Radio Navigation

Basic Propagation Theory 0.62.01

Electromagnetic waves

- Waves travel at the speed of light - 300,000km/s or 300,000,000m/s or 162,000NM

Cycle - Complete series of values of a periodical process

Frequency - Number of cycles occurring in 1 second expressed in Hertz (Hz)

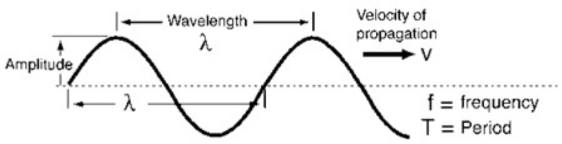
Wavelength - The physical distance travelled by a radio wave during one cycle of transmission

Amplitude - Maximum deflection in an oscillation or wave.

- **Wavelength = speed of light (c) / frequency (f)**

Phase angle - Fraction of one wavelength expressed in degrees from 000 to 360

Phase angle difference/shift - Anular difference between the corresponding points of two cycles of equal wavelength, which is measurable in degrees.



$$\text{Wavelength} = \frac{\text{Speed of Light}}{\text{Frequency}}$$

$$\lambda = \frac{v}{f}$$

3-30kHz VLF - Very Low Frequency
30-300kHz LF - Low Frequency
300-3000kHz MF - Medium Frequency

3-30 MHz HF - High Frequency
30-300MHz VHF - Very High Frequency
300-3000 MHz UHF - Ultra High Frequency

3-30GHz SHF - Super High Frequency
30-300GHz EHF - Extremely High Frequency

Modulation

- When a carrier wave is modulated, the resultant radiation consists of the carrier frequency plus additional upper and lower sidebands.

Single Sideband

- HF meteorological information for aircraft in flight (VOLMET)
- HF two-way communication

ITU - International Telecommunication Union - abbreviation

- **N0N -** Carrier without modulation as used by non-directional radio beacons (NDB)
- **A1A -** Carrier with keyed Morse code modulation as used by NDBs
- **A2A -** Carrier with amplitude modulated Morse code as used by NDBs
- **A3E -** Carrier with amplitude modulated speech used for communication (VHF-COM)

Pulse String Characteristics

- Pulse length
- Pulse power
- Continuous power

Carrier wave - Radio wave acting as the carrier or transporter

Modulation - Technical term for the process of impressing and transporting information by radio waves.

Amplitude modulation - Information that is impressed onto the carrier wave by altering the amplitude of the carrier

Frequency modulation - Information that is impressed onto the carrier wave by altering the frequency of the carrier

Pulse Modulation - Modulation used in radar by transmitting short pulses followed by larger interruptions

Phase Modulation - Modulation form used in GPS where the phase of the carrier wave is reversed.

Antennas

Antenna - Antenna or aerial is an electrical device which converts electrical power into radio waves, and vice versa.

- Simplest type is **dipole**, which is a wire of length equal to ½ of the wavelength

- Electromagnetic waves always consist of an oscillating electric (E) and an oscillating magnetic (H) field which propagates at the speed of light.
- E and H fields are perpendicular to each other. Oscillations are perpendicular to the propagation direction and are in-phase.

Polarisation - Orientation of the plane of oscillation of the electrical component of the wave with regard to its direction of propagation.

Directional Antennas

- Loop antenna - used in ADF receivers
- Parabolic antenna - used in weather radar
- Slotted planar array - used in modern weather radars

Antenna shadowing - Happens when its line of sight to the source is partially or fully blocked by another antenna in front of it.

- Antennas must be separated on an aircraft, with shielding between them. Even with well-mounted antennas, closely spaced channels in the same band may interfere with each other.

Wave Propagation

Wave Propagation - structure of the ionosphere

- Ionosphere is the ionised component of the Earth's upper atmosphere from approximately 60-400km above the surface, which is vertically structured in three regions or layers.
- D, E and F layers and their depth varies with time

- **Skywaves** - electromagnetic waves refracted from the E and F layers of the ionosphere
  - LF, MF, HF

- At night the F layer is the only layer of significant ionization, while the ionization in the E and D layers is extremely low after sunset.
- During the day D and E become much more heavily ionized, as does the F layer, which develops an additional weaker region of ionisation known as the F1 layer. F2 layer persists by day and night and is the region mainly responsible for the refraction of radio waves.

- **Ground waves -** The electromagnetic waves travelling along the surface of the Earth
  - LF, MF, HF

- **Space waves -** Electromagnetic waves travelling through the air directly from the transmitter to the receiver.
  - VHF, UFH, SFH, EHF

Doppler Principle - Phenomenon where the frequency of a wave will increase or decrease if there is relative motion between the transmitter and the receiver.

Skip Distance - The distance between the transmitter and the point on the surface of the Earth where the first sky wave return arrives

Skip zone/ dead space - Is the distance between the limit of the surface wave and the sky wave.

Fading - when a receiver picks up two signals with the same frequency, and the signals will interfere with each other causing changes in the resultant signal strength and polarisation.

- Radio waves in the VHF band and above are limited in range as they are not reflected by the ionosphere and do not have a surface wave.

Reflection - Is the change in direction of a radio wave at an interface between two different media so that the radio wave returns for radio transmissions VHF and radar
Refraction - Signal's propagation path bends and the signal changes its speed as it moves from one medium to another.
Diffraction - Phenomenon by which wave energy bends around an object the size of which is comparable to the wavelength
Absorption - Radio wave energy is the way in which the energy is taken up by the ground or atmosphere
Interference - Phenomenon in which two waves superimpose to form a resultant wave of greater or lower amplitude.

Multipath - When the signal arrives at the receiver via more than one path. (signal being reflected from surfaces near the receiver)

Radio Aids 0.62.02

Ground Direction Finding

Ground DF

- Get azimuth from an aircraft transmitting on the selected frequency and guide it to overhead the DF station.
- Limited range because of the path of the VHF signal. *

QDM - Magnetic bearing to the station
QDR - Magnetic bearing from the station

- By using more than one ground station, the position of an aircraft can be determined and transmitted to the pilot.

Range (NM) = 1.23x sqrt transmitter height (ft) + 1.23 x sqrt receiver height (ft)

Synchronous transmission - When the loop aerial received more than one transmission, within the tuned bandwidth, the null detected will be that which is the resultant of the two synchronous signals.

Multipath signals - May result in bearing errors (from the same aircraft)

VDF information is divided into classes
(according to ICAO annex 10)

- **A -** within +-2°
- **B -** within +-5°
- **C -** within +-10°
- **D -** Accurate to less than C

Non-directional beacon (NDB) / automatic direction finding (ADF)

NDB - non directional radio beacon**. Ground equipment**

- Operates in the LF and MF frequency bands
- 190 - 1750kHz
- Certain commercial radio stations transmit within the frequency band of the NDB
- NDB station has an automatic ground monitoring system
- Emits N0N/A1A or N0N/A2A

ADF - Automatic direction finding equipment. **Airborne equipment**

Locator beacon - LF/MF NDB used as an aid to final approach with a range of 10-25NM

NDB for navigation

- Transmitter used as an instrument approach for airports and offshore platforms.
- Intercepting and tracking; holding; homing; tracking;

NDB Identification

- Each NDB is identified by a one, two, or three-letter morse code callsign

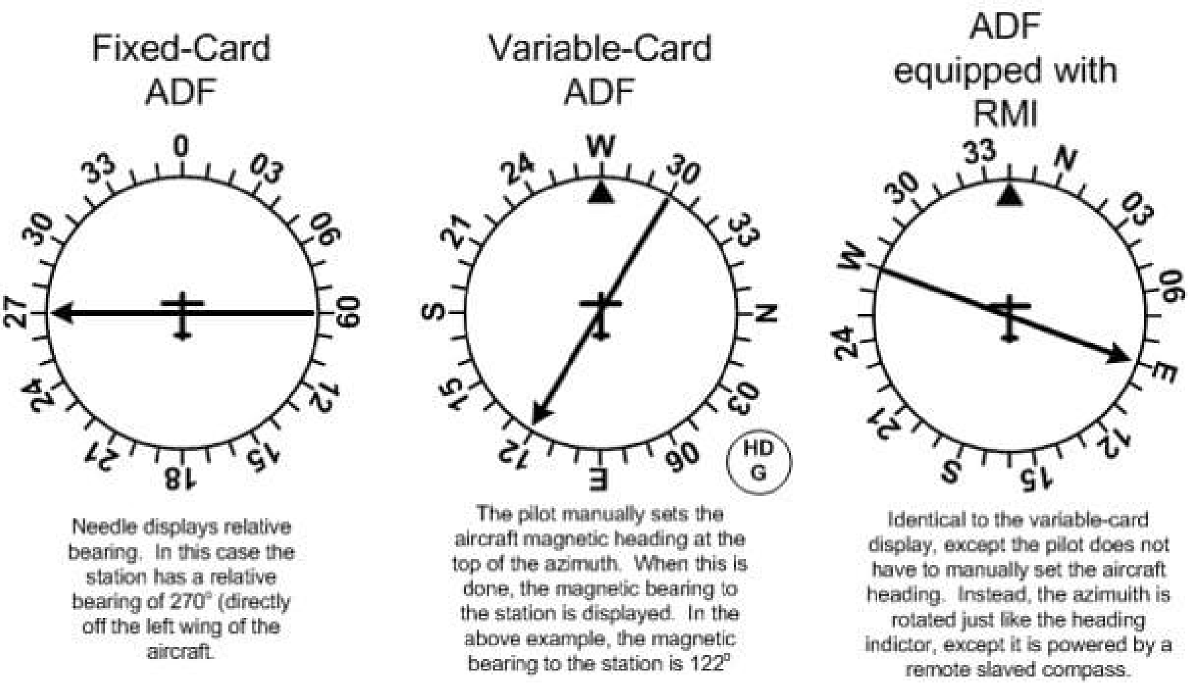
Cone of confusion - NDB beacon does not transmit a usable signal vertically upwards.

BFO - Beat frequency oscillator

- Required for identification and monitoring
- N0N/A1A NDB - BFO circuit of the receiver has to be activated
- On modern aircraft, BFO is activated automatically

Presentation and Interpretation

- Electronic display; radio magnetic indicator (RMI); Fixed-card ADF (radio compass); moving-card ADF



MB = RB + MH

TB = RB + TH

CH +dev MH +var TH

Homing and Tracking

- To a radio beacon, with RB of , if MH decreases, there’s right drift
- Towards an NDB, with constant wind, and mab. Var - relative bearing of the NDB should be equal to the experienced drift angle.

Interception of inbound QDM

- Turn onto QDM heading on the Direction indicator
- Once QDM heading observe which side the HEAD of the needle is deflected to on the RBI. Confirm that the intercepted heading is bigger than the cone angle
- Turn 60° towards the direction of the head of the needle away from the heading on the DI
- Wait for the head of the RBI need to open to 060° or 300° depending on the side which the needle was deflected initially
- Then turn onto the QDM heading on the DI.

Outbound QDR

- Turn onto QDR heading on the DI
- Once on the QDR heading observe which side the HEAD of the needle is deflected to on the RBI. Confirm that the intercept heading is bigger than the cone angle.
- Turn 30° towards the direction of the head of the needle away from the heading on the DI.
- Wait for the TAIL of the RBI needle to close to 030 to 330 depending on the side which the needle was deflected initially.
- Then turn onto the QDR reading on the DI.
- (TAIL of the RBI needle provides information on what QDR the aircraft is tracking)

Changing from QDM/QDR

Determining station passage and the abeam point

Coverage and Range

- Power of the transmitter limits the range of an NDB
- Transmission power - range is proportional to the square of the power output
    - RANGE = sqrt power output
- Range is greater over water (3x sqrt wattage)
- Land 2xsqrt wattage

- Interference between the sky waves and ground waves leads to **fading**
- Accuracy of the pilot has to fly the required bearing in order to be considered established during approach is +-5° (doc8168)
- There is no warning indication of NDB failure

- In mountainous terrain, random reflections and refraction can cause distortion of the signal bearing. Terrain errors are more troublesome when flying near the ground and in mountainous regions.

Errors and Accuracy

- **Coastal refraction** - Radio wave travelling over land crosses the coast, the wave speeds up over water and the wave front bends.
    - To minimize, bearings should be taken perpendicular to the shoreline
    - The furthest inland, the most refraction.

- **Night/twilight effect** - Influence of sky wave and ground waves arriving at the ADF receiver with a difference of phase and polarisation which introduce bearing errors.

- Interference from other NDB stations on the same frequency may occur at night due to sky-wave contamination.

Factors affecting range and accuracy

- Static radiation energy from a CB cloud may interfere with the radio wave and influence the ADF bearing indication
- Bank angle of the aircraft causes a dip error
- Low altitude multipath signals reflected from terrain can cause erroneous readings.
    - Effect diminishes with height as hills are further from the line of sight and interfere less with surface wave.

VHF (VOR): Conventional VOR (CVOR) and Doppler VOR (DVOR)

VOR Principle of operation

- Bearing determination by phase measurement.
- Bearing is established already at the transmitter and, depending on where the aircraft is in relation to the VOR station, it will receive signals that define the bearing of the aircraft FROM the VOR.
- VOR ground station transmits 2 continuous horizontally polarised signals on the same frequency. A receiver antenna would be unable to distinguish between these signals unless they had some differing characteristic.
- Reference phase, variable phase, phase difference ?

- Frequencies used are VHF 108.0-117.975Mhz
- Frequencies which have odd number in the first decimal place are used by ILS

CVOR - Conventional VOR - first generation VOR station emitting signals by means of a rotating antenna.

DVOR - Doppler VOR - Second-generation VOR station emitting signals by means of a combination of fixed antennas utilising the Doppler principle; en-route VOR for use by IFR traffic

TVOR - Terminal VOR - Station with a shorter range used as part of the approach and departure structure at major aerodrome.

VOT - Test VOR - VOR station emitting a signal to test VOR indicator in aircraft

- **ATIS -** Transmitted by VOR stations

VOR Components

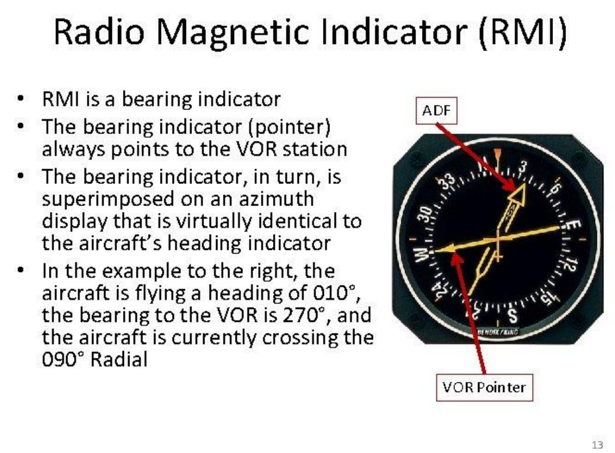
- Antenna, receiver, indicator

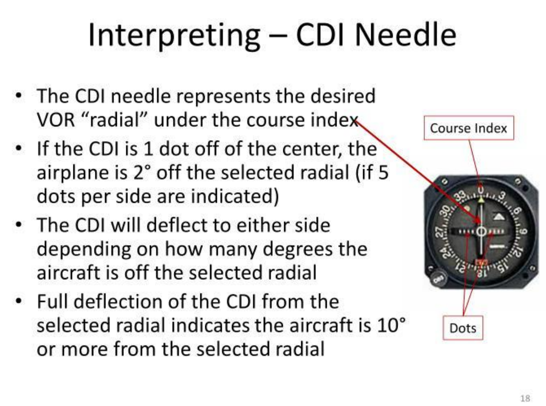
Identification

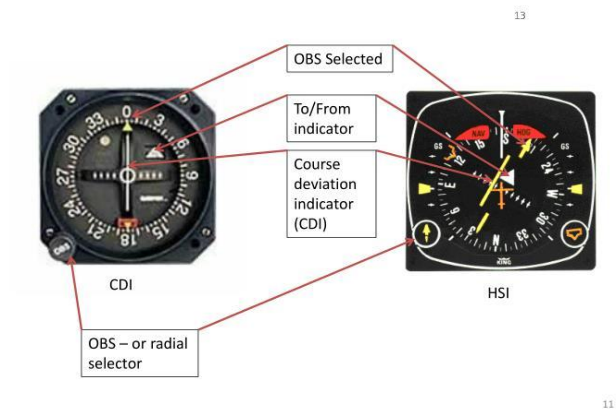
- Identifier is transmitted in Morse Code.

- VOR station has an automatic ground monitoring system.
- Failure of the VOR station to stay within the required limits can cause the removal of identification and navigation components from the carrier or radiation to cease.

Presentation and Interpretation







- **Vor tracking and influence of wind**
- **Interceptions of a radial inbound and outbound to/from a VOR**

- **Determining station passage and the abeam point.**
    - When changes from TO to FROM

- Converting a radial to True bearing, variation at the VOR must be taken into account.

Errors and accuracy

- Accuracy the pilot has to fly the required bearing in order to be considered established on a VOR track when flying approach procedures, **has to be within half-full scale** deflection of the required track.
- Due to reflections from terrain, radials can be bent and lead to wrong or fluctuating indications - **scalloping**

Distance Measuring Equipment (DME)

Principles

- Operates in the UHF band
    - 960 - 1215 Mhz
- Comprises two basic components
    - Aircraft component - interrogator
    - Ground component - Transponder

- Aircraft transmits a stream of pairs of pulses to the ground station
- Two pulses in each pair are separated by 12 microseconds
- After 50 microseconds, the ground station retransmits them.
- Aircraft equipment is known as the interrogator, as it initiates the exchange.
- Ground equipment replies

- Distance measured is slant range

- Position line using DME is a circle with the station at its centre.

- Pairing of VHF and UHF frequencies (VOR/DME) enables the selection of two items of navigation information from one frequency setting.

- Military UHF tactical air navigation aid (TACAN) stations may be used for DME information

- Identity signal shall consist of the transmission of the beacon code in the form of dots and dashes (morse code) of identity pulses at least once every 40 seconds, at a rate of at least 6 words per minute. - for co-located vor/dme

Presentation and Interpretation

- When identifying a DME station co-located with a VOR station, the identification signal with the higher-tone frequency is the DME which identifies itself every 40 seconds.
- Slant range = sqrt[(true range NM)^2 + (height NM)^2]
- State that a DME system may have a ground speed (GS) and time to station read-out combined with the DME read-out.
- DME arc is a curved route defined by a constant distance from one of the navaids.

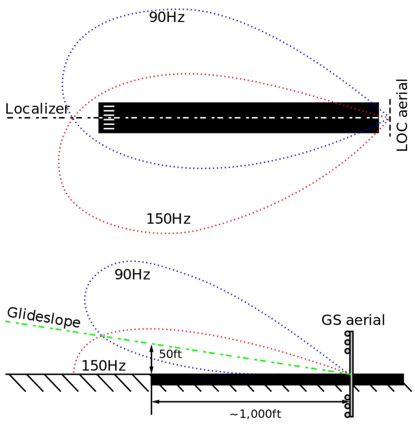
Coverage and Range

- DME responds to the strongest 100 signals.
- Flying towards/away from the DME - the furthest the more accurate GS

Instrument Landing System (ILS)

Principles

- Main Components: Localiser (LOC), glide path (GP), range information (markers or DME)
    - LOC antenna should be located on the extension of the runway centre line at the stop-end
    - GP antenna should be located beyond the runway threshold, laterally displaced to the side of the runway centre line.
- Marker beacons produce radiation patterns to indicate predetermined distances from the threshold along the ILS GP.
- Marker beacons are sometimes replaced by a DME paired with the LOC freq.
- ILS LOC freq 108-111.975, only with odd numbers on the first decimal.
- GP operates on UHF and is paired automatically by being paired with the LOC freq



- LOC and GP antenna radiate side lobes (false beams) which can give rise to false centre-line and false GP indication.

- Back beam from the LOC antenna may be used as a published non-precision approach

- Recommended GP is 3°
- Rate of descent = 5 x GS

- All markers operate on 75 Mhz carrier frequency.
- **Outer Marker -** low - 2 dashes per second continuously - blue
- **Middle Marker -** medium - continuous series of alternate dots and dashes - amber
- **Inner Marker -** high - 6 dots per second continuously - white

- Final approach area contains a fix or facility that permits verification of the ILS GP-altimeter relationship. Outer marker or DME is usually used for this purpose.

Presentation and interpretation

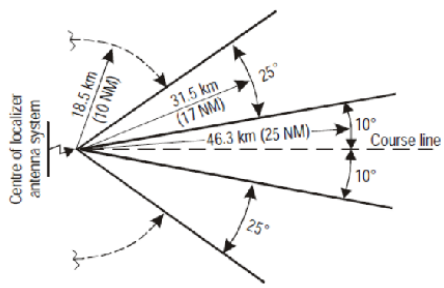
- Morse code ID that typically starts with an I, followed by a three letter code.

- ILS installation has an automatic ground monitoring system
- LOC and GP monitoring system monitors any shift in the LOC and GP mean course line or reduction in signal strength
- Warning flags will appear for both LOC and the GP if the received signal strength is below a threshold value.
    - Absence of the carrier frequency
    - Absence of the modulation simultaneously
    - Percentage modulation of the navigation signal reduced to 0
- Full scale deflection of the CDI needle corresponds to aprox 2.5° displacement from the ILS centre line
- Full scale deflection of the GP corresponds to aprox 0.7° from the ILS GP centre line

- Most installations produce a mirror image of the localiser beams on the opposing runway from what would normally be referred to as the back scatter from the localiser aerial
- HSI course selector must be set to the opposing main instrument runway QDM, the 'front course'; to make sense of the indications.

Coverage and Range

- LOC coverage area is 10° either side of the centre line to a distance of 25NM from the runway
- 35° on either side of the centre line to a distance of 17NM from the runway
- GP coverage area is 8° either side of the centre line to a distance minimum 10NM from the runway.



dard localizer coverage requirement. [3]

Errors and Accuracy

- ILS approaches are divided into facility performance categories
    - CAT I, CAT II, CAT III A, CAT III B, CAT III C
    - All CAT III ILS operation guidance information is provided from the coverage limits of the facility to, and along the surface of the runway.
    - Accuracy requirements are progressively higher for CAT I, CAT II, CAT III because RVR and DH decreases gradually to 0.
- Accuracy the pilot has to fly the ILS LOC to be considered established on an ILS track is within the half-full scale deflection of the required track; The aircraft has to be established within the half-scale deflection of the LOC before starting descent on the GP
- Pilot has to fly the ILS GP to a maximum of a half-scale fly-up deflection of the GP in order to stay in protected airspace.

- If the pilot deviates by more than half-course deflection on the LOC or by more than half-dot deflection on the GP, an immediate go-around should be executed.
- ILS beam bends as deviation from the nominal LOC and GO respectively which can be assessed by flight test.
- Multipath interference is caused by reflections from objects within the ILS covered area.

Factors affecting range and accuracy

- ILS Critical area - an area of defined dimensions around the LOC and GP antennas where vehicles, including aircraft, are excluded during all ILS operations
- ILS- Sensitive area - an area extending beyond the ILS critical area where the parking or movement of vehicles,including aircraft, is controlled to prevent the possibility of unacceptable interference to the ILS signal during ILS approach.

Microwave Landing System (MLS)

Principles

- Horizontal guidance during the approach
- Vertical guidance during the approach
- Horizontal guidance for departure and missed approach
- DME (DME/P) distance
- Transmission of special information regarding the system and the approach conditions.

- MLS operates in the SHF band on any one of 200 channels, on assigned frequencies.
- MLS can be installed at aerodromes where, as a result of the effects of surrounding building or terrain, ILS siting is difficult

Presentation and Interpretation

- Segmented approaches can be carried out with a presentation with two cross bars directed by a computer which has been programmed with the approach to be flown.
- Segments and curved approaches can only be executed with DME/P installed.
- Aircraft are equipped with multimode receiver (MMR) in order to be able to receive ILS, MLS, GPS.
- DME/P is more accurate than normal DME, giving range accuracies of +-100ft instead of +-.5NM
- When DME/P is not available the MLS can only give a straight in or offset approach (like ILS)

Coverage and Range

- Coverage area of the approach direction is a sector of +-40° of the centre line out to a range of 20NM from the threshold

Radar 0.62.03

Pulse Techniques

Applications of radar

- Primary and secondary radar;
- Airborne Weather radar

- Primary radar has to send a signal which travels to the target and back;
- Range of radar depends on pulse repetition frequency (PRF), pulse length, pulse power, height of aircraft, height of antenna and frequency used.

Ground Radar

Principles

- Provides bearing and distance of targets.
- Primary ground radar is used to detect aircraft that are not equipped with a secondary radar transponder;
- Modern ATC systems use inputs from various sensors to generate the display.

Airborne Weather Radar

Principles

- Main task is to detect and avoid significant weather like CBs and to be able to see it through the route and plan diversions;

- Modern weather radars employ frequencies that give wavelengths of about 3cm that reflect best on wet hailstones.
- Antenna is stabilized in the horizontal plane with signals from the aircraft's attitude reference system.
- Cone-shaped pencil beam of about 3-5° beam width used for weather detection.

- Off/on switch
- Function switch with WX, WX+T, and MAP modes
- Gain-control setting (auto / manual)
- Tilt/auto tilt switch.

- Colour gradients: green, yellow, red and magenta (increasing intensity of precipitation)
- Use of azimuth-marker lines and range lines in respect of the relative bearing and the distance to a thunderstorm on the screen *

Coverage and Range

- Map mode is only used to give a general indication of surrounding terrain and coastlines
- Pencil shaped beam used in preference in mapping mode beyond 50 to 60NM because more power can be concentrated in the narrower beam.
- Auto Tilt - adjusts tilt according to altitude
- Larger water droplets will give good echoes.

Errors, accuracy, limitation

- Transmission on the ground near people and equipment are avoided as the microwave emission is strong enough to damage any ground crew and equipment nearby.

Factors affecting range and accuracy

- Areas behind heavy rain (shadow area) will not be detected since the radar can't penetrate through the heavy rain that is in front. Causing a blind spot for the route.
- Take off - 5-15° up
- climb - 5°up
- High altitude - 0 tilt
- Descent - 5°up (to avoid clutter from ground returns)
- Low altitude - 5° up

- When the tilt is set too high, thunderstorms might not be picked up because it is not within the beam of the radar.

Application for Navigation

- Doppler radar that is sensitive to the horizontal movements of water droplets in the air - paints turbulence return.
- Typically works out to about 40NM of the aircraft

- Windshear is detected by doppler, or reflected radio shift, as with WX+T mode.

Secondary surveillance radar and transponder

Principles

- ATC system is based on the replied provided by the airborne transponders in response to interrogations from the ATC secondary radar.
- Ground ATC secondary radar uses techniques which provide the ATC with information that cannot be acquired by the primary radar
- Airborne transponder provides coded-reply signals in response to interrogation signals from the ground secondary radar and from aircraft equipped with TCAS (traffic alert and collision avoidance system
- SSR shows target range, bearing, aircraft identification code, aircraft altitude, selective addressing for two way data link

Modes and Codes

- Interrogator transmits its interrogations in the form of a series of pulse pairs.
- Interrogation modes: Mode A, Mode C, Mode S
- Interrogation frequency and reply frequency are different
- Decoding of time interval between the pulse pairs determines the operating mode of the transponder
    - Mode A - transmission of aircraft transponder code
        - Sequence of four digits which can be manually selected from 4096 available codes
    - Mode C - transmission of aircraft pressure altitude
        - Pressure altitude is reported in 100ft increments
    - Mode S - selection of aircraft address and transmission of flight data for the ground surveillance.
        - Receive interrogations from TCAS and SSR ground stations
        - Interrogations contain either the aircraft address, selective call or all-call address.
        - Can provide enhanced vertical tracking, using 25-ft altitude increments

- Every aircraft is allocated an ICAO aircraft address, which is hard-coded into the Mode S transponder
- 24-bit address is used in all Mode S transmission, so that every interrogation can be directed to a specific aircraft.

- SSR can be used for automatic dependent surveillance broadcast (ADS-B)

- In addition to the information provided, on request from ATC, a special position identification (SPI) pulse can be transmitted but only as a result of a manual selection by the pilot (IDENT)

- Compatibility of Mode S with Mode A and C *

Presentation and Interpretation

- Aircraft can be identified by a unique code
- Information that can be presented on the ATC display system
    - PRessure altitude, FL, flight number or aircraft reg number, GS
- Selector Modes
    - OFF, STBY, ON (mode A), ALT(mode A, C, S), TEST, and reply lamp.

GLOBAL NAVIGATION SATELLITE SYSTEM 0.62.06

GNSS

General

- Four main GNSS:
  - USA NAVigation System with timing and ranging global position system (NAVSTAR GPS)
  - Russian Global Navigation Satellite system (GLONASS)
  - European Galileo
  - Chinese BeiDou
- All four systems consist of a constellation of satellites which can be used by a suitably equipped receiver to determine position.

Operation

- There are currently two modes of operation: standard positioning service (SPS) for civilian users, and precise positioning service (PPS) for authorised users.
- SPS was originally designed to provide civilian users with a less accurate positioning capability than PPS.
- Three GNSS segments: space segment; control segment; user segment.

Space Segment

- Each satellite broadcasts ranging signals on two UHF frequencies: L1, L2
- SPS is a positioning and timing service provided on frequency L1
- PPS uses both frequencies L1, L2
- Satellites transmit a coded signal used for ranging, identification (individual PRN code), timing and navigation.
- Navigation message contains:
  - Satellite clock correction parameters
  - Universal time coordinated (UTC) parameters
  - Ionospheric model
  - Satellite health data

- Ionospheric model is used to calculate the time delay of the signal travelling through the ionosphere.
- Two codes are transmitted on the L1 frequency
  - Coarse acquisition code C/A ; and a (P) precision code
  - P code is not used for standard positioning service (SPS)

- Satellites are equipped with atomic clocks which allow the system to keep very accurate time reference.

Control Segment

- Control segment comprises: master control station; ground antenna; monitoring station
- Control segment provide: monitoring of the constellation status; correction of orbital parameters; navigation data uploading.

User Segment

- GNSS supplies 3D position fixed and speed data, plus a precise time reference.

- GNSS receiver is able to determine the distance to a satellite by determining the difference between the time of transmission by the satellite and the time of reception.

- Initial distance calculated to the satellites is called pseudo-range because the difference between the GNSS receiver and the satellite time references initially creates an erroneous range.

- Each range defines a sphere with its centre at the satellite

- There are four unknown parameters (x,y,z, delta t) (receiver clock error) which require the measurement of ranges to four different satellites in order to get the position.

- GNSS receiver is able to synchronise to the correct time reference when receiving four satellites
- Receiver is able to calculate aircraft ground speed using the space vehicle (SV) doppler frequency shift or the change in receiver position over time.

NAVSTAR GPS Integrity

- Receiver autonomous integrity monitoring **RAIM** - technique that ensures the integrity of the provided data by redundant measurements.
- RAIM is achieved by consistency checks among range measurements
- RAIM requires five satellites. Sixth one is for isolating a faulty satellite from the navigation solution.
- Agreements have been concluded between the appropriate agencies for the compatibility and interoperability by any approved user of NAVSTAR and GLONASS systems.
- Different GNSSs use different data with respect to reference systems, orbital data, and navigation services.

Errors and factors affecting accuracy

- Factors that affect accuracy: ionospheric propagation delay; dilution of precision; satellite clock error; satellite orbital variations; multipath.
- **UERE** User equivalent range error - can be computed from all factors ^

- Error from the ionospheric propagation delay (IPD) can be reduced by modelling, suing a model of the ionosphere, or can almost be eliminated by using two frequencies.
- Ionospheric delay is the most significant error
- Dilution of precision arises from the geometry and number of satellites in view. Geometric dilution of precision (GDOP)
- UERE with GDOP allows for an estimation of position accuracy.
- Errors in the satellite orbits are due to: solar winds; gravitation of the sun and the Moon

Ground based augmentation system (GBAS)

- Measure on the ground the errors in the signals transmitted by BNSS satellites and relay the measured errors to the user for correction.
- ICAO GBAS standard is based on this technique through the use of a data link in the VHF band of ILS-VOR system
- GBAS station coverage is about 20NM
- GBAS provides information for guidance in the terminal area, and for 3D guidance in the final approach segment (FAS) by transmitting the FAS data block.
- One ground station can support all the aircraft subsystems within its coverage providing the aircraft with approach data, corrections and integrity information for GNSS satellites in view via a VHF data broadcast (VDB)
- Minimum software designed coverage area is 10deg on either side of the final approach path to a distance between 15 and 20NM, and 35deg either side of the final approach path up to a distance of 15NM.
    - Outside this area the FAS data of GBAS is not used
- GBAS based on GPS is called LAAS - local area augmentation system
- GBAS-based approach is called GLS approach (GLS-GNSS landing system)

Satellite based augmentation system (SBAS)

- Measure on the ground the errors in the signals received from the satellites and transmit differential corrections and integrity messages for navigation satellites.
- Frequency band of the data link is identical to that of the GPS signals.
- Use of geostationary satellites enables messages to be broadcast over very wide areas.
- Pseudo-range measurements to geostationary satellites can also be made as if they were GPS satellites.
- SBAS consists of:
    - Ground infrastructure (monitoring and processing stations)
    - Communication satellites

- SBAS allows the implementation of 3D type A and type B approaches, and it can provide approach procedure with vertical guidance (APV)

- Examples of SBAS:
  - EUropean geostationary navigation overlay service (EGNOS) in western Europe and the Mediterranean
  - Wide area augmentation system (WAAS) in the USA
  - Multi-functional transport satellite (MTSAT)-based augmentation system (MSAS) japan
  - GPS and geostationary earth orbit augmented navigation (GAGAN) in India.

- SBAS is designed to significantly improve accuracy and integrity
  - By alerting SBAS users within a 6 second if a GPS malfunction occurs.

Aircraft based augmentation system (ABASs)

- Use redundant elements within the GPS constellation (e.g. multiplicity of distance measurements to various satellites) or the combination of GNSS measurements with those of other navigation sensors (such as inertial systems) in order to develop integrity control.
- Type of ABAS using only GNSS information is named receiver autonomous integrity system **RAIM**
- System using information from additional onboard sensors is named aircraft autonomous integrity monitoring **AAIM**
- Typical sensors used are barometric altimeter and inertial reference system (IRS)

Performance Based Navigation (PBN) 0.62.07

PBN Concept

Principles

- Factors define area navigation (RNAV) or required navigation performance (RNP):
    - Accuracy, integrity, continuity
- RNAV and RNP are necessary to optimise the utilisation of available airspace
- It is necessary for flight crew and air traffic controllers to be aware of the on-board RNAV or RNP system capabilities in order to determine whether the performance of the RNAV or RNP system is appropriate for the specific airspace requirements.

- **Accuracy** - conformance of the true position and the required position
- **Continuity** - Capability of the system to perform its function without unscheduled interruptions during the intended operation
- **Integrity** - Measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid alerts to the user.

- PBN is not sensor specific

- Raw data vs computed data: conventional radio navigation is based on raw data like information from navigation aids and measured air data.

- **Availability -** percentage of time annually during which the system is available for use.

Components

- Navigational aid (NAVAID) infrastructure
- Navigation specification
- Navigation application

PBN Scope

- In oceanic/remote, en-route and terminal phases of flight, PBN is limited to operations with linear lateral performance requirements and time constraints.
- In the approach phases of flight, PBN accommodates both linear and angular laterally guided operations
    - Linear operations -
    - Angular operations -

Navigation Specifications

RNAV and RNP

- Difference between RNAV and RNP in terms of onboard equipment - RNP requires on board performance monitoring and alerting system
- Functional requirements of RNAV and RNP specifications
    - Continuous indication of lateral deviation
    - distance/bearing to active waypoint
    - GS or time to active waypoint
    - Navigation data storage and failure indication

Designation of RNP and RNAV specification

- X in RNAV X or RNP X is the lateral navigation (LNAV) accuracy (total system error) in NM, which is expected to be achieved at least 95% of the flight time
- Aircraft approved to the more stringent accuracy requirements may not necessarily meet some of the functional requirements of the navigation specification that has a less stringent accuracy requirement.
- RNAV 2 and RNP 2 are also used as navigation specifications

- **RNAV 10** and **RNP 4 -** Used in oceanic/remote phases of flight
- **RNAV 5 -** En-route and arrival phases of flight
- **RNAV 2 -** Might be used in the en-route continental, arrival and departure phases of flight
- **RNP 2-** Used in en-route and oceanic/remote phases of flight
- **RNAV 1** and **RNP 1 -** Used in the arrival and departure phases of flight

- **RNP APCH -** used in approach phase of a flight
- **RNP AR APCH -** Authorisation required. Used in approach phase of flight.

- **RNP 0.3 -** Used in all phases of flight except for oceanic/remote and final approach - primarily for helicopters
- **RNAV 1, RNP 1, RNP 0.3 -** May also be used in en-route phases of low-level IFR helicopter flights.

Use of performance based navigation PBN

Specific RNAV and RNP system functions

- RF leg - Radius to fix - radius, an arc length, and the fix at which it ends.
- FRT leg - fixed radius transition - Used en-route procedures; tells the aircraft system to construct a transition from one route segment to another with a specific radius.
- Importance of respecting the flight director guidance and the speed constraints associated with an RF procedure **

- Fly by turn vs fly-over: fly by turns before a point, fly over flies over the point and then proceeds to the next.

- **ARINC 424 path terminators -** Set the standards for coding the SIDs, STARs and instrument approach procedures (IAPs) from the official published government source documentation into the ARINC navigation database format.

- Path terminators define a specific type of termination of the previous flight path.

- **Offset flight path -** capability to follow a route in the flight plan but with a pilot selected offset either side of the defined path

PBN Operations and principles

- Path definition error **PDE -** Inability to accurately specify desired path
- Flight Technical error **FTE -** Error in following the prescribed path, either by the auto-flight system or by the pilot
- Navigation system Error **NSE -** Accuracy of a navigation system
- Total System Error **TSE -** Geometric sum of the PDE, FTE, NSE equals TSE - navigation accuracy depends on the TSE

On-board performance monitoring and alerting
- On-board performance monitoring and alerting of flight technical errors is managed by on-board systems or flight crew procedures.
- On-board performance monitoring and alerting of navigation system errors is a requirement of on-board equipment for RNP
- Dependent on the navigation sensor, the estimated position error (EPE) is compared with the required navigation specification
- EPE is the same as total system error
- Integrity of the system to monitor the accuracy and alert in the case of a downgrade is essential for safe PBN operations
- EPE value must be equal to or less than the required navigation specification
- On board performance monitoring and alerting of path definition error is managed by gross reasonableness checks of navigation data.

Abnormal Situations
- Abnormal and contingency procedures are to be used in case of loss of the PBN capability

Database management

- Unless otherwise specified in the operations documentation or acceptable means of compliance (AMCs), the navigation database must be valid for the current aeronautical information regulation and control cycle (AIRAC)

Requirements for specific RNAV and RNP specifications

RNAV 10

- Required aircraft operating in oceanic and remote areas to be equipped with at least:
    - 2 independent and serviceable long range navigation systems (LRNSs), comprising an INS, IRS/FMS or a GNSS
- Operators may extend their RNAV 10 navigation capability time by updating.

RNAV 5

- Manual data entry is acceptable for RNAV 5

RNAV 1 / RNAV 2 / RNP 1 / RNP 2

- Pilots must not fly an RNAV1, RNAV2, RNP1 or RNP2 SID or STAR unless it is retrievable by route name from the on-board navigation database and conforms to the charted route..
- Route may be subsequently modified through the insertion (from the database) or deletion of specific waypoint in response to ATC clearances.
- Manual data entry, or creating of new waypoints by manual entry, or either lat and log or place/bearing/distance values is **not permitted.**

RNP APCH

- Pilots must not fly an RNP APCH unless it is retrievable by procedure name from the on-board navigation database and conforms to the charted procedure
- RNP APCH to LNAV minima is a non-precision IAP designed for 2D approach operations.
- RNP APCH to lateral navigation (LNAV)/VNAV minima has lateral guidance based on GNSS and vertical guidance based on SBAS or baro-VNAV
- RNP APCH to LNAV/VNAV minima may only be conducted with vertical guidance certified for the purpose
- RNP ACH to LNAV/VNAV minima is based on Baro-VNAV may only be conducted when the aerodrome temperature is within range because of **the assessment of the vertical position of the aircraft, in relation to the glide path angle GPA during the approach is based on barometric data**
- Correct altimeter setting is critical for the safe conduct of an RNP APCH using BARO-VNAV

- RNP APCH to LNAV/VNAV minima is a 3D operation
- RNP APCH to localiser performance with vertical guidance (LPV) minima is a 3D apch
- RNP APCH to LPV minima requires a final approach segment (FAS) data block
    - FAS data block is a standard data format to describe the final approach path
- RNP APCH to LPV minima requires SBAS

- RNP AR APCH required authorisation

A-RNP

- Integrates: RNAV 5, RNAV 2, RNAV 1, RNP2, RNP1, RNP APCH