RADIO NAVIGATION 1 – BASIC RADIO PRINCIPLES

BASIC TERMS

- Radio waves travel at the **speed of light**:
  - $c = 3 \times 10^8$ m/sec
- **Frequency (f) –** Number of complete cycles per second. Measured in Hertz (Hz)
  - 1 cycle per second = 1 Hz
  - 1 kHz = 10^3 Hz
  - 1 MHz = 10^6 Hz
  - 1 GHz = 10^9 Hz
- **Wavelength (λ) –** Distance travelled in one complete cycle. Measured in metres.
- **Time period (T) –** Time taken to complete once cycle. **T = 1 / f**
- $C = \lambda \times f$
- Low Frequency = Long Wavelength
- High Frequency = Short Wavelength

ANTENNA LENGTH

- Ideal antenna length is ½ the wavelength.
- If not possible, then 1/4 , 1/8 etc will do.

PHASE DIFFERENCE

- Can only be measured when the signals have the same **frequency** (or wavelength).

POLARISATION

- The electrical and magnetic components of a radio wave travel at **right angle** to each other and in the **direction of propagation.**
- **Plane of electrical component = plane of polarisation.**
- Transmission from **vertical** aerial gives a vertical electric component and horizontal magnetic component.
- Transmission from **horizontal** aerial gives horizontal electrical component and vertical magnetic component.
- In **circular propagation,** both components spin about the axis of advance.

POLAR DIAGRAMS

1. **Omnidirectional**
2. **Directional** (Inc unwanted side lobes)

- Applies to both Tx and Rx aerials.

MODULATION

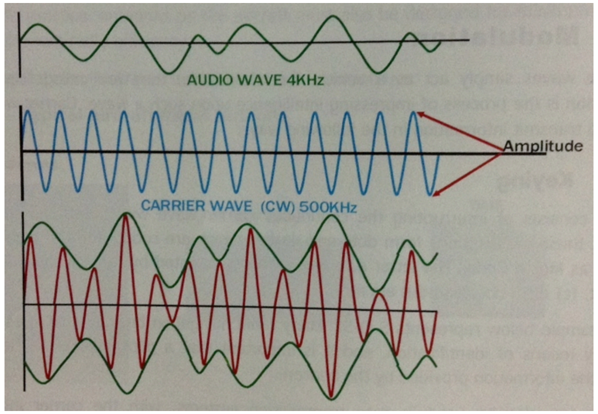
- Modulation **adds information** to an otherwise empty carrier wave.

MODULATION TYPE 1 - KEYING

- **Interrupting** the carrier wave to give morse code.
- Will temporarily interrupt the nav aid output in order to tx the morse code.

MODULATION TYPE 2 - AM

- AM = **Amplitude Modulation**
- Amplitude of the carrier wave is varied in accordance with the audio signal amplitude.
- Carrier wave frequency is kept constant.
- **Oldest method** apart from keying.
- Small amplitude areas give a weak signal that is prone to **interference** (especially since it operates in low frequency spectrum)
- Modulation circuit requires **extra power** to vary the amplitude.



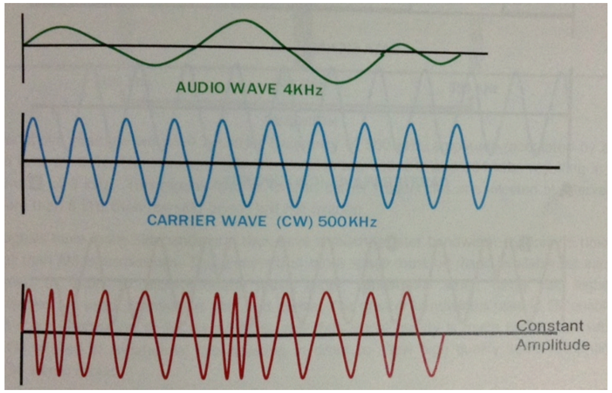
RADIO NAVIGATION 1 – BASIC RADIO PRINCIPLES

MODULATION TYPE 3 - FM

- FM = **Frequency Modulation**
- Frequency of the carrier wave is varied in accordance with the audio signal amplitude.
- Carrier wave amplitude is kept constant.
- A +ve amplitude = higher frequency
- A –ve amplitude = lower frequency

- FM TX's are **simpler and cheaper than AM**
- **Lower modulation power** required
- Constant amplitude = stronger
- VHF operation = almost **static free**
- **Horizontally polarised** so suffers less from weather induced static (vertically polarised)

- **Receivers** are more complex.
- **Wider frequency band** required.



MODULATION TYPE 4 - PULSE

- Radio wave is switched on and off at regular intervals, effectively forming pulses of radio energy.
- Use in radar.
- Transmits 0's and 1's effectively.

AM SIDEBANDS

- Whenever a carrier is AM modulated by a frequency lower than itself, sidebands are created.
- Carrier Wave = 500 kHz, Audio Freq = 4 kHz
  - 4 kHz is filtered out.
  - 496 kHz / 500 kHz / 504 kHz output
- **Passband** is a filter used to get rid of unwanted frequencies so bandwidth can be reduced.
- **Single Sideband (SSB)** – Often only 1 of the outputs is TX'd. The sideband carries the information rather than the carrier.
  - With all TX power focused on one sideband, range is increased.
- FM has many more sidebands than AM.

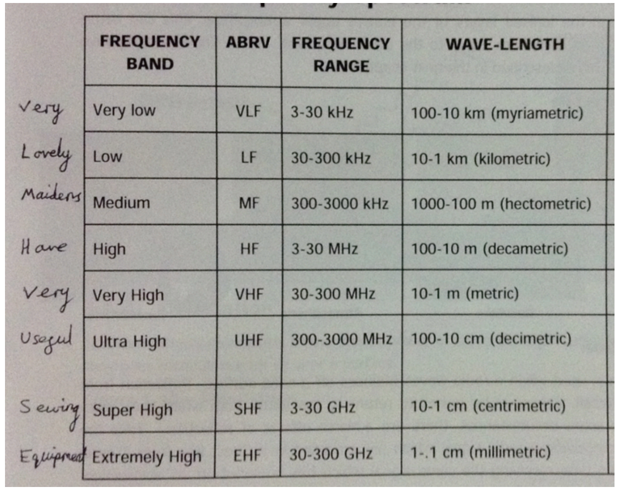
HF COMMS & HF VOLMET

- Use single sideband
- HF SSB = J3E

FREQUENCY SPECTRUM

- Frequency range repeats (kHz / MHz / GHz)
  - 3 – 30
  - 30 – 300
  - 300 - 3000

- Wave-length can be derived with $C = \lambda \times f$



	FREQUENCY BAND	ABRV	FREQUENCY RANGE	WAVE-LENGTH
Very	Very low	VLF	3-30 kHz	100-10 km (myriametric)
Lovely	Low	LF	30-300 kHz	10-1 km (kilometric)
Maidens	Medium	MF	300-3000 kHz	1000-100 m (hectometric)
Have	High	HF	3-30 MHz	100-10 m (decametric)
Very	Very High	VHF	30-300 MHz	10-1 m (metric)
Useful	Ultra High	UHF	300-3000 MHz	100-10 cm (decimetric)
Sewing	Super High	SHF	3-30 GHz	10-1 cm (centrimetric)
Equipment	Extremely High	EHF	30-300 GHz	1-.1 cm (millimetric)

EMMISSION CODES

- 1st = Type of modulation
- 2nd = Nature of modulating signal
- 3rd = Type of information transmitted

RADIO NAVIGATION 1 – BASIC RADIO PRINCIPLES

REFRACTION

- Radio waves are refracted when travelling **obliquely from a medium of one density to another of different density.**
- Due to different velocities there is a slight change of wavelength.
- **Low to high density** = slows down and **bends towards the normal.**

- **Types of refraction:**
  - **Coastal** (Land to sea. Flying higher or moving beacon towards coast will reduce effects)
  - **Atmospheric** (Density change with altitude.
  - **Ionospheric**

REFLECTION

- Radio waves **bounce off a solid surface.**
- If two signals arrive at the same time but out of phase, there can be fading / temporary losses.

DIFFRACTION

- **When a radio wave passes a solid object, radio energy is scattered.**
- Allows radio waves to be received behind a mountain.

SURFACE ATTENUATION

- **As a radio wave passes over a surface it loses energy.**
- Higher frequencies are more susceptible as they hit the surface more often.

IONOSPHERIC ATTENUATION

- **The ionosphere and particles in the atmosphere can absorb and block a radio wave.**

ATMOSOHERIC / RADAR ATTENUATION

- **When radar energy strikes water droplets, some energy is absorbed (and attenuated) and some is reflected.**

DOPPLER EFFECT

- **+ VE Doppler Shift:** If the distance between the source and the receiver is reducing, the received frequency appears greater than that transmitted.
- Occurs because **more waves are detected** than if stationary.
- **- VE Doppler Shift:** Distance increasing / frequency appears lower.
- Actual wavelength stays the same.

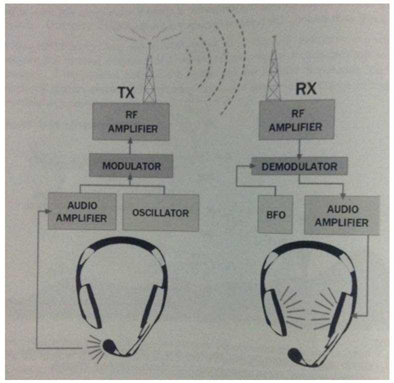
ATTENUATION & REFRACTION BY FREQ

- Top Column = A - RADAR

Frequency Band	ATMOSPHERE		EARTH'S SURFACE		IONISED LAYERS	
	Attenuation	Refraction	Attenuation*	Diffraction	Attenuation	Refraction
VLF	Lowest	Lowest	Lowest	Highest	Highest	Highest
LF	↓	↓	↓	↑	↑	↑
MF						
HF						
VHF						
UHF						
SHF	Highest	Highest	Highest	Lowest	Lowest	Lowest

BASIC RADIO CIRCUIT

- **Human Ear:** 20 Hz – 20 kHz



RADIO NAVIGATION 2 – PROPOGATION

PROPOGATION

- Describes the path of the radio wave from the transmitter to receiver.
- VLF / LF / MF / HF Propagation:
    - Surface Wave
    - Sky Wave
- VHF / UHF / SHF Propagation:
    - Direct Wave

DIRECT WAVE

- Essentially 'line of sight'
- Range depends on:
    - Height of Tx + Rx
    - Power of Tx
    - Height of intervening high ground

$$\boldsymbol{Max\ Range\ (nm) = 1.23(\sqrt{H_T} + \sqrt{H_R})}$$

- Range can be reduced if required by lowering the power of the transmitter.
- **Space waves** = Direct + Reflected + Sky

SURFACE WAVES

- Due to **diffraction** and surface **attenuation.**
- Attenuation slows the bottom of the wave, giving it a **forward tilt** allowing it to follow the curvature of the earth.
- Attenuation is reduced over the sea (waves travel twice as far)
- Lower frequencies have a longer range as attenuation is less.
    - Drawbacks are low efficiency aerials (not ½ wavelength), static and transmitting power required.

SKY WAVES

- When radio signals are **refracted by ionosphere** (bent) sufficiently to return to earth.
- **Lower frequencies are refracted more.**

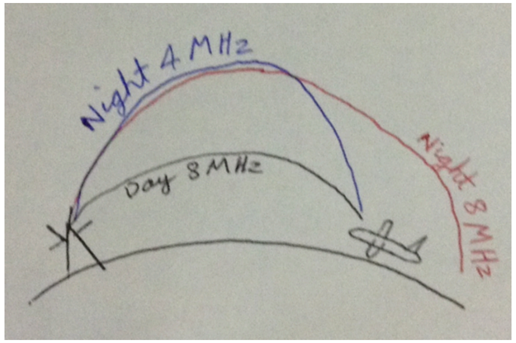
- Ionosphere is approx**. 50 – 500 km.**
- **3 layers to the ionosphere.** Higher frequencies are refracted by the higher layers but anything VHF or greater passes straight through:
    - F Layer – HF
    - E Layer – LF / MF
    - D Layer – VLF

- At dawn / dusk there may be no signal due to **re-ionisation.**

SKY WAVES AT NIGHT

- Changes **at night**:
    - D layer disappears
    - E & F layer increase in height

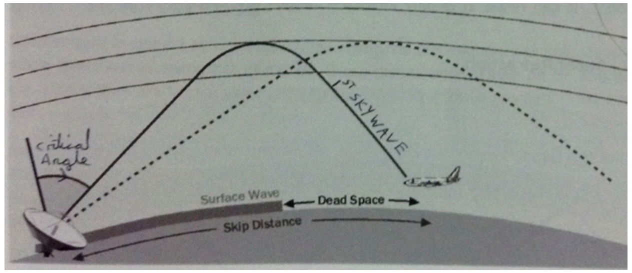
- An 8 MHz frequency will go higher in the atmosphere at night due to layers increasing in height.
- In order to avoid signal going out of range, using approx. half the frequency will cause it to refract more and stay in range.



RADIO NAVIGATION 2 – PROPOGATION

SKY WAVE TERMINOLOGY

- **Critical Angle –** Minimum angle at which a radio wave will refract and return to earth.
    - Anything less = no refraction
    - Anything more = incr. skip distance
- **Skip Distance –** Distance between transmitter and the point where the first sky wave arrives.
- **Dead Space –** Area between the limit of the surface wave and the 1^{st} sky wave.
    - Mainly HF band.
    - Minimised with a lower frequency.



SKY WAVE FREQ INCREASE

- **Less refraction** at a higher frequency.
    - Critical angle increases
    - Skip distance increases

MF / LF SKYWAVES

- MF / LF gets attenuated too much during the day and there are **no skywaves during the day.**
- Night is fine as attenuation is less.
    - Can cause interference by night with surface waves (eg NDBs) so Tx power may be reduced at night.

RANGE OF SKYWAVES

- Transmitter Power
- Quality of receiver
- Frequency transmitted
- State of ionosphere

DUCT PROPOGATION

- Created by a **temperature inversion and / or rapid decrease in humidity with height.**
- Causes **super-refraction** and VHF and above can have unexpected ranges.
- Layer is normally no more than 1,000 ft

SIGNAL-TO-NOISE RATIO

- High SNR when amplitude of wanted signal is **greater** than that of the unwanted signal.

RADIO NAVIGATION 3 – GROUND DIRECTION FINDING

VHF DIRECTION FINDING

- GDF mainly operates in the **VHF and UHF** bands.
- Since UHF is rarely used in civil world, GDF is commonly referred to as **VDF (VHF Direction Finding).**
- Can also operate in MF and HF bands but very rare.

VDF AERIALS

- Use either **Adcock or Doppler** aerials.
- Doppler is the most common and the direction of the incoming radio wave is calculated by the phase of the Doppler shift.
- Aerials are **vertically polarised.**

FREQUENCY SPACING

- 25 kHz = “Frequencies”
- 8.33 kHz = “Channels”

VDF PROCEEDURES

- **QDL –** Series of QDMs are given.
  - Pilot interpreted
- **QGH –** Heading and heights are issued to the aircraft to maintain the published pattern.
  - ATC interpreted

DIRECTION FINDING Q CODES

- **QDM –** Magnetic to the station
- **QDR –** Magnetic from the station
  - Radials go outwards
- **QUJ –** True to the station
  - True to the union jack
- **QTE –** True from the station
  - Cutey from ATC

VDF CLASSES

- Class A: ± 2 Degrees (Not normally used)
- Class B: ± 5 Degrees
- Class C: ± 10 Degrees
- Class D: Worse than 10 Degrees

VDF RANGE FACTORS

- **Line of sight limitations** - Tx, Rx and terrain height.
- **Power of transmitter**
- **Sensitivity / quality of receiver**

- Range may be increased by **duct propagation.**
- Range may be decreased by **sub-refraction** (due to temperature and humidity).

VDF ACCURACY FACTORS

- **Equipment errors**
- **Propogation errors** (reflections, refraction, duct propogation etc)
- **Site Errors** (Reflections from objects near to the receiver)
- **Multipath Errors** (Reflections from objects between aircraft and ATC)
- **Crossed transmission**

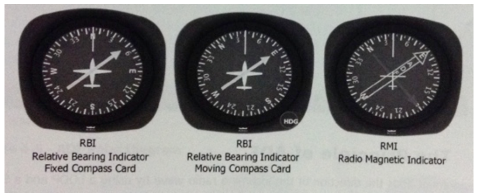
RADIO NAVIGATION 4 – AUTOMATIC DIRECTION FINDING

RELATIVE BEARING

- The ADF will measure the **relative bearing** of an NBD from the nose of the aircraft.
- **QDM = MH + RB**

ADF DISPLAYS

- **Fixed RBI** (Relative Bearing Indicator) will require use of mental maths to obtain QDM.
- **RBI (With Moving Compass Card)** will show QDM when current MH is set on the display.
- **RMI (Radio Magnetic Indicator)** will always show QDM as it's linked to the compass.

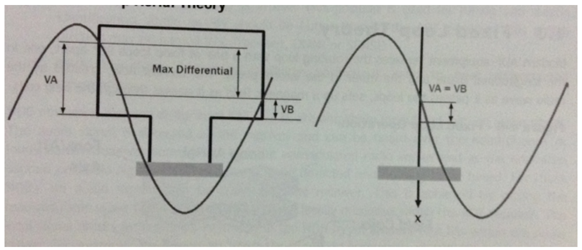


NDB CHARACTERISTICS

- **Omnidirectional**
- **Vertically Polarised**
- **LF & MF Bands (190 – 1750 kHz)**
- **Surface Wave Propogation** (Sky waves could interfere at night)
- **Range: 10 nm – 500 nm**
- **Power Range: 25 Watts – 10 Kilowatts**
- **Ident: 2/3 More Code Letters**
- **NON A1A –** Unmodulated
- **NON A2A –** AM Modulated

LOOP AERIAL

- Different orientations of the aerial will give different voltage differentials.
- Maximum differential when parallel.
- Minimum differential when perpendicular.



SENSE AERIAL

- Required in order to resolve the direction as two positions can give the same differential.

CARDIOID POLAR DIAGRAM

- **Loop (Fig 8) + Sense (Circular) = Cardioid**
- The direction of zero signal strength will point towards the NDB.
- Due to 0V, ident must be performed regularly to check NDB is still active.

FIXED LOOP THEORY

- The rotating loop is replaced with a pair of fixed loops 90 degrees apart.
- A electro magnetic field is set up.

NDB RANGE

- 200 – 500nm most common
- Increase TX power = Increase range
- Increase frequency = Decrease range
- NON A2A used power for modulation so has a lower range than NON A1A

ANT SWITCH (REC / OMNI / SENSE)

- **Sense aerial only** is used.
- Needle should point to 90 degrees
- Once deselected, needle should point to beacon.

RADIO NAVIGATION 4 – AUTOMATIC DIRECTION FINDING

BFO SELECTOR

- Used to **ident** the **N0N A1A** (unmodulated)
- NON A2A are amplitude modulated with an audio signal so no BFO required to ident.

- NDB frequencies are outside the audio range so an appropriate sideband must be created to hear the ident.
- A frequency of 299 kHz (for example) could be mixed with an NDB of 300 kHz to produce a beat frequency of 1 kHz.

MANUAL TUNING

- Another use of the BFO is in the **manual tuning of an ADF**.
- Required for both N0N A1A and N0N A2A.

ADF SELECTION PROCEDURE

- Check aircraft within NDB stated range
- Increase gain
- Select frequency
- Select ANT to test
- Select BFO as required **
- Check Ident
- Select ADF

** Even if not required for ident (if NDB was N0N A2A), the BFO will always produce a higher quality signal as the loop aerial is removed. It can be used therefore to check interference.

NDB ERRORS

MUTUAL INFERENCE

- **NDBs transmitting on the same or similar frequency** can lead to mutual interference.
- Cannot use them inside the overlapping area.
- Stick to the published range (applicable to day only).

NIGHT EFFECT

- **Skywaves** from other NDBs by night can cause interference.
- Minimised by listening to the BFO (to check clean signal) and identing.

STATIC (PRECIPITATION)

- **Dust and water droplet** rub against aerial creating static.
- Causes PD disruptions.
- Must make physical contact with aerial.

STATIC (THUNDERSTORMS)

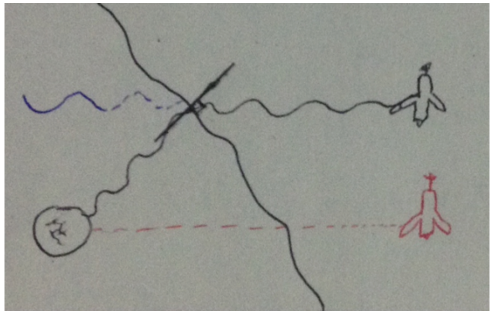
- **Nearby thunderstorms** will cause ADF to point towards lightning strikes.
- Just vicinity (not direct contact) sufficient.

MOUNTAIN / MULTI PATH EFFECT

- **Reflection / refraction** of the signal in the mountainous areas.

COASTAL REFRACTION

- Aircraft RBI points at 270^0 rather than 220^0
- When plotted on the map, aircraft appears **'closer to the coast'** than in reality.



- Minimised by flying higher or moving NDB closer to the coast.

LACK OF FAILURE WARNING

- 0V (as used in cardioid) is also present when **NDB is off or in a cone of silence** (above NDB)

RADIO NAVIGATION 4 – AUTOMATIC DIRECTION FINDING

QUADRANTAL EFFECT

- **A signal arriving at 45^0** to aircraft structure will be bent by the metal framework construction.
- Normally fixed internally so no longer an issue.

DIP ERROR

- When in a banked condition, **the PD is distorted.**
- Needle will dip **towards the lower wing**.
- **Approx 10^0** in a light aircraft although varies from aircraft to aircraft.

ACCURACY

- **NDB Accuracy:** ± 5^0 (Day)
- **ADF Accuracy:** ± 6.9^0

NDB LOCATOR

- A low powered NDB
- Usually installed as a supplement to ILS at the sites of the outer and middle markers.

FINDING DISTANCE FROM NDB

$$\frac{\textit{Elapsed Time (Mins) x Groundspeed}}{\textit{Change In Radial}}$$

RADIO NAVIGATION 5 – VHF OMNIDIRECTIONAL RANGE (VOR)

VOR FREQUENCIES

- **108 – 112 MHz: VOR & ILS**
  - 40 Channels Each
  - ILS Freq if first decimal digit is odd (108.10 MHz & 108.15 for example)
- **108 – 118 MHz: VOR**
  - 120 Channels

- 50 KHz spacing
- Total VOR Channels = 160

EMISSION TYPE

- **A9W**
- **Horizontally Polarised**
  - Less noise as atmosphere is vertically polarised.
- **2 Methods of IDENT**
  - Keyed AM morse code every 10 secs
  - Voice

VOR TYPES

- **Terminal (108 – 112 MHz)**
  - Up to 50 watts
  - 25 – 100 nm
  - 40 channels
- **Enroute (112 – 118 MHz)**
  - Up to 200 watts
  - 200 nm (Max 300 nm)
  - 120 channels

VOR TYPES

- **Broadcast VOR**
  - Normally a terminal VOR
  - Transmit radial & ATIS
- **TEST VOR**
  - Transmits just 360 radial.
  - ± 4 degrees requires servicing

RMI DISPLAY

- **Tail of needle = QDR**
  - Head therefore points to QDM

CVOR (CONVENTIONAL VOR)

- **Signal 1: Reference Signal**
  - Omni-directional
  - Transmitted on a sub carrier
  - FM modulated at 30 Hz
- **Signal 2: Variphase Signal**
  - Directional
  - Transmitted on main carrier wave
  - Appears AM modulated at 30 Hz
  - Rotates at a rate of 1800 rpm
- Reference + Variphase **= Rotating Limacon**
- The **phase difference** is measured when the voltage drops on the rotating limacon.
  - The phase difference is equal to the radial (QDR)
  - Zero phase difference when on the 360 degree radial.
  - Does not drop to zero like cardioid.

SITE ERROR

- Obstacles near the transmitter cause radio waves to be **reflected.**
- Limacon pattern is disorted and amplitude does not rise / fall in the predicted manner.

CONE OF CONFUSION

- Overhead VOR
- Can result in flickering of the ambiguity indicator (to / from flag)
- Possible failure flag (often prevented)

TERMINOLOGY

- CDI = Course Deviation Indicator
- OBI = Omni Bearing Indicator
- OBS = Omni Bearing Selector

RMI VS CDI

- RMI shows bearing
- CDI shows displacement

DISPLACEMENTS DOTS

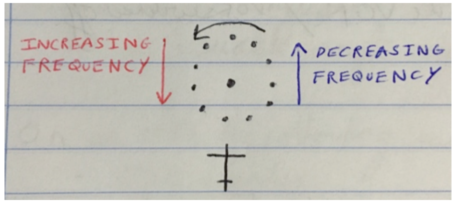
- Each Dot = **2 Degree** Displacement
- The outside of a centre circle if present counts as one dot.
- Full Scale Deflection = 10 Degrees

RADIO NAVIGATION 5 – VHF OMNIDIRECTIONAL RANGE (VOR)

DOPPLER VOR

- **Signal 1: Reference Signal**
  - AM Modulated
  - Transmitted on main carrier
- **Signal 2: Variphase Signal**
  - FM Modulated
  - Transmitted on sub-carrier

- The variphase signal is transmitted on 50 different aerials in turn around the reference signal.
- **Doppler shift** is used to calculate phase difference.



DOPPLER VS CVOR

- A **larger aerial** is required to reduce **site error** in a CVOR.
  - Impractical to rotate a large aerial
- Doppler aerial is much **more accurate** and there is **very little site error.**

FAILURE FLAG

- Receiver failure
- Transmitter failure
- Ambiguity Indicator Fail (often prevented)
- Signal too weak / out of range

VOR MONITOR

- Will power-off VOR or remove ident when:
  - Bearing exceeds ± 1 degree
  - Signal strength drops by 15% or more
  - VOR monitor fails

VOR RANGE FACTORS

- **Transmitter Power**
- **Line of Sight Limitations**
- **DOC**
- **Nature of Terrain**

VOR ACCURACY FACTORS

- **Site Error** (Reduced by Doppler)
- **Propagation Error**
  - Irregular terrain causing oscillations
  - Slow Oscillations = Bends
  - Rapid Oscillations = Scalloping
  - Scallops cannot be followed
- **Airborne Equipment Error**
- **Interference Error** (DOC / Below LOS)
  - Irregular terrain causing oscillations

OVERALL VOR ACCURACY

- **± 5 degrees 95% of the time**
- **Worst case ± 7.5 degrees**

DISTANCE BETWEEN VORs

- Distance required to ensure no conflict between VORs will be **range x2**

VOR DISTANCE - AIRWAYS

$$Track\ Error = \frac{Distance\ Off}{Distance\ Gone} \times 60$$

- If VOR accuracy is ± 7.5^0, what's the max distance the VORs can be apart assuming the airway is 10 nm wide?

$$7.5 = \frac{5}{Distance\ Gone} \times 60$$

Distance Gone = 40 nm (Midway Point)
=> Max Distance is 80 nm

VARIATION & VOR / ADF

- For **VOR** use variation at **VOR** beacon.
- For **ADF** use variation at **aircraft.**

GREAT CIRCLE

- Flying along a VOR radial, you will be following a great circle track.

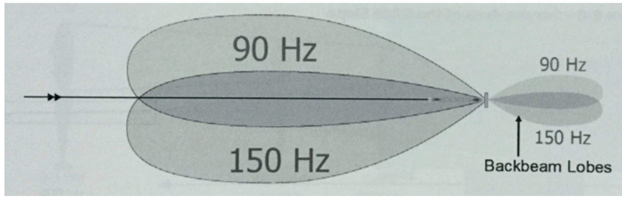
RADIO NAVIGATION 6 – ILS

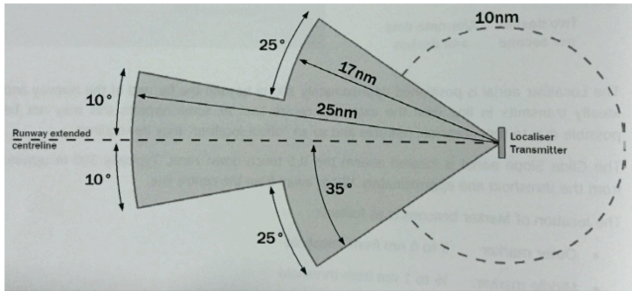
ILS CHARACTERISTICS

- **A8W**
- **Horizontally Polarised**
- **VHF Band (108 – 112 MHz / Odds)**
- **3 Letter Morse Ident**

LOCALISER

- **VHF Band**
- Located **300m beyond end of the runway.**
- Left lobe AM modulated at 90 Hz
- Right lobe AM modulated at 150 Hz
- Difference in **Depth of Modulation (DDM)** determines position of localizer needle.
    - Equal depth = centreline
    - Linear increase in DDM from centreline



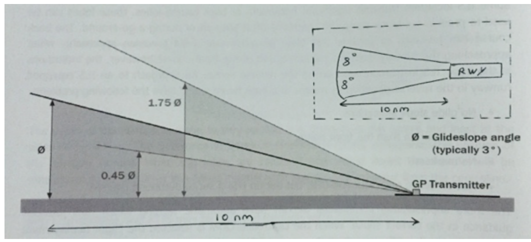


BACKBEAM

- Can be used to provide **centreline guidance after takeoff or during a go-around.**
- **Backbeam approaches are non-precision**
    - No glideslope indication
    - Less accuracy
    - No markers
    - Needle sense reversed

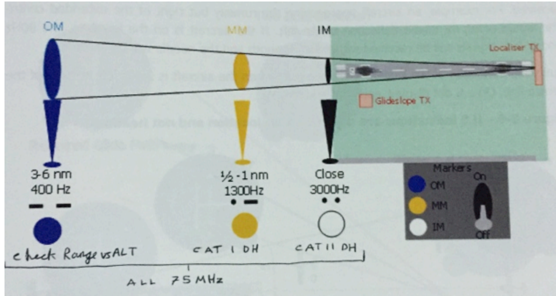
GLIDESLOPE

- **UHF Band (329 – 335 MHz)**
- **Abeam TDZ (300m from threshold)**
- **Offset 120m from centerline**
- Top lobe AM modulated at 90 Hz
- Bottom lobe AM modulated at 150 Hz
- **Lateral Range**
    - 8^0 either side of centerline
    - Extends 10nm from runway
- **Vertical Range**
    - Bottom of lobe at 0.45 x G/S Angle
    - Top of lobe at 1.75 x G/S Angle
- EG/ 3^0 glideslope extends to a distance of 10nm, 8^0 either side of centreline with a vertical coverage between 1.35^0 and 5.25^0



ILS MARKERS

- **All markers transmit at 75 MHz but have different pitch.**



OBS / COURSE INDEPENDENT

- Localiser needle will indicate deviation in correct sense regardless of OBS / Course selector setting.
- Measures DDM rather than phase difference.
- Good practice to set RWY QDM however.

SCALE DEFLECTION

- **Localiser**
    - Each dot 0.5^0C
    - Full scale is 2.5^0C
- **Glideslope**
    - Each dot 0.14^0C
    - Full scale is 0.7^0C

- Once established**, max ½ scale deflection.**

RADIO NAVIGATION 6 – ILS

FAILURE INDICATIONS

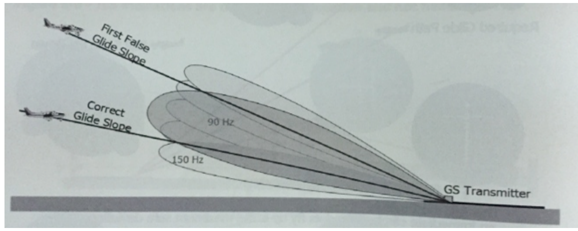
- Localiser Fail = NAV Flag
- Glideslope Fail = G/S Flag

ILS MONITOR

- If installed, a second transmitter will be brought online.
- If no second transmitted:
    - Transmissions stopped
    - IDENT removed
    - Maintenance alerted

FALSE GLIDESLOPE

- The lower 150 Hz lobe is sometimes **reflected** from the ground.
- Approach is always made from **below glideslope** to avoid intercepting the false one.



BENDING

- Bending of the localiser and glideslope can occur due to other aircraft and vehicles.
- **Critical Area** established for CAT I
- **Sensitive Area** established for CAT II / III

ILS CATs

- CAT I = 200 ft DH (Guidance to 200ft)
- CAT II = 100 ft DH (Guidance to 50 ft)
- CAT III = 0 ft DH

- CAT II + CAT III require autopilots.

RATE OF DESCENT

$$ROD = Glideslope \times \frac{Groundspeed}{60} \times 100$$

GLIDESLOPE HEIGHT

G/S Height = G/S Angle x Range x 100

FM IMMUNITY

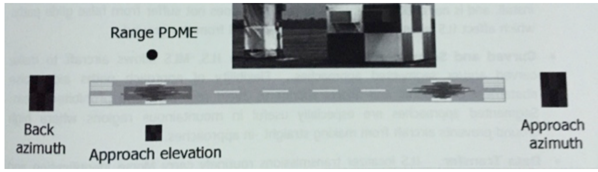
- FM transmission near to 108 MHz may interfere with ILS LOC & G/S.
- **Can lead to erroneous localizer readings**
- Modern aircraft are fitted with FM filters to filter out this interference.

RADIO NAVIGATION 7 – MLS

WHY MLS?

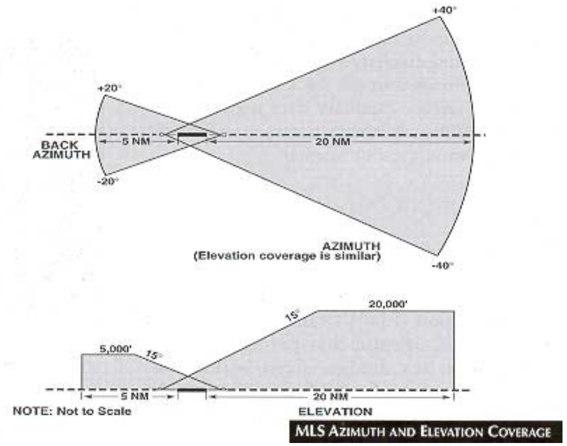
- An attempt at overcoming the shortcomings of the ILS which are:
    - Expensive
    - Bending of the beam
    - Poor runway occupancy during LVPs
- Whilst it was being invented however, the GPS came along.

INSTALLATION



COVERAGE

- **Approach Azimuth:** 40^0 either side of centerline extending to 20 nm
- **Elevation:** 15^0 to 20,000 ft

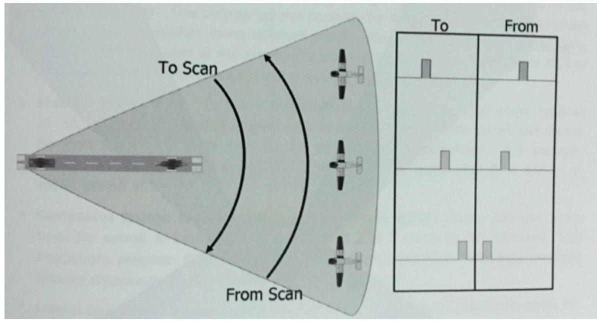


FREQUENCIES

- 5031 – 5091 MHz (SHF)
- 200 Channels (500 – 699)
- Azimuth and elevation use the **same frequency.**
- DME is on a different frequency but **frequency paired.**

PRINCIPLE OF OPERATION (TRSB)

- **Time Reference Scanning Beam**
- The difference between a TO Scan and FROM Scan is calculated and the aircrafts position can be determined.
- In the azimuth example below, there is less of a gap between the TO and FROM scan when furthest south.



MULTIPLE GLIDE PATHS

- No fixed glidepath exists as with an ILS
- **The pilot can chose any glidepath within a range of 0.1^0 - 15^0**
- Suited to a wide range of aircraft.

MULTIPLE & VARIED APPOACH PATHS

- Approach paths that vary by 60^0 or more from the direction of the associated runway can be used.
- Allows **for simultaneous approaches** to made along different paths (improved airspace capacity)
- A single MLS can be used to cover **multiple runways.**

CONTINOUS RANGE INFORMATION

- **Co-located with a PDME** (Precision DME)
- A **PDME failure** would require a straight-in approach to be flown.

OTHER ADVANTAGES

- **Simpler to install than ILS**
- **Not sensitive to terrain issues**
- **Virtually immune from scalloping** caused by vehicles and other aircraft.
- **Free from weather-induced error**
- **No false glide-paths**

GROUND – AIR DATA TRANSFER

- Transmits timings of TO & FROM scan.
- 4 letter morse at 10 second intervals.
- Transmitter locations, airport information and performance levels can be also be transmitted.

RADIO NAVIGATION 7 – MLS

MULTIPLEXING

- Transmitters transmits continuously.
- Receiver alternates between scanning elevation, azimuth, backbeam, data etc.

ACCURACY

- Stated accuracy (95% of the time) at 200 ft above MLS datum for a runway 10,000 ft long with a 3^0 glideslope.

- Laterally: ± 50 ft
- Vertically: ±12 ft

RADIO NAVIGATION 8 – BASIC RADAR PRINCIPLES

CALCULATING RANGE

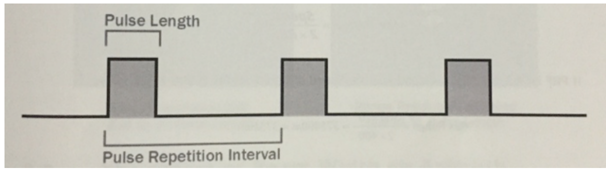
- Measuring the time taken for a pulse of radio energy to return to the antenna will allow us to calculate the distance.
- Radio waves travel at a known speed of 3 x 10^8 m/s (metres per second) or **300 m/µsec (metres per micro-second)**

RADAR MILE

- **12.36 m/µsec**
- Time taken for transmission to travel 1 nm out and 1 nm back.

RADAR DEFINITIONS

- **Pulse Length**
  - Duration of the pulse in microseconds.
- **Pulse Width**
  - Length of the pulse in metres
- **Pulse Repetition Interval (PRI)**
  - Time interval from start of one pulse to the start of the next.



- **Pulse Repetition Frequency (PRF)**
  - Number of pulses transmitted per second.

PRI & PRF RELATIONSHIP

PRI = 1 / PRF

PRF = 1 / PRI

THE RADAR CYCLE

- **Pulse of energy is transmitted** for the duration of the pulse length.
- Once transmitted, the transmitted is turned off and the receiver is turned on.
- The receiver now waits for the echo's to return
- This 'listening phase' is known as the **recovery period.**
- After the PRI is reached, it is switches from RX to TX mode and another pulse is sent.
- Note that for the majority of the time, the radar is listening for echoes rather than transmitting.
  - Pulse Length < PRI

POWER & RANGE

- A normal transmitter requires four times the amount of power to double the range (2^2).
- Since RADAR must travel there and back, **16 times the original transmitter power is required to double to RADAR range (2^4)**

MAX RANGE

- **Determined by the PRI**
- A long recovery period is required for a long range RADAR. This ensures there is sufficient time for the pulses to return before transmission begins again.
- So, **Longer Range = Longer PRI**

Distance = Speed x Time

Max Range = C x PRI x ½

MIN RANGE

- **Determined by the pulse length**
- When a target is close to the transmitter, there is a risk it may return the radar energy before the transmitter has switched to RX mode.
- So, **Shorter Range = Shorter Pulse Length**

Distance = Speed x Time

Min Range = C x Pulse Length x ½

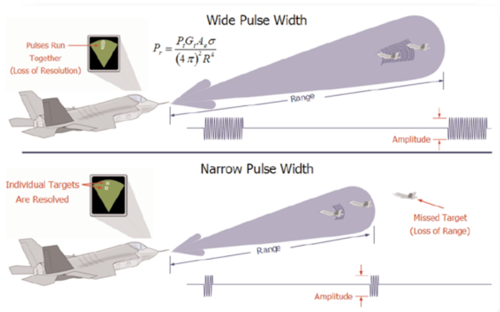
OR…

Min Range = Pulse Width x ½

RADIO NAVIGATION 8 – BASIC RADAR PRINCIPLES

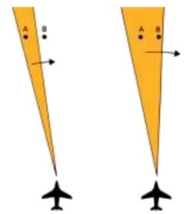
RADIAL RESOLUTION (PULSE WIDTH)

- A large pulse width may cause targets that are close together to return as a single contact.
- EG/ A pulse length of 1 μsec will stretch the target by 150 metres. If another aircraft is within 150 metres they will merge on the display.
- **A short pulse width will therefore be required to improve radial resolution.**
- Shortening pulse width however reduces the time the target is illuminated by the pulse, thus **reducing the chance of a good return.**



AZIMUTH RESOLUTION (BEAM WIDTH)

- **A narrow beam will improve azimuth resolution.**
- A narrow beam can be produced with **higher frequencies.** However, a big antenna is required to achieve a higher frequency which will require **a lot more power.**



Ability to resolve targets in angle is determined primarily by antenna beamwidth. Targets can be resolved if beamwidth is less than their angular separation.

WAVELENGTH CONSIDERATIONS

- **Short wavelength** (high frequency) will be subject to **greater attenuation.**
  - Suited for weather radar
- **Long wavelength** (low frequency) will be subject to **less attenuation.**
  - Suited for ATC radar as transmission are less affected by cloud and precipitation.

ANTENNA TYPES

- **Parabolic Antenna** - Old Type
- **Phase Array Antenna –** New Type
  - Requires less power as arrays are powered individually rather than all together at once.

SECONDARY RADAR (SSR)

SECONDARY RADAR

- **Ground transmitter requires less power**
  - Signal only needs to reach aircraft
- **Small aerial can be used on aircraft**
  - Aircraft emits omnidirectional reply
- **Echoes Eliminated**
  - Only target replied are accepted
- **Ground transmitter requires less power**
  - Signal only needs to reach aircraft
- Reply strength **independent of target reflection properties.**
- **Replies can be coded with additional info**

SYNCRONISITY

- Secondary radar normally transmits its pulse **once a primary return has been received.**
- **Minimises transmission time** on 1030 MHz which is the common SSR frequency.

MOVING TARGET INDICATOR (MTI)

- Only moving targets (identified by Doppler shift) are displayed on the radar screen.
- Fixed objects (buildings etc) are therefore **filtered to reduce clutter.**

RADAR APPROACHES

SURVEILLANCE RADAR APPROACH (SRA)

- Uses the ASR (Aerodrome Surveillance Radar)
- Provides **azimuth information only**
- Normally terminated 2nm from touchdown
- "You are right of the centerline, turn left two degrees. At 3 miles from touchdown you should be passing 1200 feet. 3 miles now."

PRECISION APPROACH RADAR (PAR)

- Utilises a **scanning beam**
- Provides both **azimuth and glideslope** information.
- Both **SRA & PAR are normally military** approaches and only used by civil traffic in case of emergency.

RADIO NAVIGATION 8 – BASIC RADAR PRINCIPLES

OTHER RADAR TYPES

SURFACE MOVEMENT RADAR

- Allows control of **aircraft and vehicles** moving on apron, taxiways and runways.
- Operates in the **SHF band.**
    - EHF was blocked by precipitation.

ADS

- **Automatic Dependent Surveillance**
- Aircraft identifies its position using GPS then transmits this to ATC.
- Useful for areas without radar coverage / obstructions.

Radar Type	Usage	Range	Wavelength	RPM	Pulse Length
Long Range	Airways	250 nm	50 cm	↓	↑
Terminal	DEP / ARR	75 nm	25 cm		
Aerodrome Surveillance Radar (ASR) + SRA	Vectoring	25 nm	10 cm		
PAR	Precision Appr	10 nm	3 cm	Scanning	
SMR	Surface MVT	2.5 nm	3 cm	Highest	

RADIO NAVIGATION 9 – AIRBORNE WEATHER RADAR

OPERATION PRINCIPLE

- Uses **primary RADAR** to detect reflection from **water droplets**.
- Whilst the wavelength would ideally be ½ the average water droplet size, this would create a very high frequency and attenuation would be too great. A compromise is therefore used.

AWR FACTS

- **Frequency: 9.75 GHz (SHF)**
- **Wavelength: 3 cm**
- **Beam Width = 3.5⁰ → 5⁰**

ANTENNA TYPE

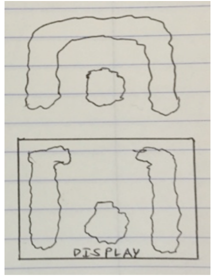
- A **phased array** antenna is used.
- The narrow beam required can be produced without requiring a large antenna and high power consumption.
- Phased array also produces **less side lobes.**

AWR COLOURS

- Green / Yellow / Red / Magenta
- **Colour gradient indicates turbulence**

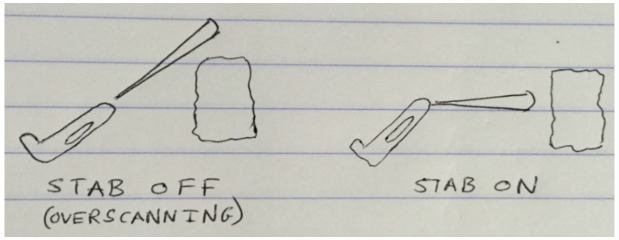
FALSE ALLEY

- When TS is present behind another cloud, radar attenuation can cause no return from the clouds behind.
- Can create the impression of a false alley on the radar display.



STABILISER (STAB) FUNCTION

- With STAB ON, the antenna is **stabilised in pitch and roll** by gyros.
- Without STAB, the radar could overscan (miss the cloud) in a climb for example.



WX MODE & WX/ TURB MODE

- With WX/TURB mode, the **doppler function** is activated and turbulence detection is available.
- **High PRF is used so range is reduced** to about 50 nm.

GAIN CONTROL

- Gain **controls the amplification of the radar echoes.**
- Gain amplifies input signals whereas volume amplifies output signals.
- It is **manually adjusted when in MAP mode.**
- **AUTO is selected when in WX mode** in order to allow the STC to function.

STC (AUTO GAIN)

- **Sensitivity Time Control**
- Active when in WX mode and gain on AUTO.
- Without STC, clouds which are closer will appear stronger than those further away (due radar attenuation) even though the intensity may be the same.
- Applies less gain to closer returns in order to pain a more accurate picture.
- Operates to a range of 60 nm.

TILT

- **Tilt is ± 15⁰**
- Scanning too low can cause reflected ground return to mix with weather return.
- Scanning too high could lead to overscanning.

RADIO NAVIGATION 9 – AIRBORNE WEATHER RADAR

MAP MODE

- New aircraft = Beam shape unchanged, STC deactivated and gain used manually to highlight terrain features.

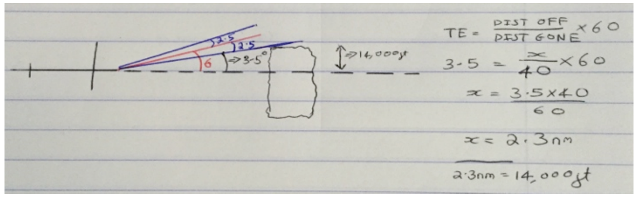
- Older aircraft use a **cosecant fan shaped beam**
- More power is deflected to the ground further away to provide a uniform picture.

CALCULATING HEIGHT OF CLOUDS

- **Use the 1 – 60 rule**

- Range 40 nm
- Cloud just disappears when 6^0 up tilt is set
- STAB – ON
- Beam Width 5^0
- FL 120

- Height of cloud = 14,000 ft + 12,000 ft = FL260



RADIO NAVIGATION 10 – SECONDARY SURVEILLANCE RADAR

OPERATION PRINCIPLE

- Primary radar identifies that a target is present
- Secondary radar then interrogates the target to obtain more information.
    - The amount and type of additional information obtained depends on the SSR mode in use.

OPERATION PRINCIPLE

- **Primary radar identifies** a target is present
    - Provides ATC with target return and trend information.

- **Secondary radar interrogates** the target to obtain more information.
    - The amount and type of additional information obtained depends on the SSR mode in use.
    - SSR will use primary radar principles to additionally derive the aircraft groundspeed

SSR FREQUENCIES

- Transmits on 1030 MHz
- Receives aircraft replies on 1090 MHz

TRANSPONDER COMBINATIONS

- There are 8^4 = 4096 squawk code combinations available.

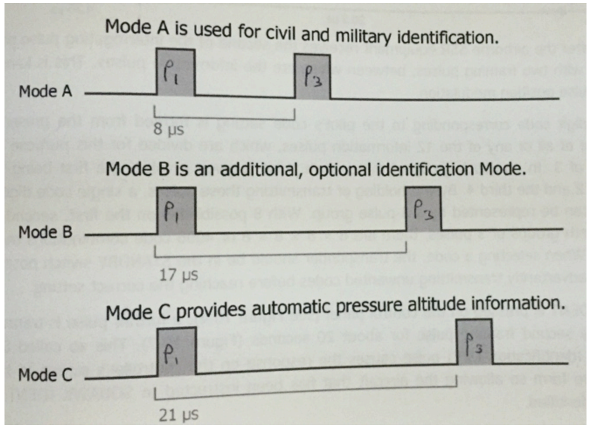
SQUITTER

- As well as replying to SSR interrogation, aircraft will send out information every second for use by other aircraft in TCAS.

INTERROGATION PROCESS

- By altering the PRI between Pulse 1 and Pulse 3, the transmitter can interrogate either Mode A or Mode C.
- By using these fixed PRI's, there is less likely to be confusion from interference as the aircraft is only listening to the expected PRIs.

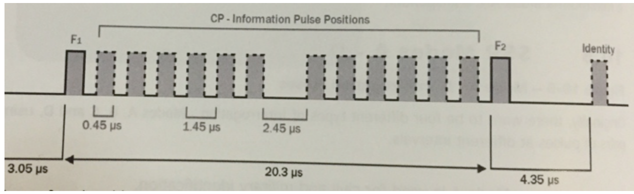
- Mode A (Transponder Code) = 8 μsec
- Mode C (Pressure Altitude) = 21 μsec



REPLY PROCESS

- The aircraft will transmit **2 framing pulses 20.3 μsec apart.**
- In between these, are **information pulses** which supply ATC with the required information.
- This process is called **pulse position modulation**.

- If IDENT is sent, it will transmit for **20 seconds** after the second framing pulse.



SPECIAL CODES

- 7700 – General Emergency
- 7600 – Radio Failure
- 7500 – Unlawful Interference

- 2000 – Entering airspace from non SSR region
- 7000 – General Conspicuity

RADIO NAVIGATION 10 – SECONDARY SURVEILLANCE RADAR

MODE C ACCURACY

- Pressure altitude is transmitted which is based on 1013 hPa.
- The height transmitted to ATC could be up to **50 ft different from the actual altitude** due to rounding during transmission.
- EASA allows a **max discrepancy of 300 ft** between reported level and readout.

SSR DISADVANTAGES

- **Garbling**
  - Replies of 2 aircraft in close proximity overlap and result in random readouts.
- **Fruiting**
  - Aircraft transmit omnidirectional
  - Radar picking up the wrong reply since aircraft transmit omnidirectionally and on the same frequency.
- **Antenna Shielding**
  - Aerial on bottom of aircraft is hidden from radar during a turn
- **Ghost Targets**
  - Reflection from terrain
- **Only 4069 Codes**

SSR ADVANTAGES

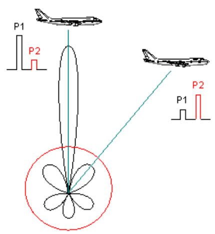
- **Longish Range**
- **No Clutter**
- **Reply gives range, bearing, height and speed**
- **Less power required**
- **Reduced comms**

SIDE-LOBE SUPPRESION

- To allow aircraft to distinguish between the main lobe and side lobes, a **second pulse is transmitted between P1 and P3.**
- P2 is sent out omnidirectionally

- If the amplitude of P2 > P1 the aircraft can tell it is picking up a side lobe and will not reply.

- If the amplitude of P1 > P2, the aircraft will reply as it is genuinely being interrogated.



MODE S

MODE S ADVANTAGES

- **Eliminates fruiting and garbling**
- **Datalink** allows for air-air / ground-air / air-ground data transmissions
- Provides **TCAS enhancements**
- **Greater height accuracy (±25 ft)**

INTERROGATOR CODES (IC)

- Each ground station has an interrogator code
- IC = II + SI

- **II (Interrogator Identifier) = 15 codes**
- **SI (Surveillance Identifier) = 63 codes**

AIRCRAFT IDENTIFICATION

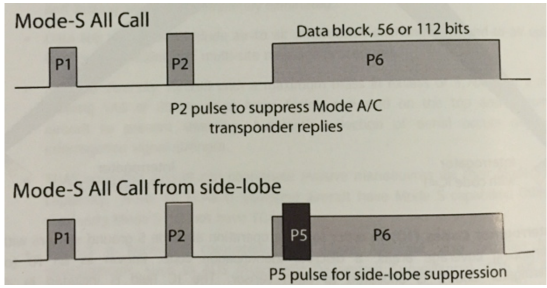
- Aircraft are identified by the following means:
- **24-Bit ICAO Aircraft Address (AA)**
  - Hard coded into the transponder
- **Aircraft Identification**
  - Flight No / Aircraft Registration
  - Incorrect entry is the biggest problem with mode S
- **Squawk Code**

MODE S ALL-CALL

- Ground station sends out an **all-call** periodically in order to check for new aircraft entering its airspace.

- **P2 pulse suppresses Mode A / C response**.
- **P3 is replaced by P6** which is a data-block.
- The data-block will include the ground stations IC code.
- **Side lobe suppression achieved with P5**

- On receiving the all-call for the first time, an aircraft will reply with **the IC code and it's AA (aircraft address).**
- Ground station then **locks out** the aircraft and asks it not to reply to further all-calls for **18 seconds.**



RADIO NAVIGATION 10 – SECONDARY SURVEILLANCE RADAR

ROLL-CALL

- **Once locked-out, the aircraft will only reply to selective interrogations.**
- Inclusion of IC and AA in interrogations and replies **reduces fruiting and garbling.**
- Also **prevents over interrogating** (minimises transmission time on 1030 MHz and 1090 Mhz)

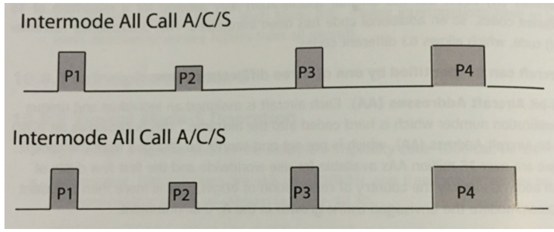
MODE INTERLACE PATTERNS

- **1/3 of time is spent on the all-call**
- **2/3 of time is spent on roll-calls.**

INTERMODE ALL-CALL

- Allows for ground stations to elicit response from both mode A / C aircraft and mode S equipped aircraft.

- P1, P2 and P3 as normal to interrogate Mode A / C aircraft.
- P4 pulse included at end which is regognised by mode S aircraft.
- **Long Pulse = Mode S Reply Required**
- **Short Pulse = Mode S Reply Not Required**



TRANSPONDER REPLY FORMAT

- **25 possible Mode S reply forms**
- **Message consists of a preamble followed by a data block.**

LEVELS OF SURVEILLANCE

- **Elementary Surveillance**
    - Identifications used to reduce fruiting and garbling.

- **Enhanced Surveillance**
    - Additional downlink aircraft parameters (DAPs) are included to provide **current state vector information:**
    - Groundspeed
    - Track Angle
    - Turn Rate
    - Roll Angle
    - Vertical Rate
    - Magnetic Heading
    - IAS
    - Mach No
    - True Track Angle

- **Future Developments**
    - Aircraft intention information

RADIO NAVIGATION 11 - DME

DME CHARACTERISTICS

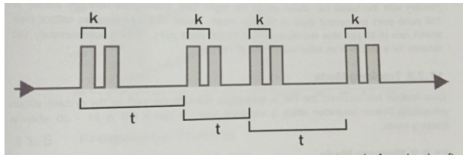
- **Vertically Polarised**
- **PON**
- **UHF (962 – 1213 MHz)**
- **256 Channels**
    - 126 X Channels (12 μsec)
    - 126 Y Channels (36 μsec)
- **Typical Range: 200 nm**

FREQUENCIES

- Interrogator (located in aircraft) transmits on the DME frequency between 962 – 1213 MHz.
- Ground station replies with a frequency **±63 MHz different**

1. JITTERED PRF

- Interrogator transmits a series of pulses in pairs.
- The interval between two pulses making a pair is kept constant.
- The interval between pairs of pulse however is randomly generated.
    - Prevents fruiting



2. GROUND STATION REPLY

- On the ±63 MHz frequency, the ground station sends back any pulses received after a **delay of 50 μsec**

3. RECEIVER

- The receiver on the aircraft is tuned to the ±63 MHz frequency and picks up all the replies from the ground station.
- Amongst all the replies, it searches for it's interval pattern which was transmitted.
- Once a match has been found, it computes the range from the station.

$$Range = \frac{Time\ Elapsed - Delay}{12.36\ (Radar\ Mile)}$$

MODES

- **Search Mode**
    - Before a 'lock-on' has occurred, the aircraft searches out to its max range in order to identify the presence of the DME ground station.
    - This takes place at 150 pps
    - If 15,000 pulses have been sent and no lock-on has occurred, it reduces to 60 pps

- **Tracking Mode**
    - Once lock on has occurred, 24 – 30 pps is used to reduce load on ground station.

- **Memory Mode**
    - When signal drops out, memory mode is entered for 10 seconds.
    - Range calculated based on last trend info
    - After 10 seconds and no further signal, search mode is re-entered.

BEACON SATURATION

- DME ground equipment is normally limited to 2700 pulse pairs per second (pps)
- If all aircraft were on s**earch mode, only 18 aircraft** could interrogate the ground station simultaneously (2700 / 150)
- If all aircraft were on **tracking mode, 120 aircraft** could interrogate simultaneously.
- In practice, most aircraft will be on tracking mode and a few on search mode.
- **Average capacity = 100 Aircraft**

OVERSATURATION

- In the event more than 100 aircraft try to interrogate the ground station, **receiver gain is reduced.**
- This results in the ground station only listening to those aircraft closer to the station which have a higher priority than those further away.

GHOST FREQUENCY

- Since civil pilots cannot tune UHF, a **ghost VHF frequency is displayed on the charts etc.**
- This is **frequency paired to the correct UHF frequency.**

RADIO NAVIGATION 11 - DME

CO LOCATED IDENTS

- **Co-Located when VOR & DME within:**
  - 2000 ft (En-Route)
  - 100 ft (Terminal)

- Idents of VOR and DME will be the same

- VOR idents every 10 seconds
- DME idents every 30 – 40 seconds

- DME ident is at a higher frequency of 1350 Hz (2700/2)

SAME LOCATION IDENTS

- When in same location but too far apart to be 'co-located'

- Last letter of DME ident changed to a Z

SLANT RANGE

- A long ranges, **slant range ~ plan range**
- When closer than **3 x height**

GROUND SPEED AND TIME

- A **decrease in ground speed readout can be expected when nearing the beacon** at a constant height.
- This is because the change in slant distance decreases closer to the beacon.
- On ILS, you are following a constant slant so this is not a factor.

ACCURACY

- Best accuracy when flying directly TO / FROM the beacon.
- Worst accuracy when flying abeam the beacon.

- Old Beacon accuracy (answer is ±):

$$0.25\ nm + \left(\frac{1.25}{100} \times Distance\right)$$

- New beacon accuracy: ± 0.2 nm

- **DME is more accurate than VOR except when directly overhead the beacon**.

RADIO NAVIGATION 12 - RNAV

RNAV TYPES

- Basic RNAV (B-RNAV) – ± 5 nm 95% of time
- Precision (P-RNAV) - ± 1 nm 95% of time

ERROR TYPE

- With VOR, the error is a radial error.
- With RNAV, the error is a **cross track error**

NAVAIDS USED

- DME – DME most accurate
- ADF not used in RNAV

5 Dot Display		
Mode	**Full Scale**	**1 Dot**
VOR	10^0	2^0
ENR	5 nm	1 nm
APP	1.25 nm	0.25 nm

2 Dot Display		
Mode	**Full Scale**	**1 Dot**
VOR	10^0	5^0
ENR	4 nm	2 nm
APP	1 nm	0.5 nm

AUTO / MAN MODE

- In AUTO, NAVAIDs are selected and tuned automatically based on range / geometry.
- Better to use two navaids that intersect at 90^0

RADIO NAVIGATION 13 - GNSS

CONSELLATION

- 24 Satellites (21 Operational & 3 Spares)
- 1 Orbit – 12 Hrs
- 6 Orbital Planes with max of 4 per each plane
- Cross EQ at 55^0 with 60^0 between planes.
- Height of orbit – 20200 km

PRINCIPLE OF OPERATION

- Signal sent to aircraft which includes the satellites position and time the message was sent.
- Aircraft can then calculate it's distance from satellite.
- **3 Satellites** required for basic position fix

PSEUDORANGE

- The aircrafts receiver clock is inaccurate in comparison to the satellites atomic clock.
- Due to this error, the range obtained is termed **psuedorange**
- This error is minimised by use of a **fourth satellite** to help obtain the correct timing information.

DATABASES

- **Almanac** – Positions of all satellites
- **Ephemeris** – Position of individual satellite

SEGMENTS

- User
- Control
- Space

CONTROL SEGMENT

- Manages performance of the system
- Provides NAV DATA upload
  - Almanac – Every 24 Hrs
  - Ephemeris – Every 2 Hrs
- Monitors satellite constellation

DATABASE SYNCING

- A ground station downloads the latest almanac database from the first satellite it finds after being powered on.
- This gives it a rough idea as to the location of other satellites.
- Once it has located the other satellites, it will download their individual ephemeris data.

IDENT CODES

- C / A – Coarse Acquisition Code (Civil)
- P – Precise Code (Military)

FREQUENCIES

- Satellites / Space Vehicles (SV) – SHF
- Users = UHF

- **Satellites transmit on L1 and L2 at the same time.**
- Military users can compare L1 and L2 in order to calculate the depth of the ionosphere and obtain better accuracy.

- L1 = 1575.42 MHz (Civil + Military)
- L2 = 12276.6 MHz (Military Only)