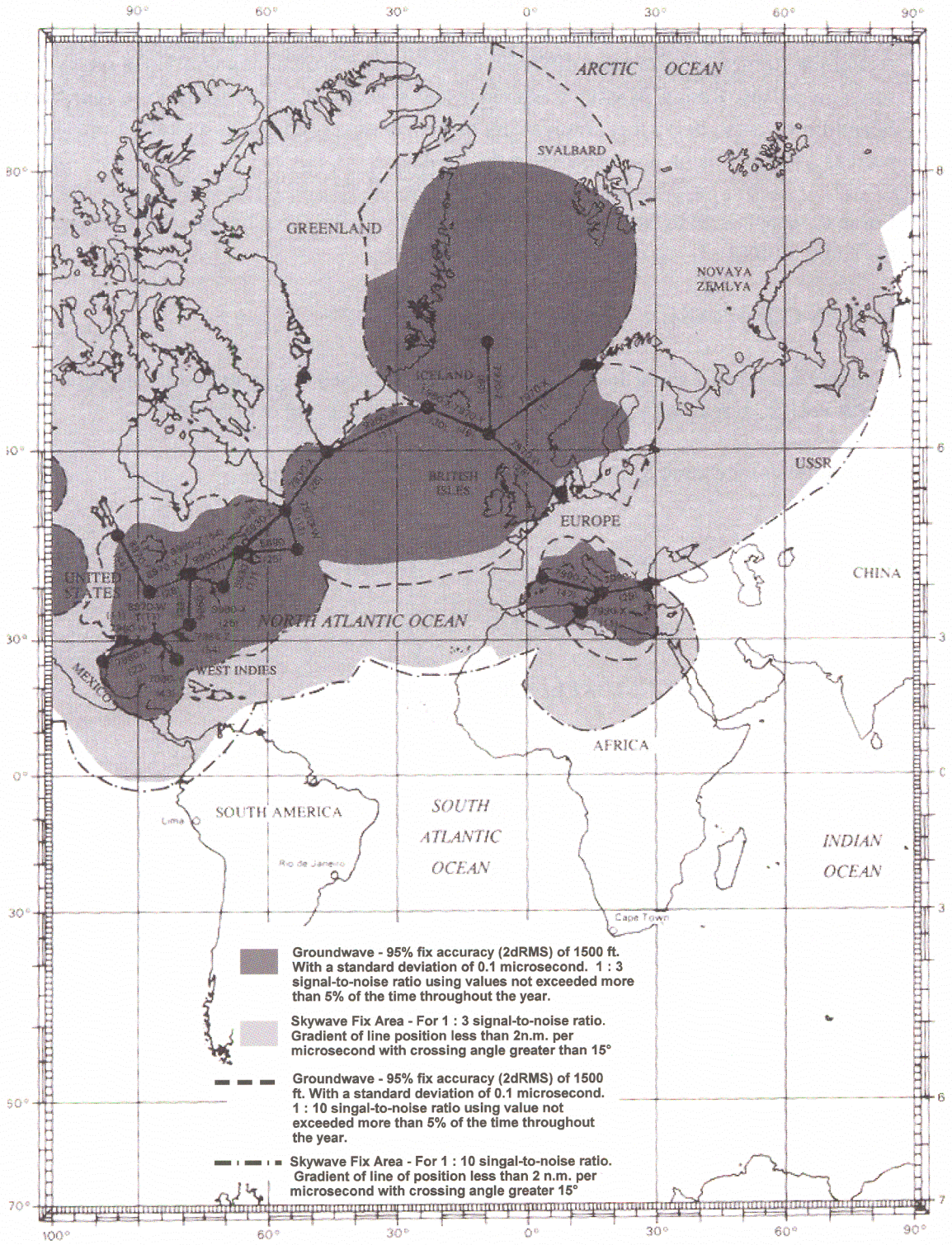

Figure 16.1. Atlantic Coverage.

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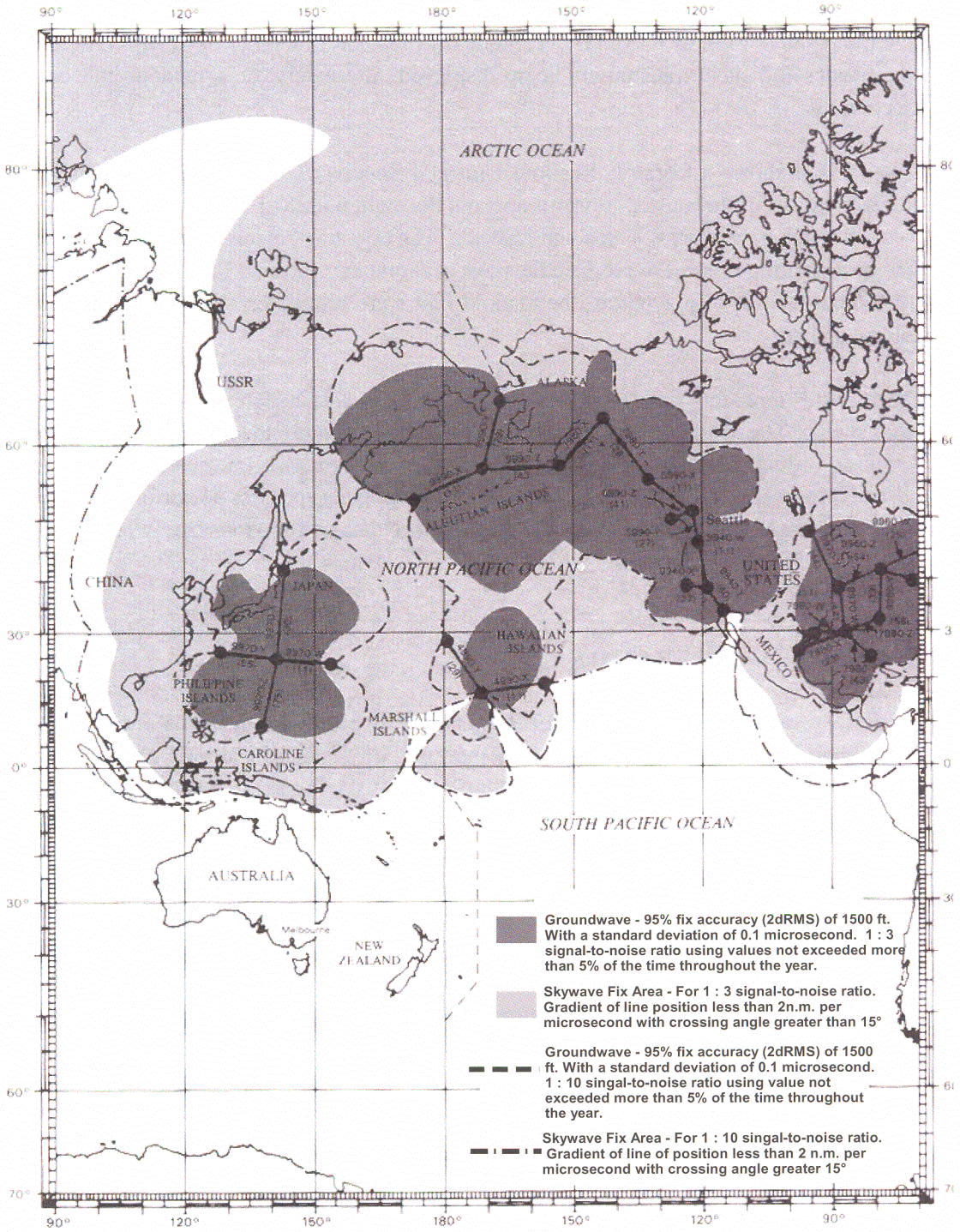

Figure 16.2. Pacific Coverage.

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16.3 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 16.4 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.

16.4 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 16.4). Figure 16.5 shows part of a Loran C chart. Consider master-slave time differences of 50000 μs and 64600 μs as shown in figure 16.6.

a) **Timebase 1** (Figure 16.6a.) 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.

b) **Timebase 2** (Figure 16.6b.) 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.

c) **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 16.6c.

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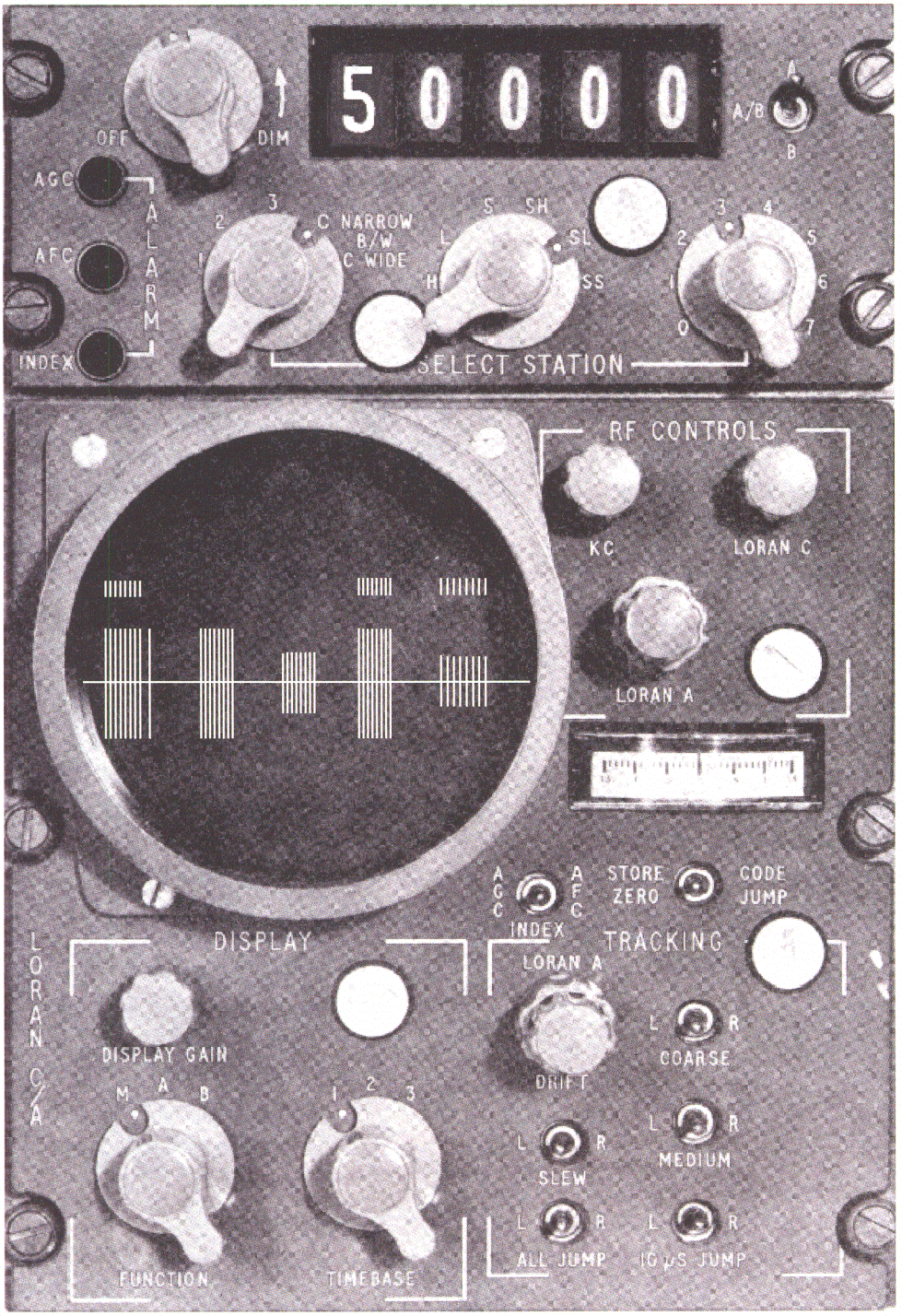

Figure 16.3. Readout unit & Receiver/CRT presentation

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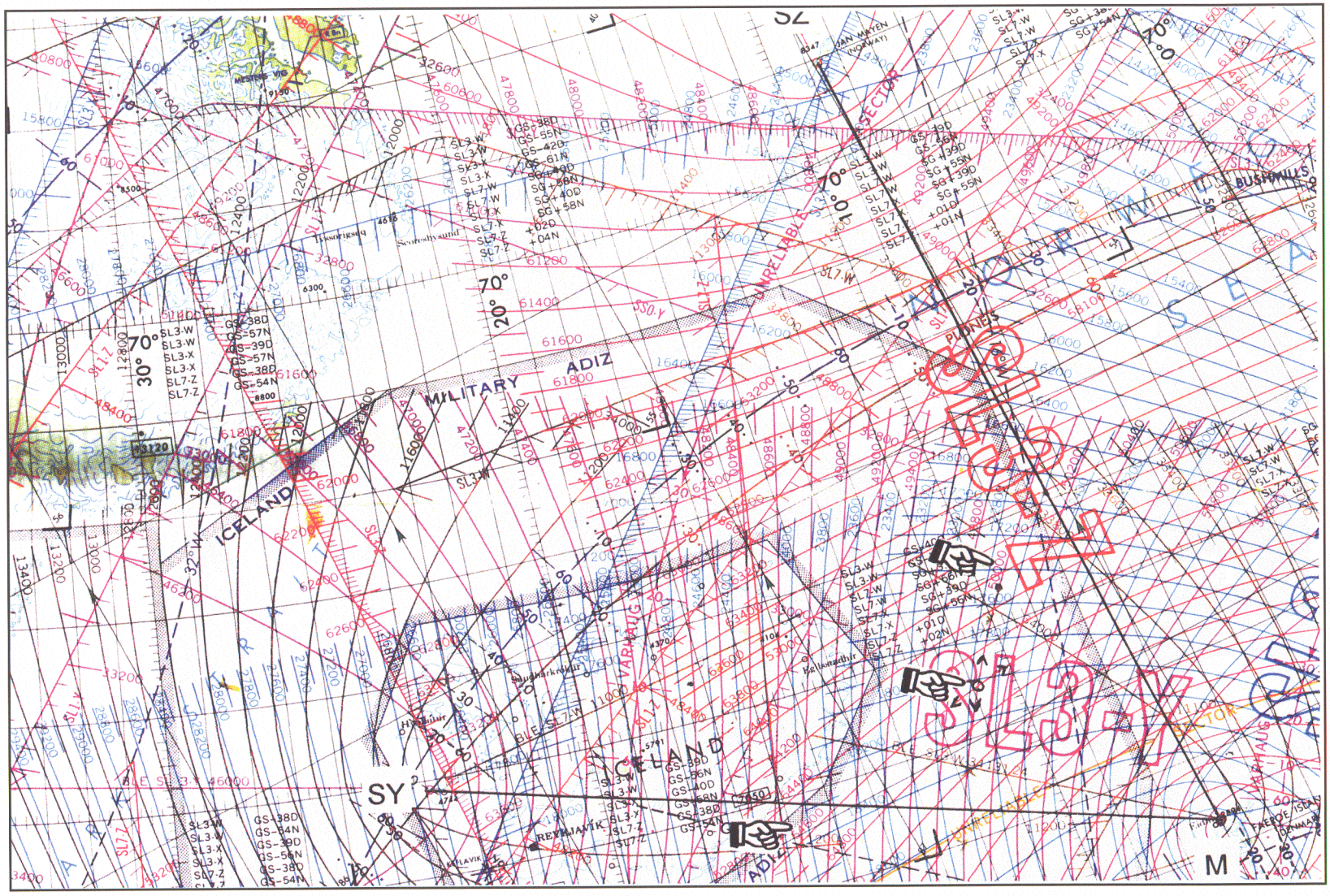

Figure 16.4. Portion of Loran C Hyperbolic Chart.

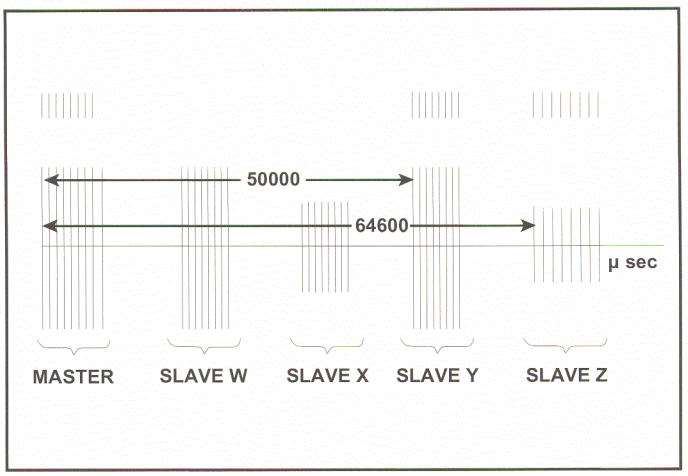

Figure 16.6a. Master and Slaves Gated.

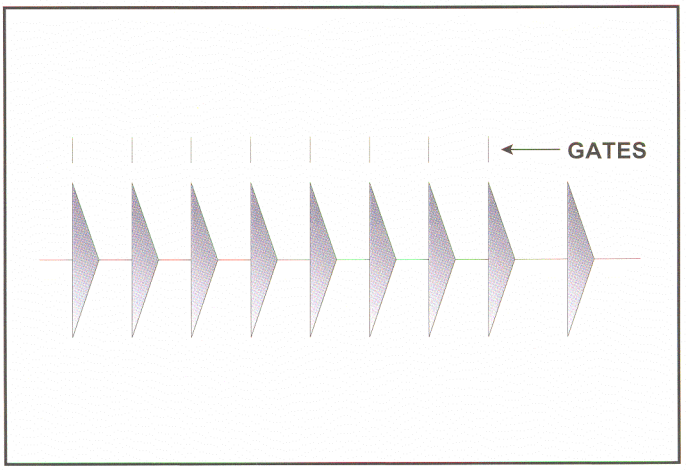

Figure 16.6b. Master more accurately Gated.

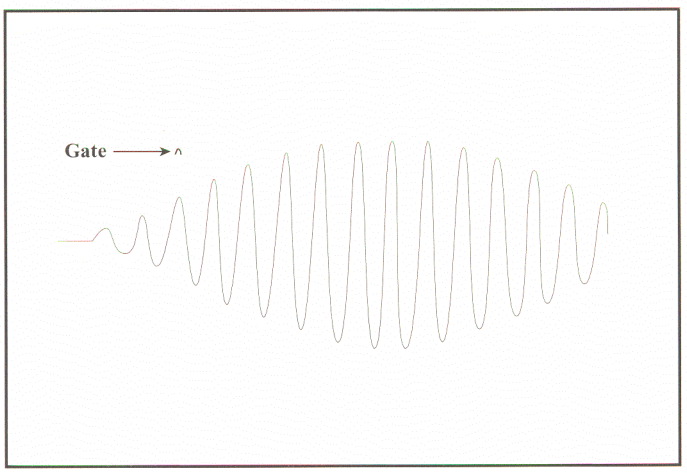

Figure16.6c. Combined Pulses and 3rd. Cycle gated.

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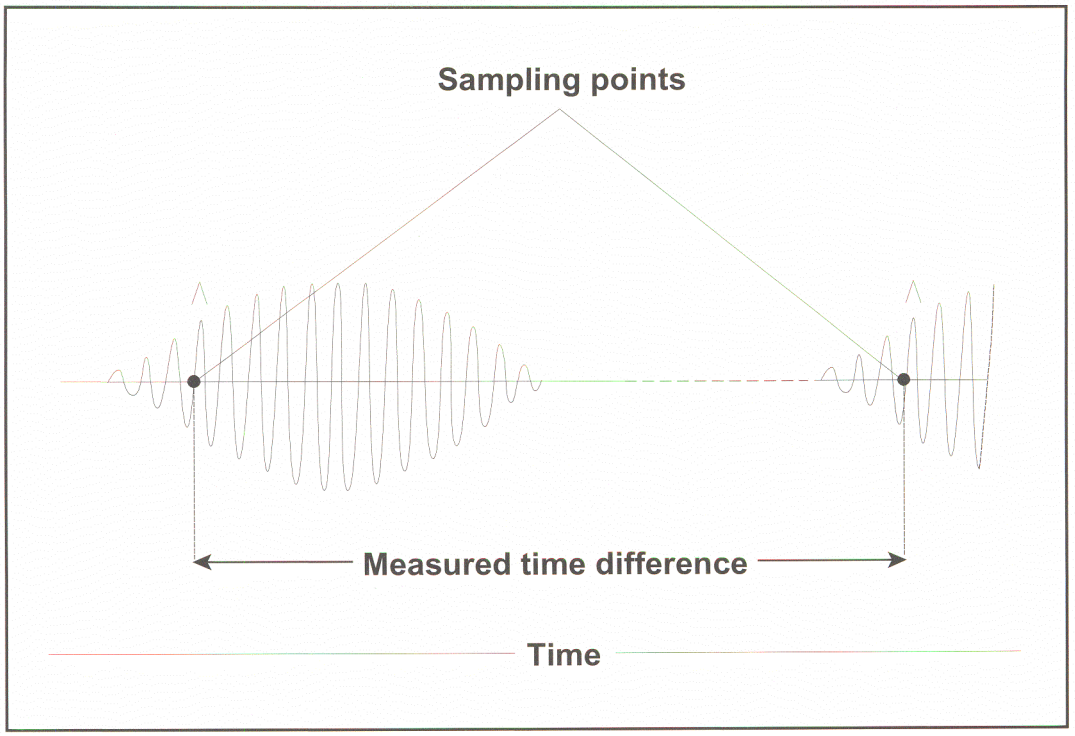

Figure 16.6d. Cycle matching or Indexing.

Figure 16.6d 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.**

16.5 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

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

a) 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. (See Figure 16.3.)

b) 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.

16.6 SLAVE STATION - TIME DELAYS

It can be seen from the diagram of the pulses displayed on the CRT, Figures 16.4/5., 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 16.7.). 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.

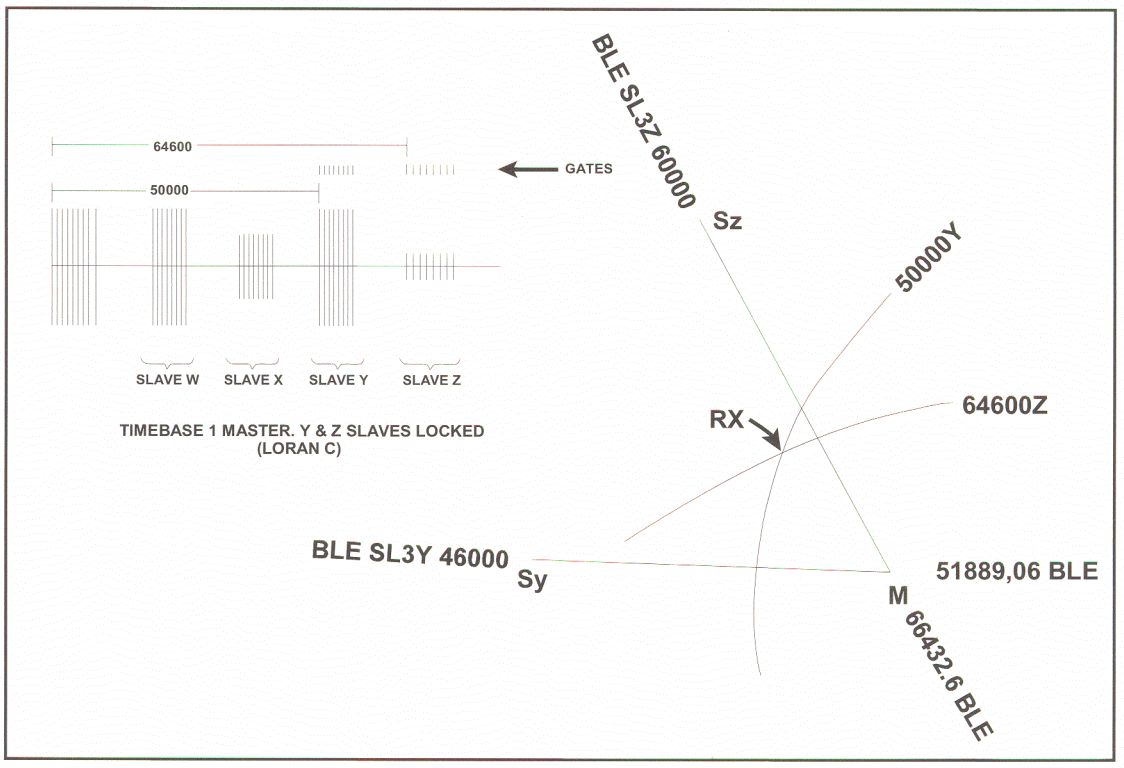

Figure 16.7. Baseline Extension Time Delays.

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16.7 DIFFERENTIAL RANGE BY TIMING

Consider that 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.

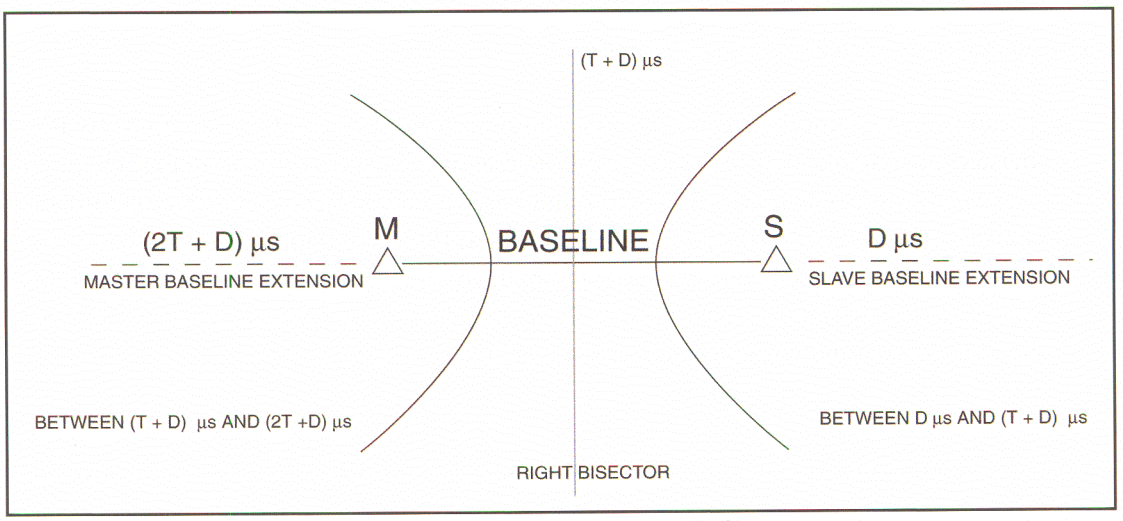

Figure 16.8 Propagation Delay

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

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

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16.8 RANGES AND FACTORS AFFECTING RANGE

a) **Ground Wave Range**

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

i) **1200 nm** over **water.**

ii) **900 nm** over **land.**

b) **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.**

c) **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.

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16.9 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 16.9a. The phases of the pulses in a group would be coded in a predetermined sequence as shown in Figure 16.9b. 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.

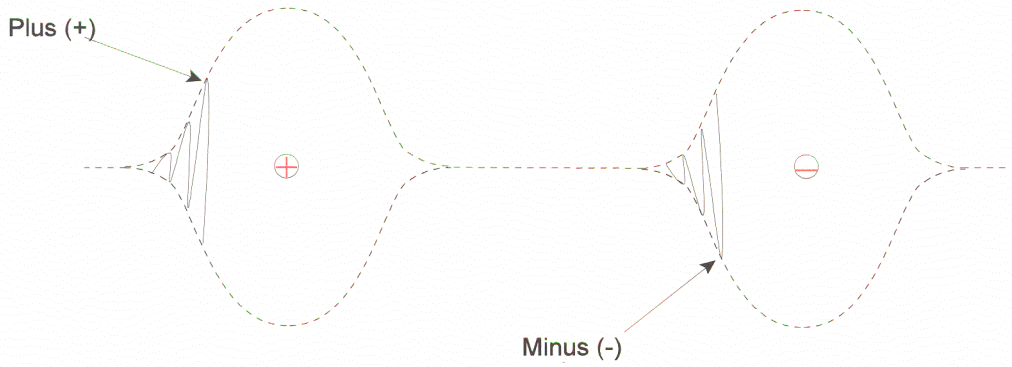

Figure 16.9a Carrier Wave Phase

Figure 16.9b Phase Coding

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16.10 FIX ACCURACY

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

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

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

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

d) 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.

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16.11 APPENDIX 16 A [NOT REQUIRED FOR JAA EXAMS]

1 Calculation of Baseline Distance (Figure 16.7).

Delays at SY and M are 46000µsec and 51889.06µsec

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

$$= \underline{\underline{477\text{nm}}}$$

Delays at SZ and M are 60000µsec and 66432.6µsec

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

$$= \underline{\underline{521\text{nm}}}$$

2 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:

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

$$= 2944.53\mu\text{sec}$$

$$\text{Delay at SY} = 46000\mu\text{sec}$$

$$\text{SY to receiver} = 50000\text{-}(46000+2944.53)\mu\text{sec}$$

$$= \underline{\underline{1055.47\mu\text{sec}, 171\text{nm}}}$$

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.

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3 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:

a) Station not transmitting.
b) Incorrect number of pulses.
c) Incorrect pulse spacing.
d) 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.

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16.12 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 Operation

Differential range by pulse technique or timing
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 Range

From propagation delay between pulses from master and slave stations.

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.

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16.13 QUESTION PAPER

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.

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ANSWERS

QUESTION	ANSWER
1	c

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CHAPTER SEVENTEEN - DECCA

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17.0 The last DECCA chain was withdrawn on 31st December 2000, and, whilst the subject remains in the syllabus until the amendment process goes through, the CAA have stated that it will not be examined.

17.1 INTRODUCTION

DECCA is a hyperbolic navigation system using radio frequencies in the LF range. It has been in use for over 50 years and is due to be phased out after the year 2000. DECCA works on the principle of **differential range by phase comparison**. The earlier systems required a navigator to plot the aircraft position by taking readings from indicators called decometers and identifying hyperbolic lines on charts. Later systems provided the aircraft position on a read-out or a moving map display once the system had been set up correctly.

17.2 HYPERBOLAE

a) Definition

A hyperbola is the path (locus) of a point having a **constant difference in distance from** two fixed points called **the foci.** A series of such hyperbolae is known as a family as shown in figure 17.1 where the foci are called Master and Slave.

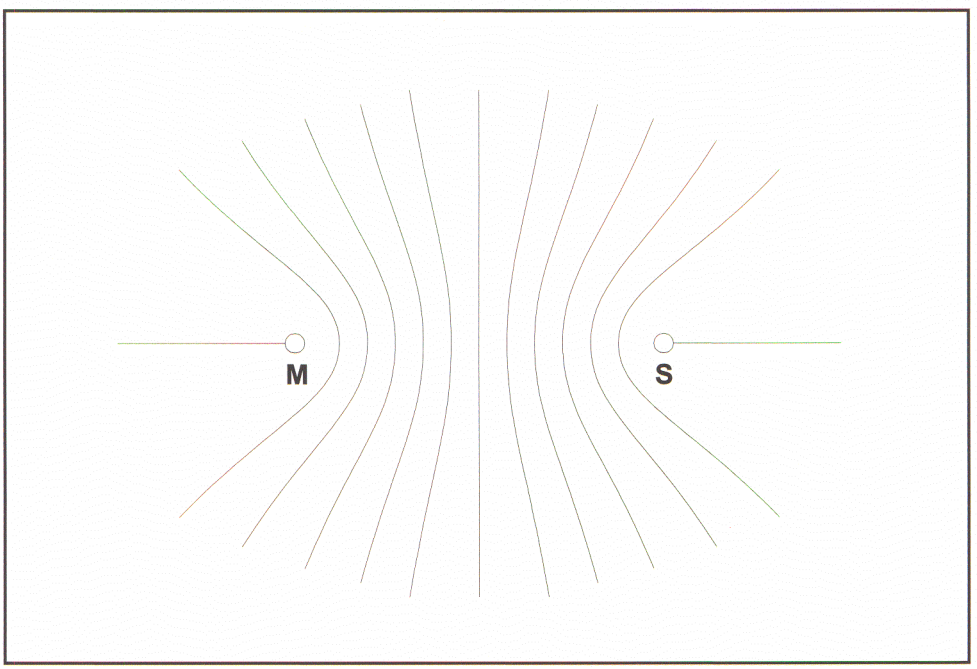

Figure 17.1. Family of Hyperbolae.

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b) **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 17.2.

The line joining C, B, A, B_1, C_1 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.

c) **Baseline Extensions**

The baseline extensions, from M or S, shown in figure 17.3 are also a hyperbolae as the difference in distance along those lines is a constant M to S or baseline distance.

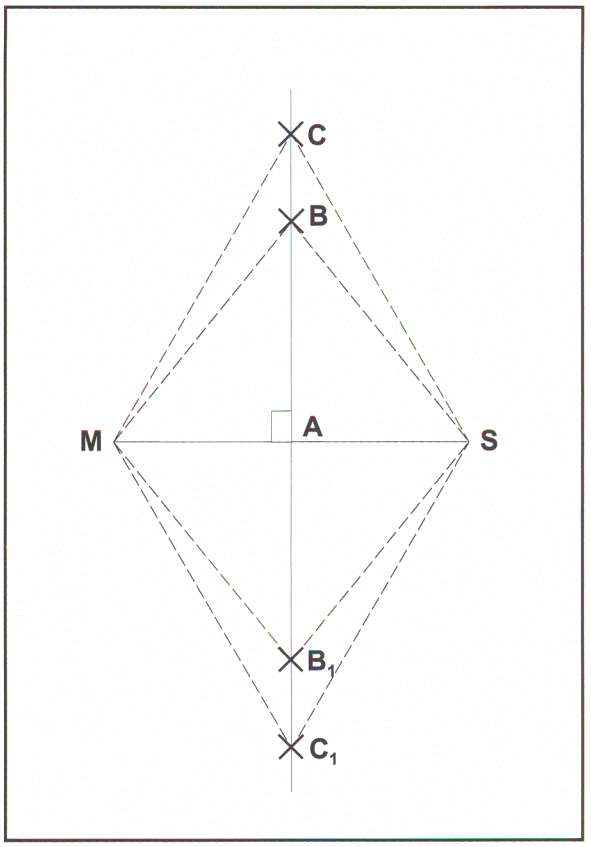

Figure 17.2. Baseline Right Bisector.

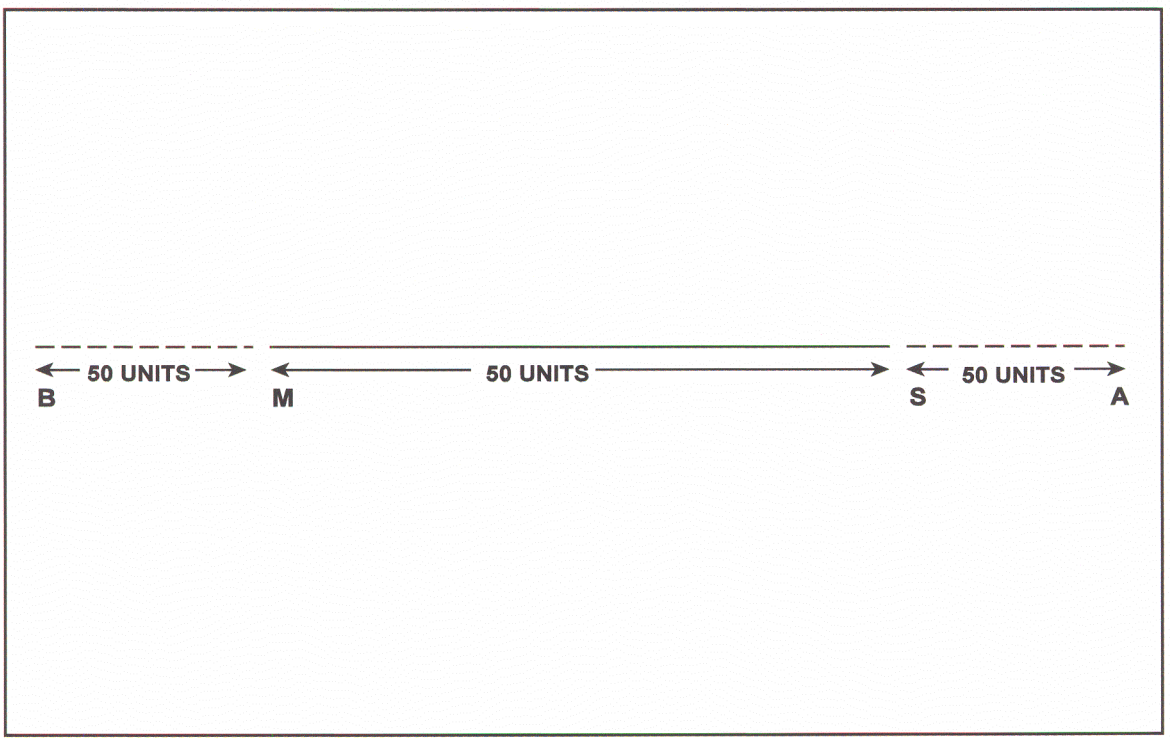

Figure 17.3. Baseline Extensions

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d) **Curved Hyperbola**

Any hyperbola constructed in the areas between the right bisector and the extended baseline will be curved. See Figure 17.4. Thus any point on a curved hyperbola has a constant range difference from M and S.

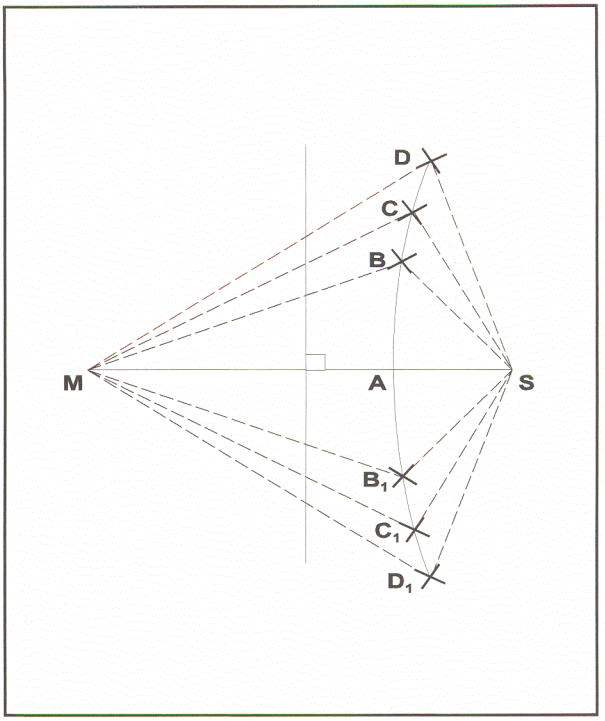

Figure 17.4. Curved Hyperbola.

17.3 DECCA CHAINS

A Master and Slave transmitter will produce a family of single hyperbola and thus an aircraft could be at any point on a particular hyperbola. Therefore, to resolve its position, at least one other judiciously sited Slave transmitter is required to provide another hyperbolic family, to form a **hyperbolic lattice**; the intersection of a minimum of two hyperbolae thus produces a fix. In reality Decca consists of a **chain** made up of a **Master and up to three Slave transmitters** which are synchronised to the master transmitter. Figure 17.5 shows the layout of one such DECCA chain. The distance between master and slave stations is 50 to 100 nm.

An infinite number of hyperbolae could be drawn between the Master and Slave transmitters of an appropriate DECCA or LORAN C chart. In practice only those hyperbolae that facilitate plotting are printed; other values can then be interpolated. Hyperbolic navigation systems enable an aircraft to fix its position from the intersection of two or more lines of position (LOP). For ease of plotting the hyperbolae are colour coded and printed on DECCA or LORAN C charts, which are still available.

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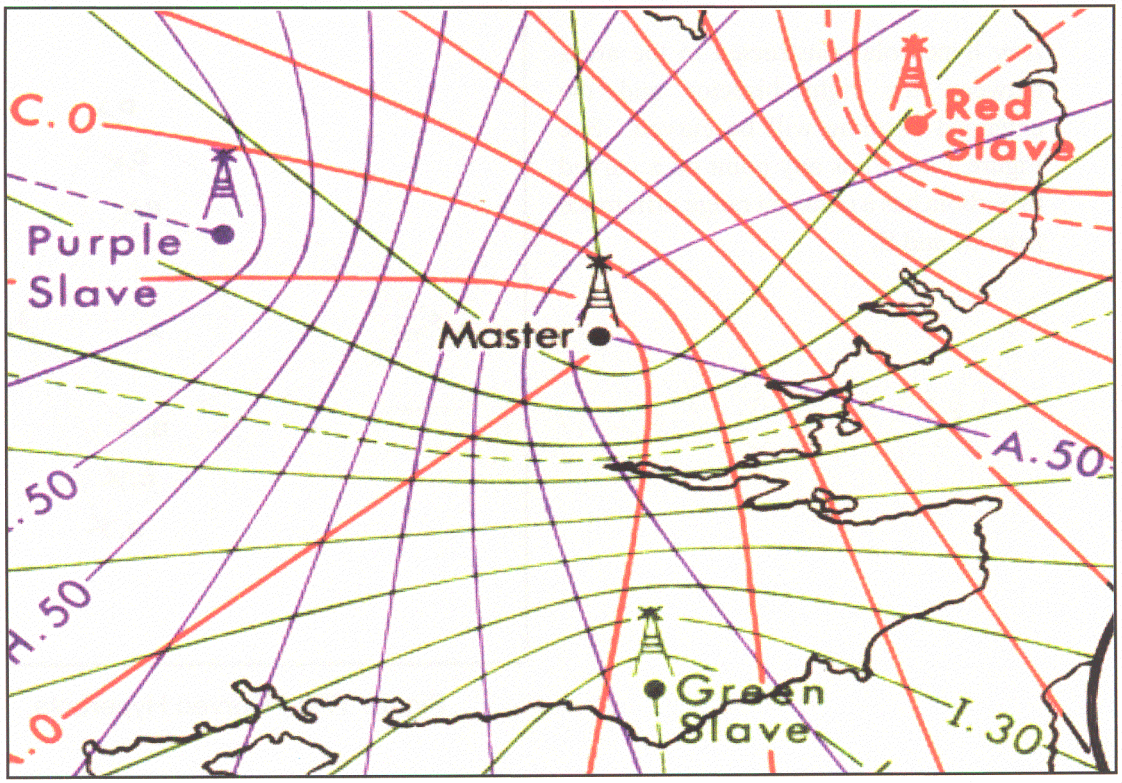

Figure 17.5 Layout of Typical Chain.

17.4 POSITION FIXING

Figure 17.6. shows the layout of a Decca chain with an aircraft positioned at the intersection of **Red hyperbola I. 16.3** and **Green hyperbola D. 35.8.** The I and D denote the appropriate Red and Green Zone whilst the figures indicate the zone's lane number and decimal portion.

Before the advent of computers a trained crew member would plot the aircraft's position on the appropriate the navigational hyperbolic chart from information displayed on decometers or a Loran C read-out unit. Nowadays, the navigational information is computerised and automatically converted to latitude and longitude, or distance to go/across track information, all of which are displayed on a Control Display Unit (CDU).

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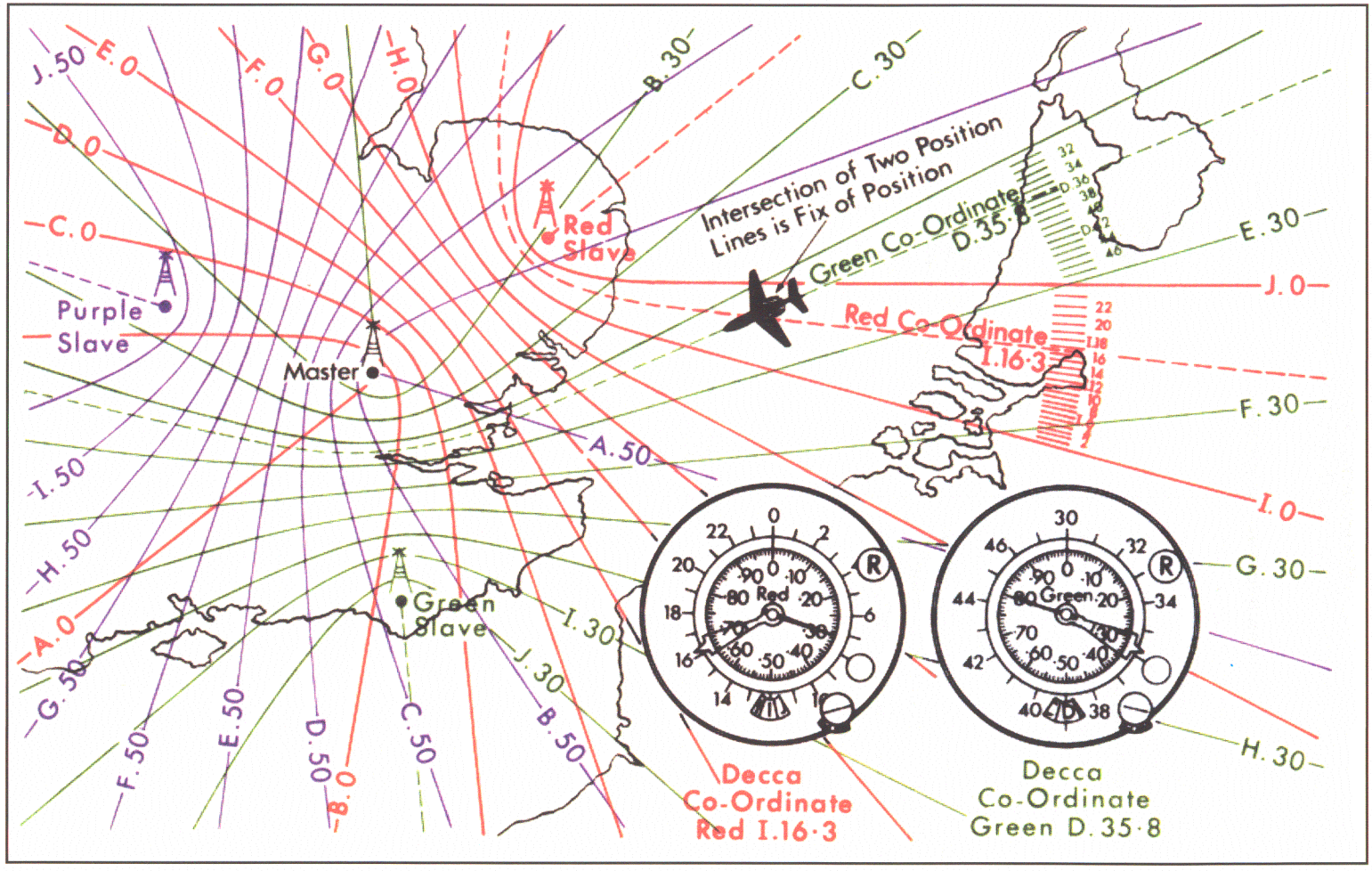

Figure 17.6. Hyperbolic Lattice and Chains.

17.5 FUNDAMENTAL AND COMPARISON FREQUENCIES

DECCA works on the principle of **differential range by phase comparison**. In practice the master and slaves cannot transmit on the same frequency as the transmissions would merge at the aerial producing a single voltage; phase comparison cannot take place unless each transmission has a separate identity. Therefore to maintain their identities the master and slaves of a chain **each transmits a different frequency**, which is a **multiple of the chain's allocated fundamental frequency** *f*, which itself is never transmitted.

The fundamental frequency *f* is always close to 14kHz. The transmitters thus transmit fixed harmonics of *f*:

Master	- 6*f*
Red Slave	- 8*f*
Green Slave	- 9*f*
Purple Slave	- 5*f*

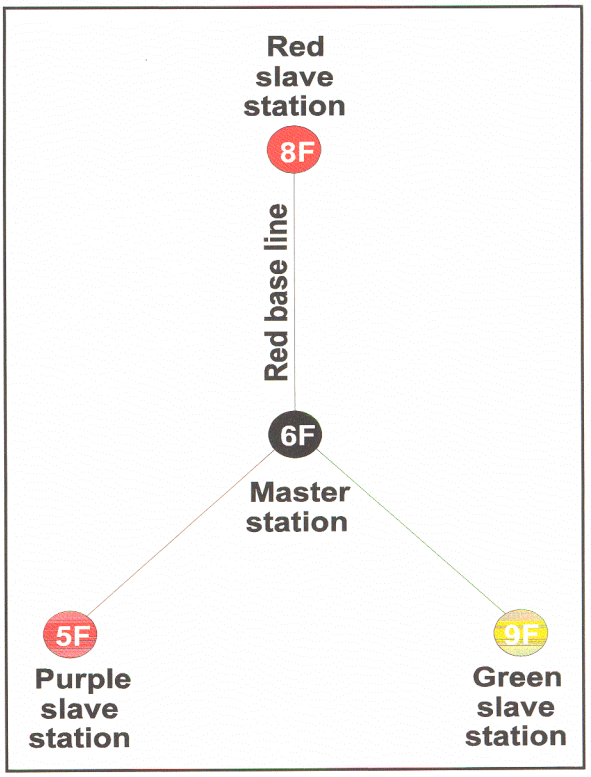

Figure 17.7. Fundamental Frequency Multiples

Thus the transmission frequencies for a Decca chain with a fundamental frequency *f* of 14.2kHz would be: MASTER 6*f* = 85.2kHz, RED 8*f* = 113.6kHz, GREEN 9*f* = 127.8kHz, PURPLE 5*f* = 71kHz.

The problem of separating and identifying the frequencies at the receiver has thus been solved but phase comparison between different frequencies is not possible. To surmount this problem each master/slave combination is now stepped up within the Decca receiver to a common frequency. This is done by multiplying each master/slave combination's lowest common multiple (LCM) by the chain's particular fundamental frequency *f*, to produce a **Comparison Frequency**:

Master 6*f* / Red 8*f* LCM = **24*f*** which is the **comparison frequency** for this pair.

Master 6*f* / Green 9*f* LCM =**18*f*** which is the **comparison frequency** for this pair.

Master 6*f* / Purple 5*f* LCM = **30*f*** which is the **comparison frequency** for this pair.

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17.6 ZONES AND LANES

When phase comparison is carried out between two signals the phase angle difference depends upon the position of the receiver. At some point this angle will be zero and we find that, along the baseline, the zero phase angle is repeated at a distance of exactly half the wavelength of the frequency being considered. This results in zones or lanes between the two stations which relate to the wavelengths of the frequencies considered. The distances along the baselines can be calculated from a knowledge of the frequencies.

The width of the Zone relates to the fundamental frequency and is the same for all the red, green and purple stations. The width of a zone is half the wavelength of the fundamental frequency along any baseline. Zones are denoted by letters from A to J.

A zone is divided into a number of lanes which are denoted by numbers in a particular way. The width of the lane is determined by comparison frequency for that master-slave pair. Therefore we have a different number of lanes in each of the red, green and purple zones; there are **24** Lanes to a **Red Zone**, **18** Lanes to a **Green Zone** and **30** Lanes to a **Purple Zone**. The width of a lane along the baseline is **half the wavelength of the comparison frequency** for that pair**.** Inspection of a Decca chart will show that the widths of the lanes and zones increase markedly as the distance from the baseline increases. Red lanes are numbered from 0 to 23, green from 30 to 47 and purple from 50 to 79.

Figure 17.8 shows that at the receiver the resulting phase comparisons are displayed on the appropriate Red, Green or Purple decometer as Zone by letter, and a Lane by number and fraction. Refer to Figure 17.6. for decometer and chart presentation.

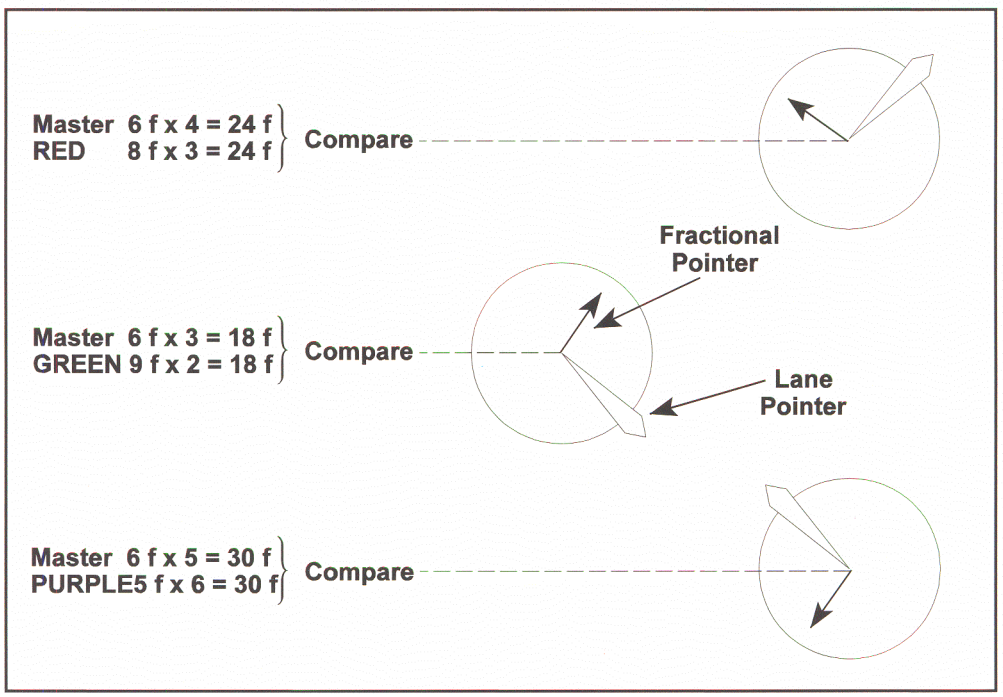

Figure 17.8. Basic Decca information presented on decometers.

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17.7 ACCURACY AND AMBIGUITY

a) Factors Affecting

Any errors due to the airborne equipment, accuracy of the transmitted frequencies, synchronisation of Master and Slave transmissions, and radio wave propagation, will be a minimum along the baseline where the hyperbolae are closest together. As range from the baseline increases the hyperbolae diverge and any system error becomes increasingly magnified. The base-line extension areas are the least accurate. (See Figure 17.9). The extreme curvature of the hyperbolae in the baseline extended areas may also give rise to plotting errors due to the ambiguity inherent in the choice of the correct position line. figure 17.10).

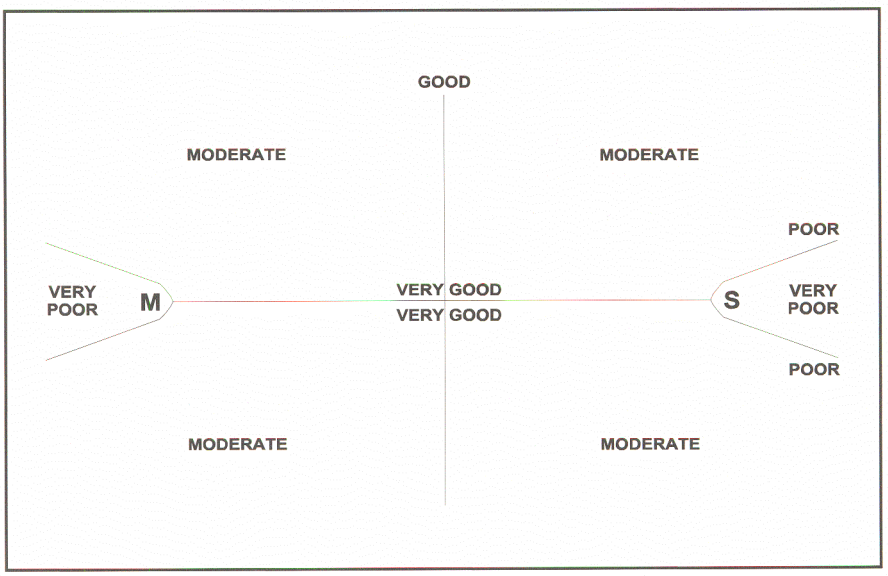

Figure 17.9. Accuracy Spread.

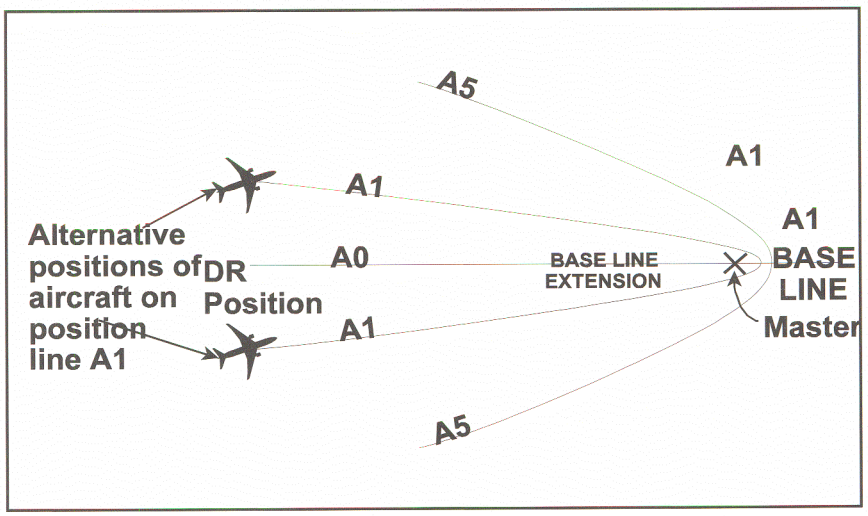

Figure 17.10 Ambiguous Area.

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Furthermore, the angle of cut of the hyperbolae furthest away from the base-line is too small to provide an accurate fix i.e. the accuracy is affected by the geometry of the position lines. (See figure 17.6). This limits the maximum range at which hyperbolic navigation systems can be used. Modern automated hyperbolic systems will automatically choose the best hyperbolae and change to another chain when the extremities of the present chain are reached. Also they can assess, simultaneously, data from more than one chain.

b) **Accuracy**

Within the area of coverage 95% of fixes are better than:

- 4nm by night.
- 2nm by day in winter. (some skywave present due to weak D layer)
- 0.5nm by day in spring, summer and autumn.

The accuracy of the Decca chain is affected by speed of propagation of the signals and the accuracy to which the frequency and phase of the slave stations is maintained. The inaccuracy due to **propagation delay** can be corrected to some extent by using appropriate **Decca data sheets.**

c) **Lane Identification**

The process of lane identification is made possible by the use of a **'multipulse'** system which uses short breaks in the normal transmissions. Lane identification periods last for half a second when the receiver switches to an alternative mode to permit master-slave phase comparisons at a different frequency from those used for the normal pattern.

17.8 DECCA COVERAGE

Decca is a short- range, land-based, LF (70 - 130kHz) hyperbolic navigation system with very limited geographical coverage. (See Figure 17.11). It is used mainly by surface vessels, helicopters and short range aircraft, though most of these are now switching over to the use of **GPS due to its greater accuracy and coverage**.

With the introduction of airborne computers decometers are no longer necessary as the Decca navigation information is converted to latitude/longitude or along/across track co-ordinates which are displayed on a CDU of an RNAV system.

Before the DECCA can be used it is necessary to set the initial positions. This was done by setting the appropriate lane numbers in the old equipment and in modern sets it is done by setting the dead reckoning position in latitude and longitude.

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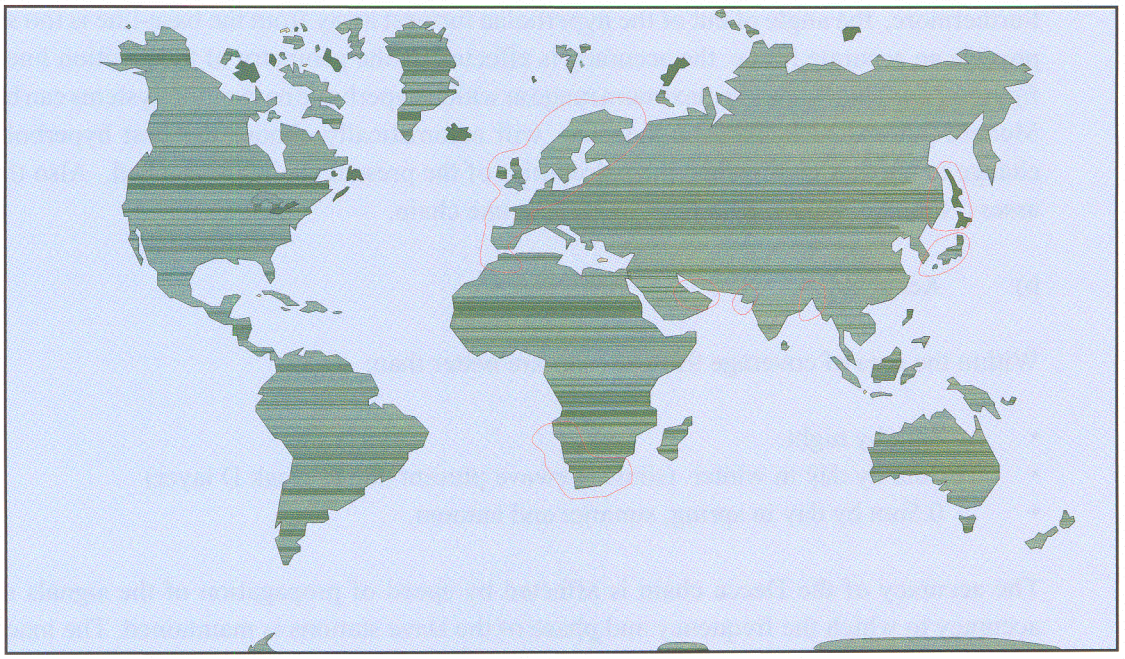

Figure 17.11 Coverage.

17.9 DECCA - ERRORS

a) **Height Error.** Decca charts are based upon ground level propagation. Therefore, very small position errors will occur , especially if the receiver is at very high altitudes.

b) **Night Error.** The Decca hyperbolae are calculated assuming surface wave, direct path, radiation. Because it is an LF aid sky waves from the transmitters will be present in the aerial at night at distant ranges. At night, at dawn and dusk, and during the day in winter, the transmissions should be used with caution at ranges more than 200nm from the Master transmitter.

c) **Static Interference.** Incorrect readings can result due to precipitation static; this includes snow. Thunderstorms and sunspot activity also effect LF transmissions.

d) **Lane Slip.** The 0.5 second interruption in reception during the equipment's inbuilt lane identification process can result in the loss of a lane when flying at 200kt or more along the baseline area. The effect would be worse in the Purple Zones as their lanes are the narrowest. However, modern systems now incorporate a memory device which takes over during the lane identification procedure.

17.10 RANGE

The maximum range is 300nm by day and 200nm by night from the Master, based upon surface wave propagation. The maximum range is limited by the poor geometry of the position lines.

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17.11 QUESTION PAPER

1. When using Decca lane slipping may occur when the aircraft:

   a) is operating in the ambiguous area near to the base line extension.
   b) is flying along the right bisector between the master and slave station.
   c) is between 200 and 300 nm from the master station.
   d) speed is greater than half a lane per second.

2. Within the area of Decca coverage the accuracy of _____of fixes is better than ____ ,_____ in winter and _____through spring, summer and autumn.

   a) 100%; 4 nm by night, 2 nm by day; ½ nm by day.
   b) 95%; 4 nm by night, 1 nm by day; ½ nm by night.
   c) 95%; 4 nm by night, 2 nm by day; ½ nm by day.
   d) 95%; 4 nm by day, 2 nm by night; 1 nm by day.

3. Individual Decca chains_____ a fundamental frequency_____and the baseline distances between a master and slave transmitter are _____.

   a) transmit, of 100kHz, 40 to 110nm.
   b) transmit, of 14kHz, 40 to 110nm.
   c) are allocated, in the order of 14kHz, 40 to 110nm.
   d) are allocated, of 14kHz, up to 1000nm.

4. Decca:

   a) is a hyperbolic navigation system which transmits in the VLF band at a fundamental frequency of around 14kHz and utilises the principle of differential range by phase comparison.
   b) is a hyperbolic system of chain, each with a master and up to four slave transmitters..
   c) is a hyperbolic navigation system which transmits in the LF band and utilises the principle of differential range by phase comparison.
   d) is a hyperbolic navigation system which transmits at 100kHz and utilises the principle of differential range by pulse technique.

5. When using Decca at night fixing is limited to a range of 200nm from the master station because of:

   a) the poor cut of position lines.
   b) skywave interference from other Decca chains.
   c) skywave interference from the required chain.
   d) the decrease in surface wave range at night.

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6. The accuracy of Decca is greatest:

a) by day in Summer.
b) by day in Winter.
c) by night in Summer.
d) by night in Winter.

7. A hyperbola is defined as:

a) a line joining points which are an equal distance between two fixed points.
b) a line joining points which have a constant difference in range between two fixed points.
c) a line which bisects the base line between a Master and a Slave Transmitter.
d) a line which crosses the base line at 90^0.

8. A Decca chain having a fundamental frequency of 14.2khz would have a green Zone width of approximately:

a) 21km
b) 1.17km
c) 586m
d) 10.56km

9. Decca is a navigation aid operating in the _____ band employing _____ type emission an utilising the principle of _____.

a) MF A2A Phase comparison
b) LF PON Frequency comparison
c) LF NON Phase comparison
d) MF A1A Frequency comparison

10. The Decca navigation system is:

a) a VLF area navigation system, utilising 8 stations giving worldwide coverage and using the principle of fixing by direct ranging.
b) a LF area navigation system, comprising chains that have a master and three slave stations which use the principle of differential ranging by phase comparison to calculate an aircraft's position.
c) an LF area navigation system that determines differential range by pulse technique.
d) a VHF navigation system using differential range by phase comparison.

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ANSWERS

QUESTION	ANSWER
1	d
2	c
3	c
4	c
5	c
6	a
7	b
8	a
9	c
10	b

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CHAPTER EIGHTEEN - TEST PAPERS

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CHAPTERS 1 - 10

1. VOR operates in the ..... band, it transmits a bearing signal by means of a ..... and uses ..... to determine the radial.

a)	VHF	stationary limacon	phase comparison
b)	UHF	stationary cardioid	envelope matching
c)	VHF	rotating limacon	phase comparison
d)	UHF	rotating cardioid	envelope

2. The bearing signal transmitted from a Conventional VOR beacon is:

a) produced by a 30Hz amplitude modulated signal, a Limacon, which rotates at 30revs./sec.
b) produced by a 30Hz amplitude modulated signal, a Cardiod, which rotates at 30revs./sec.
c) produced by a 30Hz frequency modulated signal rotating at 30revs./sec.
d) produced by a 30Hz amplitude modulated signal, a Limacon, which rotates anti - clockwise at 30revs./sec.

3. The modulation technique used in ILS and a typical localiser frequency are:

	MODULATION	FREQUENCY
a)	A9W	329.30Mhz
b)	A8W	110.30Mhz
c)	A9W	110.70Mhz
d)	A8W	118.30Mhz

4. An aircraft DME receiver does not lock on to signals reflected from the ground because:

a) DME uses the UHF band.
b) DME transmits twin pulses.
c) the pulse recurrence rates are varied.
d) the reflections are not at the receiver frequency.

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5. The advantage of a narrow beam in a primary pulsed radar system is that:

a) target definition is improved.
b) system range (ignoring any PRF limitations) is improved
c) differentiation between adjacent targets is more likely to occur.
d) all of the above advantages apply.

6. The middle marker of an ILS system has an audible code which is:

a) alternating dots and dashes at 400Hz.
b) alternating dots and dashes at 1300Hz.
c) alternating dots and dashes at 3000Hz.
d) high pitch dots.

7. Assuming an accuracy of +/- 5.5^0,the maximum spacing of two VOR's, defining the centreline of an airway, that would ensure no aircraft could be outside the airway is:

a) 54nm
b) 51nm
c) 109nm
d) 132nm

8. When tuning, identifying and monitoring an NDB which has the emission characteristic NONA1A, it is necessary:

a) for the BFO to be on for all three.
b) for the BFO to be off for tuning only.
c) for the ADF function to be selected.
d) for the ANT function to be selected.

9. Accurate glidepath coverage in elevation is provided for ILS installations in the UK between:

a) an angle of 1.35^0 to an angle of 5.25^0 above the horizontal, for a 3^0 glidepath.
b) an angle of 1.85^0 to an angle of 4.75^0 above the horizontal, for a 3^0 glidepath.
c) an angle of 2.15^0 to an angle of 5.75^0 above the horizontal, for a 3^0glidepath.
d) an angle of 1.00^0 to an angle of 6.0^0 above the horizontal, for a 3^0glidepath.

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10. SELCAL functional check must be made:

a) only on the ground before departure of a flight into an area where SELCAL is available.
b) on initial contact and when entering an area where SELCAL is available.
c) with the local ATCC before take-off.
d) when crossing the coast inbound.

11. When a Mode C check is carried out in UK airspace, the controller's readout must agree with the pilot's reported level at the same time, within:

a) +/- 50ft
b) +/- 1000ft
c) +/- 500ft
d) +/- 200ft

12. An aircraft at FL 250 is using an Airborne Weather Radar (stabilisation on) with a beam width of 5^0. An isolated cloud at a range of 25nm just ceases to paint when the tilt control is at 1^0 tilt up. The approximate altitude of the cloud top is:(use 1 in 60 rule)

a) 21000ft
b) 25000ft
c) 29000ft
d) 33000ft

13. When using an Airborne Weather Radar in the weather mode the strongest returns on the screen indicate:

a) areas where high concentrations of large water droplets exist.
b) areas of moderate or severe turbulence.
c) areas of probable windshear.
d) areas of thunderstorm activity.

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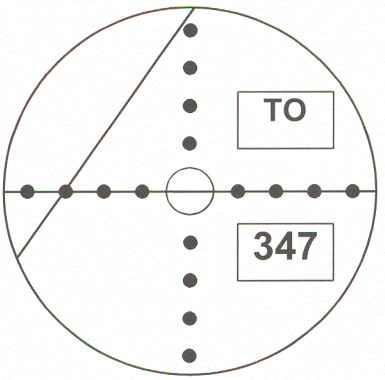
The VOR in an aircraft is correctly tuned and set to fly the centreline of an airway within UK airspace. The indication on the VOR/ILS deviation indicator is shown below. At the same time the DME gave a range of 115 nm from the facility. Use this information to answer the next two s.(Assume 1 dot equals 2^0)



14. At the time of the observation, the aircraft was on the ..... radial and, assuming still air conditions, on regaining the centreline it will be necessary to turn ..... .

a) 159^0 right onto 347^0
b) 175^0 left onto 167^0
c) 339^0 right onto 167^0
d) 355^0 left onto 347^0

15. At the time of the observation the aircraft was displaced from the centre line by:

a) 4nm
b) 8nm
c) 12nm
d) 15nm

16. Operational Performance Category 2 is a _____with a___lower than _____and a RVR _____.

a) precision instrument approach and landing; MDH; 60m (200ft); not less than 300m.
b) precision instrument approach and landing; DH; 60m (200ft) but not lower than 30m (100ft); not less than 300m.
c) precision instrument approach and landing; DH; 30m (100ft) or no DH; not less than 200m.
d) ILS approach and landing; DH; 60m (200ft) but not lower than 30m (100ft); not less than 300m.

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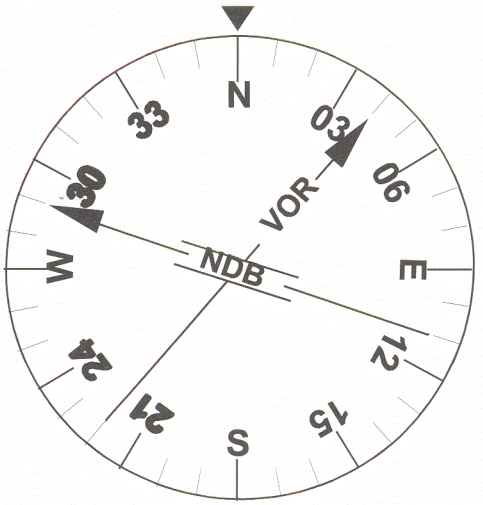
17. Both the VOR and the ADF in an aircraft are correctly tuned and identified. The indications from both are shown on the RMI illustrated:
The information given by the RMI is:

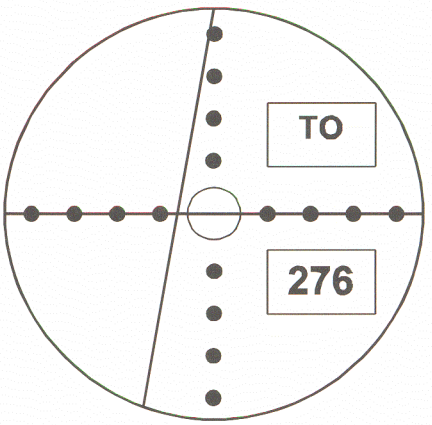


a) that the aircraft is heading 360^0(M), is on the 220 radial from the VOR, and bears 110^0(M) from the NDB.
b) that the aircraft is heading 360^0(M), is on the 040 radial from the VOR, and bears 110^0(M) from the NDB.
c) that the aircraft is heading 360^0(M), is on the 220 radial from the VOR, and bears 290^0(M) from the NDB.
d) that the aircraft is heading 000^0(T), is on the 220 radial from the VOR, and bears 110^0(M) from the NDB.

18. The rate of descent of an aircraft with an approach speed of 140kt on an ILS approach with a glide path angle of 3.25^0 is (use 1 in 60):

a) 700 ft/min
b) 780 ft/min
c) 860 ft/min
d) 1050 ft/min

19. Study this diagram of a VOR presentation. Assuming the proper selection has been made, choose the line which contains the words to correctly complete the following statement:



"You are on the ..... radial and, on reaching the selected radial you should turn ....., assuming still air conditions.

	RADIAL	TURN
a)	279	left
b)	099	right
c)	273	left
d)	093	right

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20. When using an NDB with the emission designation of NONA2A the BFO position is:

	TUNING	IDENTIFYING	MONITORING
a)	ON	ON	ON
b)	OFF	OFF	OFF
c)	OFF	ON	ON
d)	ON	OFF	OFF

21. In a conventional VOR the reference signal is ..... and the variable signal is ..... .

a)	FM	AM
b)	AM	FM
c)	FM	FM
d)	AM	AM

22. A typical ILS localiser frequency, in Mhz, is:

a) 329.30
b) 110.30
c) 110.45
d) 75.00

23. With reference to airborne weather radar the principle of operation and the frequency band in which it operates are:

	PRINCIPLE	BAND
a)	secondary radar	UHF
b)	primary radar	EHF
c)	secondary radar	VHF
d)	primary radar	SHF

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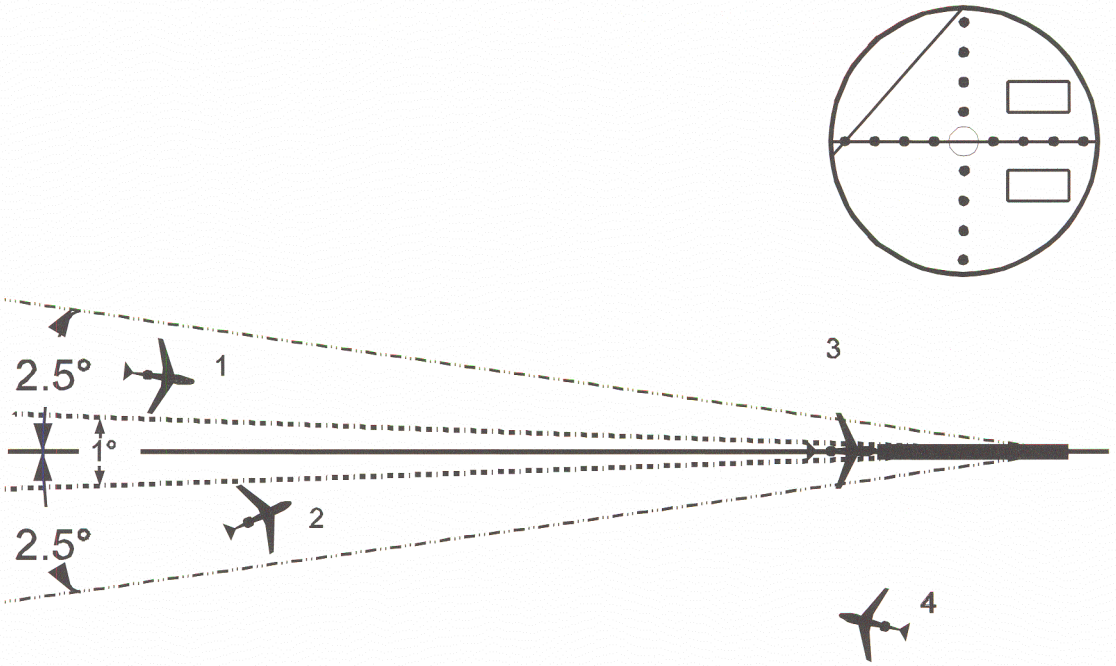

24. The diagram above shows four aircraft in relation to the localiser beam of an ILS. The aircraft position which corresponds to the illustration of the ILS presentation shown is:

a) 1
b) 2
c) 3
d) 4

25. The correct SSR code to indicate radio failure is:

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

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26. A primary radar has a PRF of 500 pulses per second The maximum theoretical range, ignoring all other factors, is:

a) 300 nm
b) 162 nm
c) 600 nm
d) 324 nm

27. The ILS outer market transmits on ..... and is identified by an aural signal of ..... .
The line with the correct terms to complete the above statement is:

a)	75Mhz	2 dashes per second.
b)	75khz	alternate dots and dashes
c)	75Mhz	alternate dots and dashes
d)	75khz	2 dashes per second

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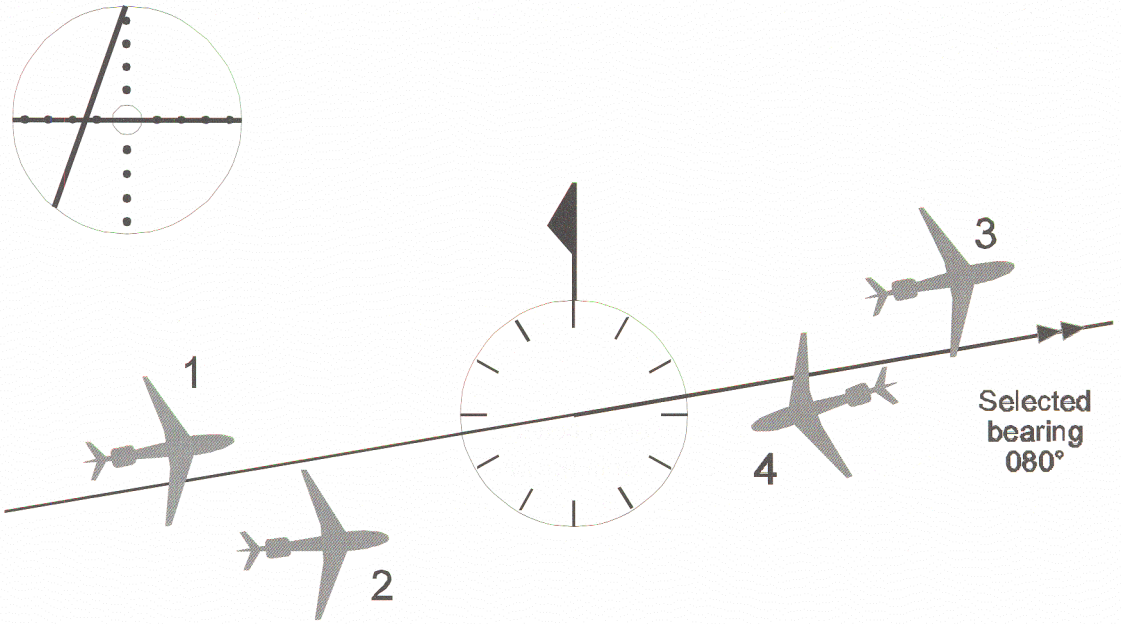

28. The diagram above shows four aircraft in relation to a VOR. Assuming that in each case the pilot has selected 080 on the OBS, the aircraft position which corresponds to the VOR presentation shown is:

a) 1
b) 2
c) 3
d) 4

29. VLF surface waves achieve greater range than LF surface waves because:

a) VLF diffraction is greater and attenuation is less.
b) VLF diffraction and attenuation are less.
c) VLF diffraction is less and attenuation is greater.
d) VLF diffraction and attenuation are greater.

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30. With reference to a DME the time interval between the aircraft transmission and the reception of a reply pulse is 2,000 μ secs. The slant range is:

a) 300km
b) 81nm
c) 60nm
d) 162km

31. When using airborne weather radar to obtain a fix from a ground feature the pencil beam is used in preference to the mapping beam:

a) because the wider beam gives better definition of ground features.
b) the angle of tilt is restricted in the mapping mode.
c) at ranges over about 50 nm because greater power can be concentrated in the beam.
d) because it overcomes the problems of "hill" shadows.

32. The maximum theoretical range at which an aircraft at FL 225 can receive signals from a VOR station situated 1,600 ft AMSL is:

a) 194nm
b) The DOC range limit.
c) 237.5nm
d) 68.75nm

33. On selecting a DME beacon the pointer or counters of a DME indicator revolve rapidly to a maximum value and return to zero and continue the process. This indicates:

a) a range search and that the aircraft's DME receiver is searching for responses from the ground transponder.
b) a range search and that the aircraft's DME interrogator is searching for responses from the ground transponder.
c) a range search and that the DME beacon's receiver is searching for interrogations from the aircraft..
d) that the system is "jittering".

34. A class B true bearing from a ground VDF station is a ..... with an accuracy of ..... .

a) QTE $+/-5^0$
b) QDM $+/-5^0$
c) QUJ $+/-5^0$
d) QDR $+/-5^0$

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35. Category 2 ILS installation provides accurate guidance to:

a) 100 ft on the threshold QFE.
b) 50 ft above aerodrome elevation.
c) 200 ft above aerodrome elevation.
d) 50 ft above the plane containing the runway threshold.

36. When a VOR is selected, the identification is PSV and the paired DME channel identification is PSZ. This means that:

a) the two aids are associated and the aerials are less than 2000 feet apart.
b) the two aids can together be used for an airfield approach.
c) the two transmitter aerials are in totally different positions.
d) the two transmitter aerials are within 6nm of each other and the two aids can be used together for normal airways navigation.

37. An aircraft is required to intercept and home to a VOR along the 244 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.

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TEST PAPER

1. To provide 3D positioning when flying under IFR a stand alone GPS equipment needs a minimum of:

   a) 3 satellites with adequate elevation and suitable geometry.
   b) 6 satellites above the horizon.
   c) 4 satellites with adequate elevation and suitable geometry.
   d) 5 satellites with adequate elevation and suitable geometry.

2. An apparent increase in transmitted frequency, proportional to the velocity of the transmitter, is caused by:

   a) the receiver moving towards the transmitter.
   b) the transmitter moving away from the receiver.
   c) the transmitter moving towards the receiver.
   d) the transmitter and the receiver moving away from each other.

3. With reference to the Navstar Global Positioning System (GPS) the horizontal accuracy figures quoted are based upon the assumption that position is referenced to:

   a) local datums.
   b) European Datum 1950.
   c) Nouvelle Triangulation de France (NTF) 1970.
   d) World Geodetic System 1984 (WGS84) Datum.

4. Which of the following statements is correct ?

   a) Primary radar uses echoes from a reflecting object, whereas secondary radar uses responses from a transponder beacon.
   b) Primary radar gives range not bearing, of a reflecting object.
   c) Secondary always measures the bearing of a reflecting object more accurately than primary radar.
   d) Only secondary radar can be carried on an aircraft.

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5. With reference to DME:

During the search period, to achieve a quick 'Lock-on, the aircraft's interrogator:

a) transmits at 150 pps; if 'Lock-on' is not acheived after 100 seconds the PRF is reduced to 60pps and maintained at this rate until the range search is complete.
b) transmits pulse pairs at 60pps; when lock-on is achieved the rate is reduced to between 25 and 30pps.
c) transmits at 150 pps; if 'Lock-on' is not acheived after 15000 pairs of pulses the PRF is reduced to 60pps and maintained at this rate until the range search is complete.
d) interrogates at a frequency +/- 63MHz in relation to the transponder's frequency.

6. A frequency of 15 Ghz produces a wavelength of ..... is in the ..... frequency band and is allocated to .....

a)	.002 m	EHF	ASMI
b)	2 cm	EHF	radar research
c)	2 m	SHF	high resolution SRA
d)	.02 m	SHF	ASMI

7. A Doppler VOR (DVOR) is more accurate because it minimises ..... error. The reference signals and variable phase directional signals rotate ....., are ..... and ..... respectively, and an aircraft ..... to be fitted with a special receiver.

a) site; anti-clockwise; FM; AM; needs.
b) equipment; anti-clockwise; AM; FM; does not need.
c) site; clockwise; AM; FM; needs.
d) site; anti-clockwise; AM; FM; does not need.

8. If an aircraft's groundspeed reduces by 10kt whilst it is flying an ILS approach with a 3^0 glidepath then its rate of descent:

a) should increase by 50 ft/min.
b) should decrease by 25 ft/min.
c) should decrease by 50 ft/min.
d) does not need to be adjusted as the speed change is too small to have any significant effect.

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0 - 20 nm

9. The above AWR presentation represents a particular condition encountered in flight. Which of the following statements describes the presentation correctly:

a) The CONTOUR facility has been selected; positions A indicate areas of heavier rainfall and associated CAT. Sensitivity Time Control (Swept Gain) also operates up to 25nm range.
b) The CONTOUR facility has been selected and STC (Swept Gain) is not in operation; positions B indicate areas of heavier rainfall usually associated with turbulence.
c) The CONTOUR facility has been selected and STC (Swept Gain) operates up to 25nm; positions B indicate areas of heavier rainfall usually associated with turbulence.
d) The MAPPING beam has been selected and the picture represents the contouring of islands and reefs within 50-60nm of the aircraft.

10. An aircraft at 36 400′ indicates a DME range of 10½ nm. The ground distance to the beacon is:

a) 8nm
b) between 8nm and 9nm
c) 8½nm
d) 9nm

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11. An Airfield Surface Movement Indicator Radar uses frequencies within the ..... band, beam widths in the order of ..... and its scanner rotates at around .....; it ..... be used as a high resolution radar for Surveillance Radar Approaches.

a) EHF; ½^0; 15-20rpm; can also
b) SHF; 1^0; 60rpm; can also
c) SHF; ½^0; 15-20rpm; cannot
d) SHF: ½^0; 60rpm; cannot

12. With reference to SSR operating procedures pilots shall when reporting levels under routine procedures or when requested by ATC, state the current altimeter reading to ..... If on verification there is a difference of more than ..... between the readout indicated on the controller's screen and the reported level the pilot will be instructed to ..... or select ..... The ATC screen indicates flight levels to the nearest .....

a) 100′; 200′; switch off Mode C; 0000; 100′
b) 200′; 100′; switch off Mode C; 7007; 100′
c) 100′; 200′; switch off Mode C; 0000; 50′
d) 100′; 200′; select the other transponder 0000; 100′

13. A hyperbolic navigation system where the baseline distances from the master transmitter to the individual slaves are in the order 400 to 500nm miles uses the principle of:

a) differential range by phase comparison.
b) differential range by pulse technique.
c) differential range by pulse technique using frequencies between 70 and 130kHz.
d) reflecting pulses in groups of eight and nine from the master and slave transmissions.

14. Whilst in flight you are using a Doppler VOR. Which of the following statements is true?

a) The first letter of the DVOR identification is 'D'.
b) The DVOR identification is followed by six dots.
c) You are unable to differentiate between a conventional and Doppler VOR when using the aircraft's system.
d) The last letter of the DVOR identification is a 'Z'.

15. The errors in DECCA are:

a) station interference; static interference; lane slip.
b) station interference; static interference; lane slip; height error.
c) coastal refraction; quadrantal error; lane slip; height effect.
d) night effect; static interference; lane slip; height error.

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16. With reference to VDF let-downs or QGH let-downs available at the same airfield:

a) a VDF let-down is controlled by the pilot; a QGH is controlled by the ground operator.
b) both are controlled by the pilot.
c) both are controlled by the ground operator.
d) a VDF let-down is controlled by the ground operator; a QGH is controlled by the pilot.

17. A pilot is using a VOR and DME simultaneously. The identification of each beacon is the same except that the last letter of the DME's identification is a 'Z'. If the pilot plots the bearing and range from these beacons then:

a) he will obtain an accurate fix from which it is safe to start a descent and airfield approach procedure, if he assumes the DME beacon is located with the VOR beacon.
b) he will obtain an accurate fix, even though the distance between the two beacons can be between 2000´ and 6nm, if he plots the bearing from the VOR beacon position and the range from the DME beacon's position.
c) the beacons are situated more than 6nm apart and may be frequency paired.
d) the VOR is a civilian facility, whilst the DME is a military TACAN beacon.

18. The Global Navigation Satellite System (GNSS) is a system which consists of ..... active satellites plus ..... operational spare satellites in ..... orbital planes around the earth. A minimum of ..... satellites are needed to provide a ..... dimensional fix.

a) 21; 3; 6; 3; 3;
b) 21; 3; 4; 3; 2;
c) 21; 3; 6; 4; 3;
d) 24; 3; 5; 3; 3;

19. At 1000UTC in zero wind conditions three aircraft are using the same co-located VOR/DME transponder. Aircraft A is at 120nm, FL 350, heading 270^0(M) on the 270 radial. Aircraft B is at 15nm, FL 70, heading 300^0(M) on the 120 radial. Aircraft C is at 15 nm, FL 410, heading 090^0(M) and crossing the 180 radial. Which of the following statements is correct?

a) Aircraft B's DME groundspeed computation is the most accurate.
b) Aircraft A's DME groundspeed computation is the most accurate.
c) All the DME groundspeed computations are correct.
d) Aircraft C's DME groundspeed computation is the most accurate because the aircraft is the highest and furthest from the beacon.

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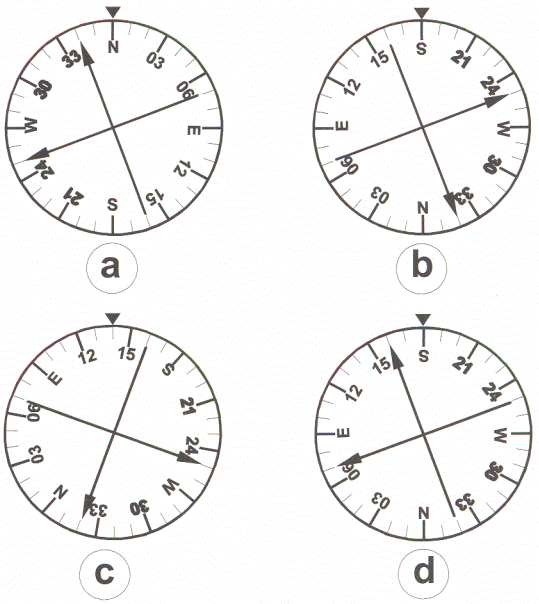
20. An aircraft is maintaining an outbound track of 160^0(M), with 20^0 port drift, from NDB A. ATC have requested a position report when the aircraft intercepts the 070 radial from VOR B. Which of the above RMIs represents the aircraft's position at the reporting point ?

a)
b)
c)
d)



21. Aircraft A is homing, with 11^0 port drift, on a track of 060^0(M) to NDB P, whilst aircraft B is maintaining an outbound track of 320°(M) with 13^0 starboard drift from the same NDB; each aircraft has a Relative Bearing Indicator. Which of the following is correct?

	Relative Bearing	
	Aircraft A	Aircraft B
a)	349^0	167^0
b)	011^0	167^0
c)	349^0	193^0
d)	169^0	193°

22. A pilot hears the morse TST from a navigational aid. This means that:

a) The station is on test and may be used with caution.
b) The facility is transmitting for test purposes only and must not be used.
c) The station accuracy has just been checked and it has passed the test
d) The aid may be used with caution and the accuracy reported to ATC

23. The sketch represents a particular type of emission whose designator is:

a) NONA2A
b) PON
c) A2A
d) NONA1A

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24. An aircraft is flying downwind within the coverage sectors of an ICAO ILS; it is abeam and to the left of the touchdown point and above the glideslope:

a) Its localiser receiver is detecting more 150Hz than 90Hz modulations and the localiser needle indicates fly "right"; the glideslope receiver is receiving more 90Hz than 150Hz modulations and the indication is to fly down.
b) Its localiser receiver is detecting more 150Hz than 90Hz modulations and the localiser needle indicates fly "left"; the glideslope receiver is receiving more 90Hz than 150Hz modulations and the indication is to fly down.
c) Its localiser receiver is detecting more 90Hz than 150Hz modulations and the localiser needle indicates fly "left"; the glideslope receiver is receiving more 150Hz than 90Hz modulations and the indication is to fly down.
d) Or, like me you are totally confused!

25. The two factors which affect the amount of Doppler shift measured by an aircraft's system are:

a) TAS and height of the terrain.
b) Ground speed and transmitted wavelength.
c) Transmitted frequency and the depression angle of the transmission beams.
d) Aircraft altitude and the Doppler's pulse repetition frequency.

26. With reference to Loran C: All the master and slave transmitters transmit on a frequency of_____. Each chain consists of a master and up to____slaves and differentiates itself from other chains on the common frequency by having_____.

a) 14kHz; three; comparison frequency.
b) 100kHz; four; pulses transmitted in groups of eight.
c) 100kHz; four; differential range by phase comparison.
d) 100kHz; four; a unique Pulse Group Repitition Interval.

27. With reference to the Global Positioning System (GPS): The minimum number of satellites, with adequate elevation and suitable geometry, to provide the RAIM function and to isolate the faulty satellite is:

a) 6.
b) 5.
c) 3.
d) 24.

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28. A transmitter is emitting a 5cm wavelength and moving towards a receiver at 500 metres per second. The received Doppler shift is:

a) 5kHz
b) 10000kHz
c) 10kHz
d) 2.5kHz

29. A CATEGORY 2 ILS ground installation provides accurate guidance down to:

a) 50ft above the aerodrome reference point.
b) 50ft above the horizontal plane containing the runway threshold.
c) 200ft above mean sea level.
d) 100ft above the ILS reference point.

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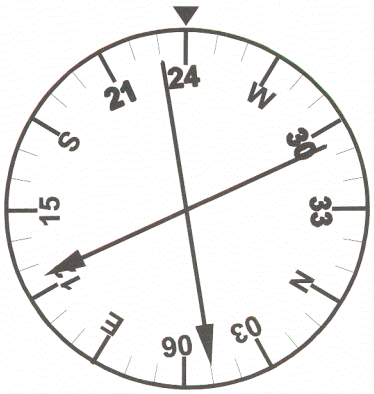
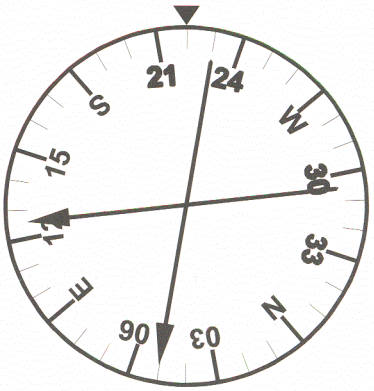
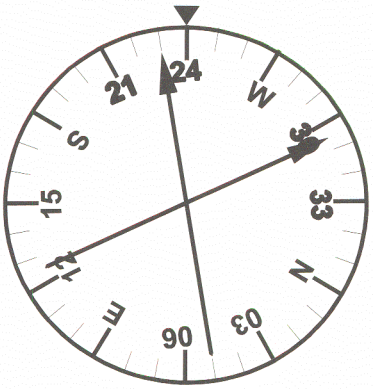
30. An aircraft is tracking away from a VOR on the 230 radial with 10^0 starboard drift. An NDB lies to the south of the VOR. Which of the illustrations below represents the RMI when the aircraft is obtaining a relative bearing of 265^0



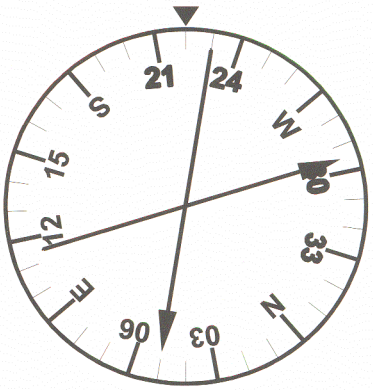
a



b



c



d

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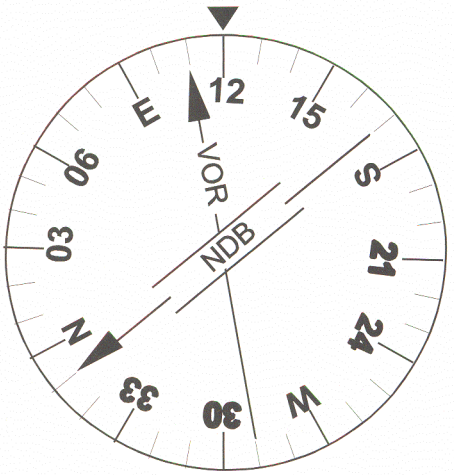
31. Both the VOR and the ADF in an aircraft are correctly tuned and identified. The indications from both are shown on the RMI illustrated. Use this information to answer the following question.



The information given on the RMI is:

a) that the aircraft is heading 012^0(M), is on the 110 radial from the VOR, and bears 350^0(M) from the NDB.

b) that the aircraft is heading 110^0(M), is on the 120 radial from the VOR, and bears 180^0(M) from the NDB.

c) that the aircraft is heading 120^0(M), is on the 170 radial from the VOR, and bears 290^0(M) from the NDB.

d) that the aircraft is heading 120^0(M), is on the 290 radial from the VOR, and bears 170^0(M) from the NDB.

32. AWR uses the frequency of 9.375GHz because it:

a) produces the best returns from precipitation, and enables narrow, efficient beams to be formed for accurate target discrimination.

b) produces the best returns from precipitation, and enables narrow, efficient beams to be formed for accurate target discrimination and mapping beyond 60nm.

c) produces the best returns from large water droplets and wet hail, indicates areas of clear air turbulence, and enables narrow, efficient beams to be formed for accurate target discrimination.

d) produces the best returns from large water droplets and wet hail, and enables narrow, efficient beams to be formed for accurate target discrimination.

33. Two navigational facilities using the principle of phase comparison are:

a) DME VOR
b) Decca Doppler
c) ILS ADF
d) Decca VOR

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34. 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 at all times when an NON A1A NDB is being used.

35. A maritime reconnaissance aircraft using a primary pulsed air to surface radar system first detects a large surface vessel at a range of 110nm. Considering only the line of sight limitations of the system, the aircraft altitude must be:

a) 230 ft
b) 790 ft
c) 2300 ft
d) 7700 ft

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TEST PAPER

1. With reference to the Global Positioning System (GPS): The number of satellites, with adequate elevation and suitable geometry, needed to perform the RAIM function without isolating a faulty satellite is:

   a) 6.
   b) 5.
   c) between 21 and 24.
   d) 4.

2. An accuracy of $\pm 5^0$ in VOR bearings received at an aircraft is achieved:

   a) within the cone of confusion by day only.
   b) at all ranges within the DOC limits day and night.
   c) within the DOC limits by day only.
   d) beyond the cone of confusion as far as the DOC limits by day and night.

3. A VOR station which continues to transmit bearings but ceases to transmit its identification:

   a) can be used only by day.
   b) can be used only in VMC.
   c) has developed an error exceeding 1^0 at the transmitter and must not be used.
   d) can be used provided the frequency selected is checked as correct.

4. The emission designator for a particular aeronautical radio facility which utilises both FM and AM could be:

   a) A9W
   b) NONA2A
   c) A8W
   d) A3E

5. Two radio navigation aids use the principle of phase comparison to establish position lines; they are:

   a) Loran C, DECCA
   b) GPSS, Decca
   c) VOR, DME, Decca
   d) VOR, Decca

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6. An aircraft is inbound, with 20^0 starboard drift, on the 180 radial from VOR "K". The relative bearing of NDB "L" is 300^0. Which of the following correctly shows the RMI presentation in the aircraft ?

	HDG(M)	"K" POINTER	"L" POINTER
a)	340	000	300
b)	340	000	280
c)	020	000	320
d)	160	180	100

7. In reference to NDB/ADF Night Effect is caused by sky-waves from_____ interferring with its omni-directional surface wave. The effect occurs at_____ and is worst _____.

a) the NDB in use; ranges of 70nm and above; at dawn and dusk.
b) other distant NDBs on the same or similar frequencies; outside the NDB's DOC and up to 70nm and above; during hours of darkness.
c) the NDB in use; ranges of 100nm and above; diurnally in the winter.
d) the NDB in use; any range; at midnight when the D layer is the weakest.

8. A radio transmitter is emitting a frequency of 10Ghz and moving away from a stationary receiver where a Doppler shift of 5khz is measured. The received frequency is:

a) 10,000005Ghz
b) 5Ghz
c) 10.0005Ghz
d) 9.999995Ghz

9. A typical ILS localiser frequency is:

a) 329.30Mhz
b) 110.30Mhz
c) 110.45Mhz
d) 75.00Mhz

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10. The United Kingdom Operating Requirements for Category 3A operations are

a) a precision approach down to 50ft above the horizontal plane containing the runway threshold.
b) a precision approach and landing with a decision height lower than 200ft but not lower than 100ft and a RVR not less than 300m.
c) a precision instrument approach and landing with a minimum descent height lower than 100ft, or no minimum descent height, and a RVR not less than 200m.
d) a precision approach and landing with a decision height lower than 100ft, or no decision height, and a RVR not less than 200m.

11. The ILS MIDDLE MARKER has the following flight deck aural and visual characteristics:

	IDENT'	RATE	LIGHT
a)	Alternate dot/dash	3/sec	Amber
b)	Alternate dot/dash	2/sec	Blue
c)	Dashes	3/sec	Amber
d)	Alternate dot/dash	3/sec	Blue

12. The maximum safe fly-up indication on an ILS approach when using a meter with a 5 dot display is:

a) 0.35^0
b) 2.5dots
c) 1.3dots
d) 0.7^0

13. Which of the following would be the normal fix for a Basic RNAV (B-RNAV) equipment:

a) DME/DME.
b) VOR/DME.
c) VOR/NDB.
d) VOR/VOR.

14. Which following statement is true ?

a) Primary radar uses echoes from a reflecting object whereas secondary radar uses responses from a transponder.
b) Primary radar can only find the range of a reflecting object.
c) Secondary radar always measures the bearing of a reflecting object more accurately than does a primary.
d) Only secondary ,not primary, radar can be carried in an aircraft.

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15. Two examples of secondary radar are:

a) VOR and DME
b) AWR and SSR
c) SSR and DME
d) VOR and DECCA

16. The Micro-wave Landing System has.....channels, is allocated the frequencies between.....and.....: it requires.....antennas to provide Back Azimuth, Elevation, Flare and Approach Azimuth/DME.

a) 252, 5031Mhz, 5090Mhz, separate.
b) 250, 5031Mhz, 5060Mhz, three.
c) 200, 962Mhz, 1213Mhz, separate.
d) 200, 5031Mhz, 5090Mhz, separate.

17. The Airfield Surface Movement Indicator radar has a.....rotation rate compared to that of standard Surveillance radars and also has a.....beam.

a) similar, wider.
b) higher, narrower.
c) slower, narrower.
d) similar, narrower.

18. Micro-wave Landing Systems in the UK provide azimuth and glideslope coverage out to .....nm. The coverage of the azimuth is.....° either side of the runway on-course line whilst the glideslope coverage is up to .....°

a) 20, 40, 10.
b) 40, 20, 40.
c) 20, 40, 20.
d) 20, 20, 20.

19. The areas of greatest turbulence, associated with storm clouds, are indicated on the colour screen of an Airborne Weather Radar by:

a) Cyclic Contouring which emphases the high intensity rainfall areas by alternately flashing them red and black.
b) the thinnest lines of colour which indicate steep rainfall gradients.
c) the black holes produced by the Iso-echo Contour facility.
d) selecting the Sensitivity Time Control function.

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20. A frequency of around 10Ghz is chosen for an Airborne weather radar because:

a) it gives the best results for ground mapping.
b) a higher frequency gives greater attenuation from all types of precipitation.
c) this frequency will produce narrow beams, for good target resolution, from antennas whose diameters are constrained by the dimensions of the aircraft's radome.
d) this frequency reflects from areas of clear air turbulence.

21. The Global Positioning System frequency available for use by civil operators is:

a) 1227.6Mhz.
b) 1575.42Mhz.
c) 2227.5Mhz
d) 1783.74Mhz.

22. With reference to NAVSTAR GPS; when used as a stand-alone system, the minimum number of satellites which must be in view at any one time, is:

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

23. The principle of operation of MLS is:

a) lobe comparison of scanning beams.
b) phase comparison of directional beams.
c) time referenced scanning beams.
d) frequency comparison of reference beams.

24. A hyperbolic navigation system where the baseline distances between the master transmitter and the slave transmitters are in the order of 70 to 110nm works on the principle of:

a) differential range by phase comparison.
b) differential range by pulse technique.
c) phase comparison of the slave signal against an atomic time standard.
d) phase comparison of both master and slave signals against an atomic time standard.

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ANSWER SHEET FOR CHAPTERS ONE TO TEN

(PAGE 18-1 TO 18-11)

QUESTION	ANSWER	QUESTION	ANSWER
01	C	21	A
02	A	22	B
03	B	23	D
04	D	24	D
05	D	25	B
06	B	26	B
07	C	27	A
08	A	28	D
09	A	29	A
10	B	30	A
11	D	31	C
12	A	32	C
13	A	33	A
14	A	34	A
15	D	35	D
16	B	36	D
17	A	37	A
18	B		
19	D		
20	D		

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ANSWER SHEET FOR TEST PAPER ONE

(PAGE 18-13 TO 18-23)

QUESTION	ANSWER	QUESTION	ANSWER
01	C	21	C
02	C	22	B
03	D	23	-
04	A	24	B
05	C	25	B
06	D	26	D
07	D	27	B
08	C	28	C
09	C	29	B
10	B or C	30	B
11	D	31	D
12	A	32	D
13	B	33	D
14	C	34	D
15	D	35	D
16	A		
17	B		
18	C		
19	B		
20	B		

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ANSWER SHEET FOR TEST PAPER TWO

(PAGE 18-25 TO 18-29)

QUESTION	ANSWER	QUESTION	ANSWER
01	B	21	B
02	C	22	C
03	C	23	C
04	A	24	A
05	D		
06	B		
07	A		
08	D		
09	B		
10	D		
11	A		
12	B		
13	B		
14	A		
15	C		
16	D		
17	B		
18	C		
19	B		
20	C		

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