RNAV

Definitions

- Pulse length/duration: duration of a pulse
- Skip distance: the distance the radio wave travels (up to the point the first sky wave is received). It increases with increasing frequency and higher level of refracting ionospheric layer
- Skip zone: it is also called silent zone. It is where nor sky and ground wave is received.
- Polarization: orientation of the plane of oscillation of the electrical component (E) of the electromagnetic wave
- Phase/phase angle: the fraction of one wavelength expressed in degrees 000-360
- Doppler effect is the shift in frequency of the radio wave due to the relative movement between transmitter and receiver. It is used in VOR, GPS and MTI (moving target indicator of radar) and Airborne Weather Radar

Modulation

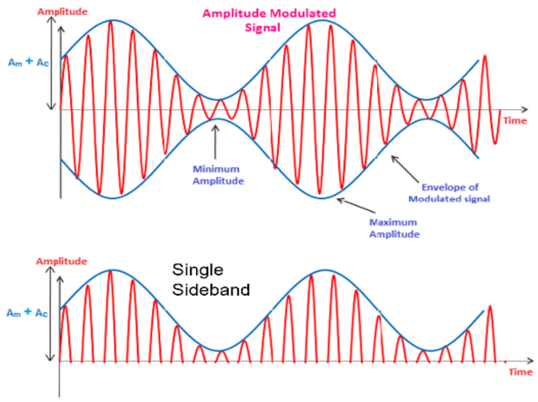
Varying one or more properties of the carrier signal with a modulating signal that contain info to be transmitted. It is the addition of a Low frequency signal (voice, …) to a high frequency carrier wave

Single-side band (SSB): used by HF in 2-way communication. It involves cutting the lower side of the modulated wave to reduce the power of the transmitter and the required bandwidth.

Hearing a click from the radio with the frequency blocked may be a signal of the transmitter sending the carrier wave without modulation.

AM = Amplitude modulation → frequency = constant
FM = Frequency modulation → amplitude = constant

Phase modulation: used by GPS
Pulse modulation: used by Radar



- N0N: carrier without modulation as used by NDBs (f and A = constant)
- A1A: carrier with keyed Morse code modulation as used by NDBs (f and A = constant)
- A2A: carrier with amplitude modulated Morse code as used by NDBs
- A3A: carrier with amplitude modulated speech used for communication (VHF-COM)

1st element (letter) = type of modulation
2nd element (number) = type of modulating signal
3rd element (letter) = type of information transmitted

Antenna

$\lambda = \frac{c}{f}$ if frequency in MHz $\lambda[m] = \frac{300}{f}$ $c = 3 * 10^8\, m/s$

- Dipole = half wave antenna = ½ λ
- Quarter wave antenna = ¼ λ

Directional antennas:
- Slotted planar array (radar, less side lobes than parabolic)
- Loop
- Parabolic
- Helical


Figure 1
Parabolic Antenna

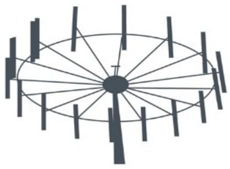


Figure 2
VDF Antenna
(Adcock Aerial)

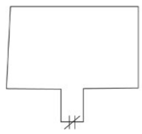


Figure 3
ADF antenna (loop)

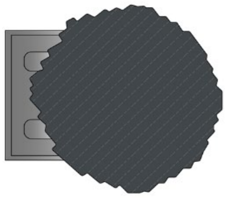
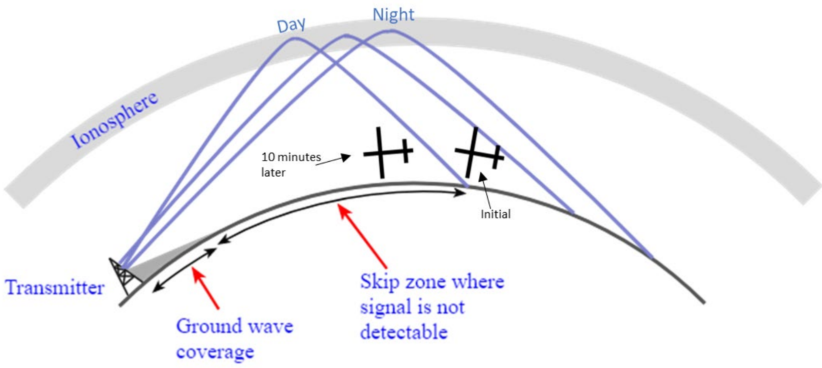


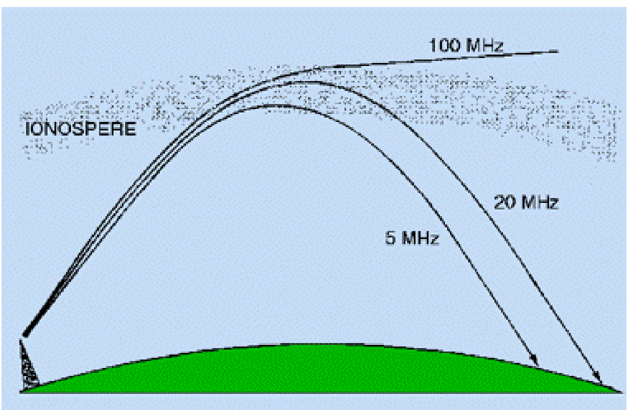
Figure 4
Flat plate antenna

Antenna shadowing: it may occur if the antenna is not placed in an optimal position, resulting in shadowing of receiving signal (VOR, GPS, ...)

Propagation

	Day	Night
VHF	SPACE (LOS)	SPACE (LOS)
HF	GND (short range) or SKY	GND or SKY
MF	GND	GND or SKY
LF	GND	GND or SKY
VLF	GND	Ionospheric ducting





Attenuation increase if

W ↓ **T**

F ↑ **D**

Radio waves propagation theory

Types of waves

Radio waves can propagate in many different ways. The most common is as a "**space wave**". This is what most people think of when it comes to radio transmission, as **this is line of sight**, meaning that the radio waves travel in straight lines only. Another propagation path is via **ground waves**, which **"cling" to the surface and follow the contours of the Earth**. The third method of propagation is via **sky waves**, which are space waves that **interact with** the charged particles in the **ionosphere**. When these waves reach the ionosphere, the subsequent ionospheric attenuation refracts the waves, changing their course, until the waves are heading downwards again. This is often referred to as "reflection" by EASA, so do not be confused; it is refraction that occurs, it just looks like the reflection from afar, and they use the terms almost interchangeably.
The "skip distance" is the distance away from the transmitter where the first sky wave returns to the surface after bouncing off the ionosphere. This can create a dead zone of reception for some frequencies which travel as both ground and sky waves, as, for example the ground waves might stop at 100 nm, but the sky waves only begin at 200 nm (these numbers are not even close to correct).
Higher frequencies receive less ionospheric attenuation, therefore refracting less, and not bending as sharply in the ionosphere. This means that higher frequency radio signals do not "bounce" off the ionosphere at steep angles, thus making the skip distance longer.
The height of the ionosphere also makes a difference, a higher ionosphere means that the signals will travel further before reaching the level where refraction begins, and will travel further on the way back down also. This means that a **higher ionosphere contributes to a longer skip distance**.

Long distance voice communications (outside the line-of-sight) in aviation are achieved by using HF radio. HF (High Frequency) radio waves travel as space waves, but are also low enough frequency to be suitably refracted in the ionosphere, and can return as sky waves. They do also travel as ground (surface) waves, but they do not have a long range in this propagation method, so are not usually used like this. In other words, they can do all 3 propagation types, but we use them as sky waves.

HF

In particular, we use **HF radio via sky waves** for long distance communication, but with this method comes some limitations and complexity.

The biggest limitation is the fact that sky waves have both a maximum range and a minimum range. The **minimum range** is that of the "first skip". As sky waves effectively "bounce" off the ionosphere, but cannot bounce at too steep of an angle (think of skimming stones), there is a minimum distance at which each frequency first arrives back at ground level. (For those who are interested, it is closer for low frequencies, and further away for high frequencies). This is called the skip distance, and **there is a large distance between the end of the ground waves and the start of the sky waves that we call "dead space" or the "skip zone"**, where no signal is received.

This "first skip" distance increases massively at night, when ionisation from the Sun is removed, and **the ionosphere becomes a lot less "bouncy" to our signals**.

Now to our scenario. Not only are we flying towards the ATC transmitter/receiver (and therefore getting closer to the "dead space area"), but the night effect is beginning and our region of dead space is getting further and further away from the ground station. This means that it is incredibly likely that "10 minutes later", we are now inside that first skip distance (but still way further away that space or ground waves), and **are therefore in "dead space"**, sometimes called the "skip zone".

Fading

Occasionally HF and MF communications are prone to variations in received signal strength - radio reception suffers from effect of Fading.

This is caused by the radio wave travelling by two alternative routes (surface wave and sky wave or two or more sky waves) before meeting at the receiving aerial. If two signals arrive "in phase" they will reinforce each other, but if they arrive in "anti-phase" they will cancel out. The ionosphere has continuous fluctuations and therefore fading will always be present but varies to a greater or lesser extent.

Concerning aviation this effect can be neglected during the day but is distinct during the twilights and night. At night the ionospheric "D" layer is insignificant and sky waves at upper LF/MF frequency range are returned to earth by the "E" and "F" layers (during day LF/MF sky wave will be absorbed by the "D" layer). These returning waves are more likely to suffer from a phase shift, leading to the effect of fading. HF frequency will be reflected by the "E" and "F" layers during daytime because it will penetrate the "D" layer.

Radio Aids

VDF (VHF Direction Finder)

- QDR: magnetic bearing from the station
- QTE: true bearing from the station

- QDM: magnetic bearing to the station
- QUJ: true bearing to the station

They all do not take into account wind!
Only a VHF radio is required to work (VDF let-down is the ground instrument)
Classes of accuracy:

- A: ± 2°
- B: ± 5°
- C: ± 10°
- D: < C (11°, 12°, …)

ADF & NDB (Automatic Direction Finder & Non-Directional Beacon)

Identifier: En-route range 3 letters | Terminal area 2 letters

Frequency: 190-1750 kHz λ ≈ 170-1600 m

Range α $\sqrt{power}$ Range over land = $2\sqrt{p}$ Range over water = $3\sqrt{p}$

Range of a locator = 10 – 25 NM | used in final approach

Flying technique: Homing = TO the station | Tracking = TO/FROM the station

QDM = HDG + RB | RB = Relative Bearing (as indicated by the ADF)

Variation has to be used with reference to the aircraft.

RMI (Radio Magnetic Indicator) needle shows QDM
To be considered **established on the NDB approach**, you have to be **± 5°** of the required course

To identify a failure, monitor the Morse code. The station stops emitting it if a failure occurs.

Factors affecting accuracy:

- Static interference
- Station interference
- Night effect (D-layer disappear, the range increases but signal is less accurate)
- Mountain effect (diffraction)
- Coastal refraction (difference of speed over land vs sea) bigger for angles 0°-30° with the shoreline. Station near the coast has a lower position error than one far from the coast if coastal refraction error is the same. It occurs up to 6000 ft. Waves deflecting toward the coast.
- Dip (when wings are not levelled)
- Quadrantal errors: given by signal bending by the aircraft metallic surfaces. Can be corrected when installing the instrument and is predictable.

BFO (Bit Frequency Oscillator)
- Makes the carrier wave audible in order to identify N0N/A1A modulated NDBs
- Used to identify NDB. On modern aircraft is automatically activated, when necessary
- Used to hear the IDENT of some NDB stations radiating a continuous wave signal
- BFO selector ON → amplitude and frequency remain the same
- The bearing indicator is erratic when a NON/A1A station is identifying

VOR (VHF Omni Directional Range)

To be considered **established on the VOR approach**, you have to be **within half full-scale deflection** of the needle.

Frequencies within the allocated TVOR range 108.0–111.975 MHz, which have an **EVEN number in the first decimal place, are used by TVOR, ODD number are used by ILS** (eg. VOR = 108,4 | ILS = 108,1).

Normal range for VOR is 108-117.975 MHz.

In a VOR-DME station the DME produce an ID signal every 40 seconds. Enter hold in sector 1-3 arc DME.

Reference signal is equal for 2 aircraft if they are at the same distance from the VOR.
Variable signal is the same for 2 aircraft only if they are on the same radial of the VOR.

DVOR range is up to 200 NM and is used for IFR en-route. Signal received as a FM signal by aircraft receiver.

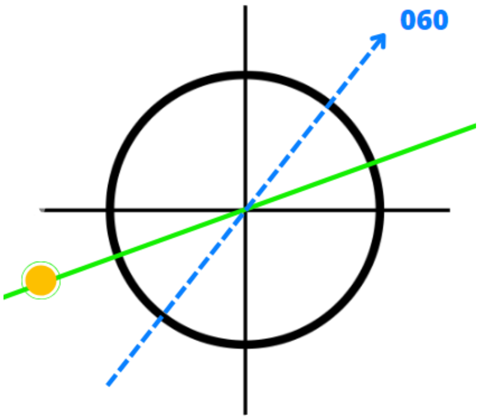
Errors:
- Scalloping (needle shift from one side to another because the receiving signal is reflected by obstacles)

The needle point to the selected radial.

The indicator ''TO'' means we are going to the station

The displacement line shows the line of the radial is to the right of the airplane position.

Consider as the aircraft has a HDG going the same as the radial of the needle (even if in CDI HDG is irrelevant) to determine left/right.



DME (Distance Measuring Equipment)

Frequency range: 960-1215 MHz (UHF)

DME transmits Slant Range

Transponder delay: 50 µs

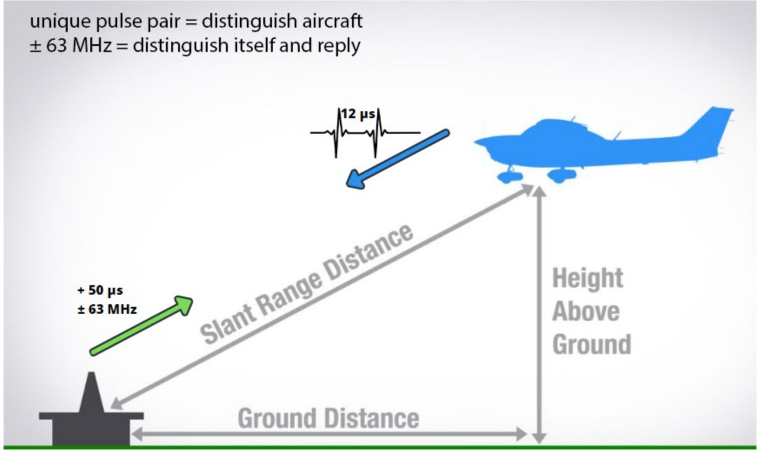
Pulse pair distance: 12 µs (distance between the 2 pulses of the same pair)

$$True\ range\ (ground) = \sqrt{(slant\ range)^2 - (aircraft\ height)^2)}$$

Each pulse pair is transmitted at random intervals so that ground station can distinguish between his own pulse pair and the response pulse pair of other aircraft.

VOR-DME stations have the same ident but transmitted at different tone. DME tone transmitted every 40 s and has the **higher pitch**.

distinguish between other aircraft = unique pulse pairs
distinguish between itself and the reply = 63MHz



LOP = line of position = drawn on chart = ground distance

The slant range became closer to the ground range the further we get from the beacon, so it is more accurate the further we are from the station.

Best accuracy of GS reading by DME is obtained flying directly towards or away from the station. Otherwise, GS speed from DME is **less than the real one**. Approaching the DME, the GS is lower than actual, reads 0 overhead.

If the aircraft lose the DME reply any time, it enters in memory mode which maintain the DME range changing at the same rate for 10-15 s. After that it enter search mode.

Echo Protection Circuit (EPC): used to eliminate errors from reflections from surface, building and mountainous terrain

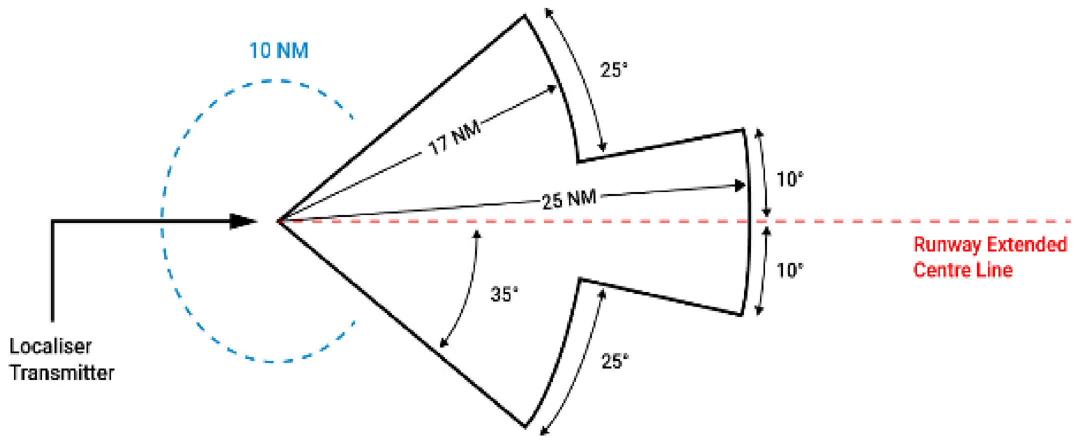
Tuning the DME interrogator in the aircraft starts the transmission of pulse pairs in search mode. When pulse pairs are received by the transponder at the DME ground station, it adjusts the frequency by which are transmitted back to the aircraft interrogator. Now that the loop is closed, info is transmitted.

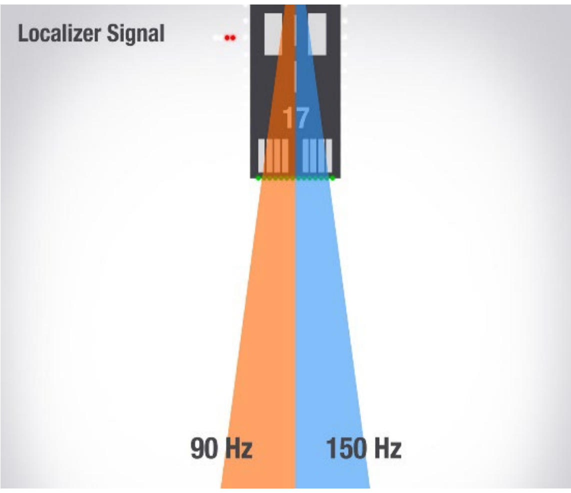
Ground station able to accommodate 100 aircraft to avoid saturation as it works with 1 receive and 1 transmit frequency. The weakest signals are denied if saturation occurs.

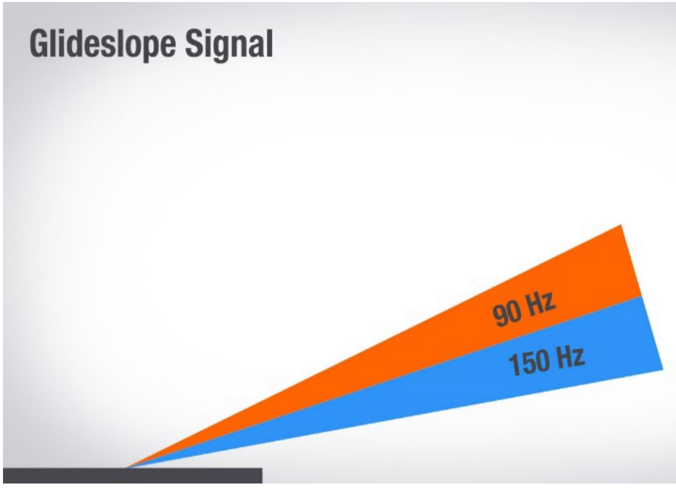
In a DME arc, Groundspeed reads 0 as slant range remain the same.

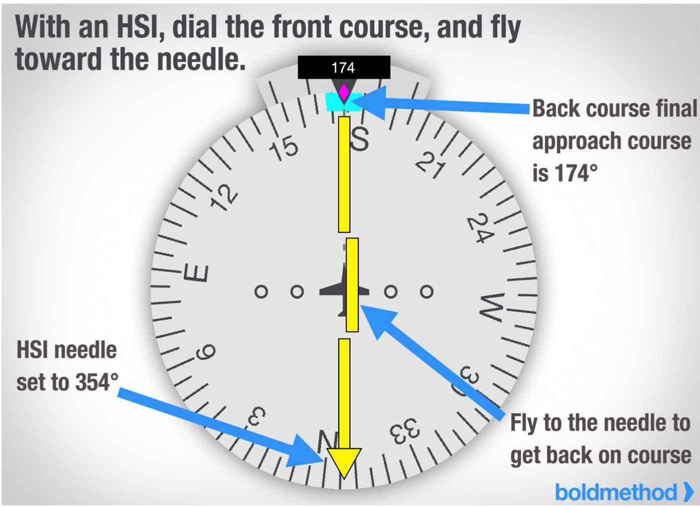
During Range search, the needle may rotate from zero to the max range rapidly

ILS (Instrumental Landing System)









Outer | Blue | 6NM | 400 Hz | Low

Middle| Amber | 0.6 NM | 1300 Hz | Mid

Inner | White | 0.3 NM | 3000 Hz | High

- ILS is Amplitude Modulated [**AM**]

- **GS interception**: 3 – 10 NM | 8° coverage each side of the centreline up to 10 NM from threshold

- GS antenna 300 m beyond threshold

- LOC antenna 300 m beyond end of approach runway (non approach end)

- **LOC -> VHF** [space wave | 108.1 – 112 MHz | AM] -> 2.5° per side | antenna in the nose | same frequency (the LOC one), different modulation frequencies (90/150 Hz)

- **GS -> UHF** [AM]-> 0.7° per side | antenna in the nose

- Depth Of Modulation linear variation with angular displacement

- **ILS back course** approach:
  - OBI reverse sense always occurs
  - HSI sense correctly using the front course

- The LOC and GS indicators don't change is the OBS is rotated as they are locked with the signal itself. The OBS needle is just a reference for the pilots.

- **Markers beacons** [75MHz carrier frequency]

- **Beam bends** occur when the radio signal bends due to fixed obstructions. They can be checked by flight tests and corrected when exceeding the requirements. They **can be followed by large aircraft** as are slight curves.

- ILS **multipath** is given by any obstacle in the coverage area [warning flag showing randomly]

- Scallopping are caused by reflections, with rapid fluctuations that cannot be followed by the aircraft

- Glide slope interception from below to avoid false signals

- **Immunity filter** or Electromagnetic Interference (EMI) filters can be used to prevent interferences from similar frequencies on the LOC (GS use UHF, so no need to protect as nothing use these frequencies)

- ILS **warning flag** on LOC and/or GS will appear in case of:
  - Absence of carrier frequency
  - Absence of the modulation simultaneously
  - % Modulation of the navigation signal is reduced to 0

- ILS **Facility performance categories** (GS height): CAT I < 100 ft | CAT II < 50ft | CAT III = 0ft | **Rule: DH/2**

- Sensitive area not to be crossed when CAT II/III approach is used

$$ROD\ \left[\frac{ft}{min}\right] = \frac{5}{3} * Groundspeed * \text{Glide Slope}(°) = 5 * Groundspeed$$

ROD variation with GS: ±10 kts = ±50 ft/min

Glidepath coverage: from 0.45*θ to 1.75*θ, where θ is the Glide path angle required

MLS (Microwave Landing System)

- 200 channels | SHF: 5.03 – 5.09 GHz |
- Azimuth: ± 40° and 20 NM
- Elevation: 15° and 20 NM
- Azimuth and Elevation transmitters are separated
- It works scanning and timing the impulses and comparing with co-located DME-P (giving the 3rd dimension)
- Select the approach by: select the published channel number + select an approach profile in azimuth and elevation
- Presented information (on screen) are 2D and represent a 3D segmented/curved approach
- Can minimise multipath error because the beam can be interrupted to avoid reflection by stationary objects
- Curved approach can be flown using flight director bars, other instruments cannot follow a curved path

RADAR (Radio Detection and Ranging)

- Minimum range depends on pulse length

- **Maximum range depends on pulse repetition frequency** (before emitting a new pulse, the old pulse reaches the further distance to relate an echo to a specific pulse).

- **Minimum range depends on pulse length**

- **Range^4 = Power** | Range doubles – Power required = x16

- $Distance = \frac{c}{2*PRF} = c * \frac{echo\ time}{2}$ [out of 2020 LOs]

- **Pulse power = peak pulse power** (use this answer in questions) = power measured over a pulse width

- All radar use pulse technique, but in different ways

- PSR uses pulse and echo technique | SSR uses PSR + Interrogation technique

- PSR can identify bearing and distance (simultaneously), but NOT altitude

- MTI = moving target indicator. The controller doesn't see stationary objects, because ground clutter is eliminated

- The info (**minimum info**) presented on the ATC display system are: **map**, pressure altitude; **flight level**; **flight number or aircraft registration number**; GS

- ASMR: Airport Surface Movement Radar allows to see shape and the type of aircraft producing return

- State which **information** can be presented on the **ATC display system**: pressure altitude; flight level; flight number or aircraft registration number; GS [**minimum is position and map information**]

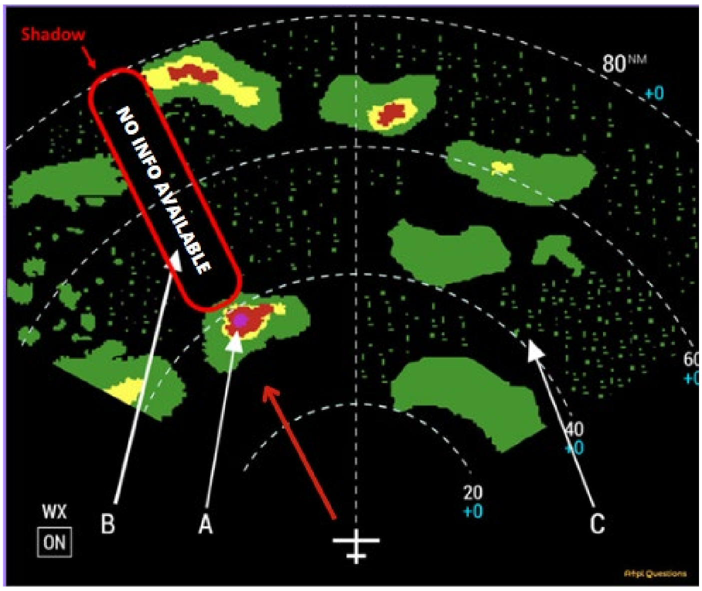
AWR (Airborne Weather Radar)

Frequency (SHF): 9375 ± 30 MHz   λ = 3cm

Stabilized in roll and pitch

Fly Upwind = against the wind direction (like the upwind leg) = opposite direction of thunderstorm

Shadowing effect: a cloud behind another cloud which cannot be detected



Slotted = Cosecant tilt down
AWR Flat plate = Pencil tilt set downward
Gain = sensitivity

Heaviest turbulence where an area of heavy precipitation is closest to the edge of the thunderstorm cell.
Doppler shift used to detect turbulence by motion of water droplets.

Wet hail has the highest reflectivity

Mapping mode can be used to establish relative bearing and distance. It tilts down to the ground, changing shape and orientation of the beam. It uses cosecant beam for 50-150 NM. It is outsmarted by EGPWS and no more in use.
Weather mode: conical pencil beam

Pencil-shaped/conical beam: is used for weather depiction and can also be used for long range ground mapping (greater than 60 NM).
Fan-shaped/cosecant beam: is produced when MAP function is selected on the AWR control panel and it is best for short range ground mapping (up to 50/60 NM). It is worth pointing out that fan-shaped terrain mapping is an additional feature and it must be turned on (it is not the operating mode in which the radar is commonly and primarily operated).

Stabilization axes: roll + pitch

Auto-tilt mode uses the EGPWS database to adjust the tilt based on aircraft position, altitude and the selected ND range.

Tilt position:
- Takeoff: tilt UP to see the weather we are going to find in climb
- Initial climb: LOWER the tilt wrt takeoff (so up, but a bit less than during takeoff)
- Cruise: LOW
- Descent: RAISED UP gradually to avoid ground clutter (returns)

When range decrease (we are nearer), beam width will also decrease, so we have a better object resolution

Cloud Top (above aircraft altitude) = (Tilt angle – beam width/2)*Distance*100   [OUT of LO]

SSR (Secondary Surveillance Radar)

The transponder calculates the time interval between P1 and P3 which determine the MODE used.
Function of P2 pulse = avoid responses from side lobes
Interrogation (ground): 1030 MHz
Answer (aircraft): 1090 MHz
Mode A = no altitude
Mode C = ±100 ft
Mode S = ±25 ft | 24-bit hardcoded code (unique code)

Mode S gives info ADS-B and communicate with SSR and TCAS | doesn't have P3
Mode
A/C/S---> Long P4
A/C---> Short P4
On = Mode A
Alt = Mode C/S
IDENT = send an additional pulse after the normal response pulse train

GNSS (Global Navigation Satellite System)

3 segments: ground control, space and user [**UHF**]

Most famous: Glonass, Galileo, Navstar GPS, Beidu

GPS and **Glonass** use **different data** for nav services but are **interoperable**

Galileo uses **4 clocks** per satellite (2 of each type) and are **non-synchronised** and **independent**
Galileo: 30 sat, 3 orbital planes, orbit 23222 km

For a satellite to be **visible** it has to be at least **5° above the horizon**.

Satellite don't do the math for position, altitude and speed. The receiver does it.

GNSS provide: **3D position, GS and time reference** [a sphere with center in the satellite]

GPS Standard Positioning Service (**SPS**) uses **L1** transmitting **C/A** (coarse acquisition) and **P** (precision) codes
GPS Precision Positioning Service (**PPS**) uses **L1** + **L2** + uses only **P** code [2 carrier frequencies]

PPS can be used by **authorised users only**, while **SPS** by **unauthorised users**

Each GPS satellite transmit ranging signal on L1 and L2 UHF frequency
Ground control segment upload navigational data to the satellite

Aircraft have a multichannel receiver

The **navigation message** [**12.5 minutes** to be transmitted] contains:

- satellite clock correction
- universal time coordinated (UTC)
- ionospheric model
- satellite health data
- ephemeris [according to LO not included, but it is actually contained, so appeal]
- almanac data [according to LO not included, but it is actually contained, so appeal]

- **User Equivalent Range Error [UERE]**: max error in position expected by the user. It is the sum of all residual errors affecting the receiver.

- **Ionospheric propagation error** can be reduced using a model of the ionosphere and comparing L1 and L2

- **Errors in GPS orbit** is due to solar wind, gravitation of the sun, moon and planets

- **Clock correction parameters** are used to correct satellite time

Dilution of precision (DOP) occur due to **not optimal satellite geometry distribution**. It can be: GDOP, HDOP, PDOP, TDOP, VDOP. [GHPTV]
GDOP can be minimized by sat 3 satellites at 120° in azimuth + satellite overhead

UERE * GDOP = Total position error = estimate of position accuracy

Doppler frequency shift is used to calculate the **groundspeed** by the aircraft.

Navstar GPS uses **2 frequencies to correct nav system errors** because **delay is proportional to** $\frac{1}{frequency^2}$ so higher frequencies have lower delays and lower frequencies have higher delays.

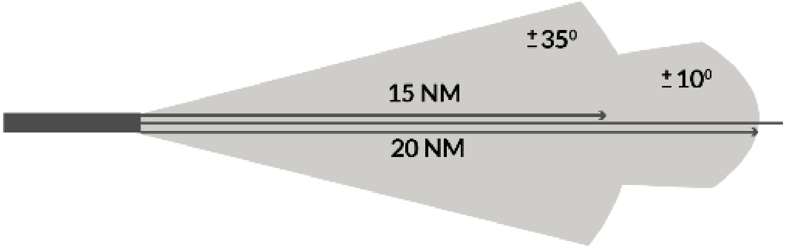
RAIM (Receiver Autonomous Integrity Monitoring) is the integrity monitoring at the user segment.
It uses redundant range measurements to verify the position produced by the minimum number of satellites required for a 3D fix.
It needs at least**: 5 satellites for Fault detection [FD]** and **6 satellites for fault detection and exclusion [FDE]**.
RAIM prediction error is mostly given by the presence of not enough satellite to achieve integrity monitoring at the given time and date.

Baro-Aiding-is a form of GNSS **integrity augmentation** than permit a **GNSS receiver to use the aircraft's altimeter** system to **provide vertical reference**, reducing the number of space vehicles required to obtain a position fix. It requires **4 sat + 1 baro altimeter to detect an integrity anomaly**.

GBAS (Ground Based augmentation System)

Use same frequency as ILS/VOR [VHF datalink]
Range: 20 NM
Coverage along the centreline:

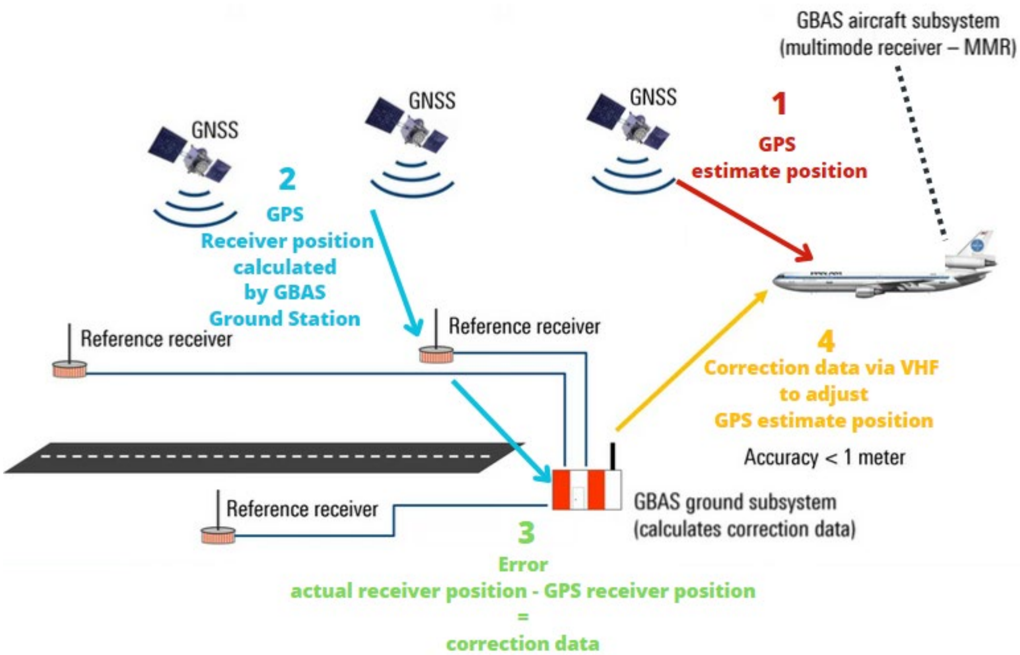
- ± 35° ≤ 15 NM
- ± 10° > 15-20 NM



Pseudolite = Ground station
DGPS = GBAS

How it works:

The aircraft calculate its position via the GPS [A].
The GBAS Ground Station (GS) is in a known fixed position[X].
The GS find its position from the GPS data [Y] and calculate the error [E] between its actual position and the known position [E = X - Y].
Such error is sent to the aircraft to correct its position [Corrected position = A ± E]
Integrity data and approach data are sent.



SBAS (Satellite Based augmentation System)

Frequency: [UHF]
Able to provide (vertical) guidance for precision approach
EGNOS (European Geostationary Navigation Overlay Service) uses 1 up to 4 satellites to transmit integrity and ranging data.
EGNOS is able to report a malfunction alert within 6 seconds
EGNOS channel is used for identification only, as datalink uses the same band as GPS

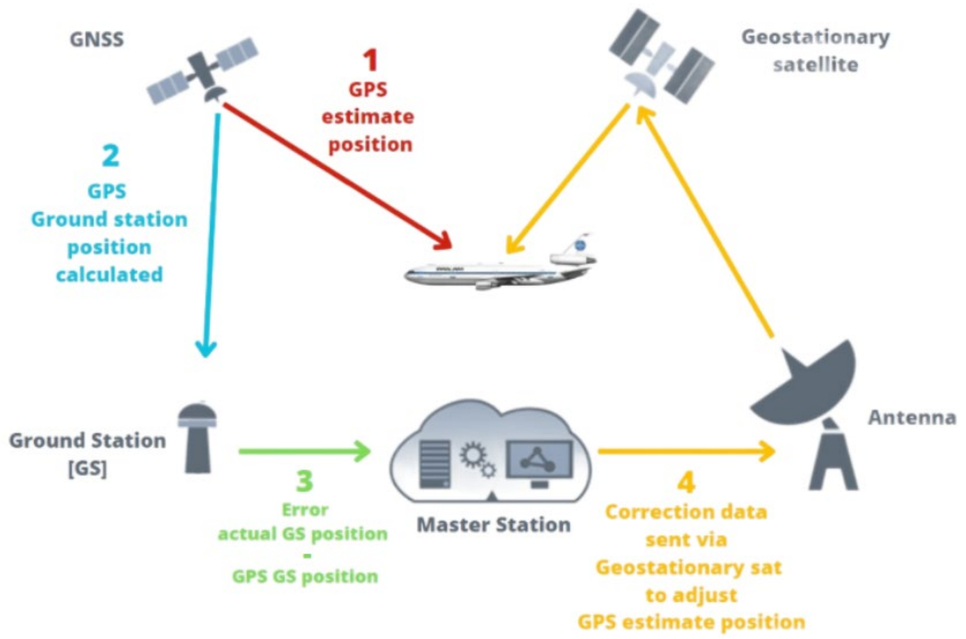
3 segments: Space, Ground, User

2 elements: Ground infrastructure and Communications satellites

WADGPS = SBAS

How it works:

The aircraft calculate its position via the GPS [A].
The SBAS Ground Station (GS) is in a known fixed position[X].
The GS find its position from the GPS data [Y] and calculate the error [E] between its actual position and the known position [E = X - Y].
Such error is sent to a master station to compute corrections and then via geostationary satellite to the aircraft [Corrected position = A ± E].



ABAS (Aircraft Based augmentation System)

Use redundant elements within the GPS constellation or the combination of GNSS measurements with those of other navigation sensors (such as inertial systems) in order to develop integrity control.

ABAS doesn't improve the stand-alone GPS accuracy, but only integrity of navigational data!

The type of ABAS using only GNSS information is named receiver autonomous integrity monitoring (RAIM).

A system using information from GNSS + additional onboard sensors is named **aircraft autonomous integrity monitoring (AAIM)**. The typical sensors used are **barometric altimeter and inertial reference system (IRS).**

RAIM = GNSS only (geometry + measurements)
AAIM = GNSS + onboard sensors

PBN (Performance Based Navigation)

Components [ISA]:
- Navigation Infrastructure - (GNSS)
- Navigation Specification - (RNP or RNAV)
- Navigation Application - (SID, STAR)

Principles: [ACIA]
- **Accuracy**: the conformance of the true position and the required position.
- **Continuity:** the capability of the system to perform its function without unscheduled interruptions during the intended operation.
- **Integrity**: a 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.
- **Availability**: the percentage of time (annually) during which the system is available for use.

The difference between raw data and computed data is that the latter are verified in terms of validity and consistency, while raw data are not subjected to any control and have to be trusted as they are displayed.

Errors [PNF]:

- **Path definition error**: Path defined in the navigation database doesn't exactly correspond with a required path (published in AIP and on Charts). It is considered negligible
- **Navigation system error**: Difference between estimated and actual position.
- **Flight technical error**: Aircraft behaviour or crew or aircraft limitation
- The errors combined give the **Total System Error** (also called Estimated Position Error), on which the navigational accuracy of the system depends. It is a statistical model of position error probabilities

Estimated Position Error [EPE] = Actual Navigation Performance [ANP] calculated via statistical model
Aircraft and crew have to be approved to fly in the RNAV/RNP airspace
Pilots can monitor Navigation System Error and Flight Technical Error

	RNAV 1	RNAV 2	RNAV 4	RNAV 5(*)	RNAV 10	RNP 0.3(*)	RNP 1(*)	RNP 2
Oceanic/Remote		X	X		X			X
Enroute Continental	X	X		X		X		X
Arrival	X	X		X		X	X	
Departure	X	X				X	X	
Approach (no final)	X					X	X	

(*) RNAV 5 may be used for initial part of the STAR outside 30 NM and above MSA.
RNAV 1, RNP 1 and RNP 0.3 may also be used in enroute phases of low-level instrument flight rule (IFR) helicopter flights.
(*) RNP 0.3 is used in all phases of flight except for oceanic/remote and final approach, primarily for helicopters.
(*) RNP 1 could be used for Helicopter routes. The RNP 1 specification is limited to use on STARS, SIDs, the initial and intermediate segments of IAPs and the missed approach after the initial climb phase. Beyond 30 NM from the ARP, the accuracy value for alerting becomes 2 NM.

Note:
RNAV10 = RNP10
Approach = initial + intermediate, but not final as RNP APCH and RNP AR APCH is used for such segment

NAVIGATION SPECIFICATION	FLIGHT PHASE							
	En-Route Oceanic Remote	En-Route Continent'l	APR	Approach				DEP
				Initial	Intermed	Final	Missed	
RNAV 10 (RNP 10)	10							
RNAV 5		5	5					
RNAV 2		2	2					2
RNAV 1		1	1	1	1		1	1
RNP 4	4							
RNP 2	2	2						
RNP 1			1	1	1		1	1
Advanced RNP	2	2or1	1	1	1	0.3	1	1
RNP APCH				1	1	0.3	1	
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	
RNP 0.3		0.3	0.3	0.3	0.3	-	0.3	0.3

EASA OPS - Only certain PBN specifications require approval and are operator dependent
ICAO DOC 9613 All RNP procedures require approval and are operator dependent

Oceanic – En-route – Terminal phase are all only subject to **Linear Lateral performance** requirements
Approach phase is subject to both **Linear and Angular** Laterally guided requirements

Required navigation functionalities of RNP/RNAV specifications:

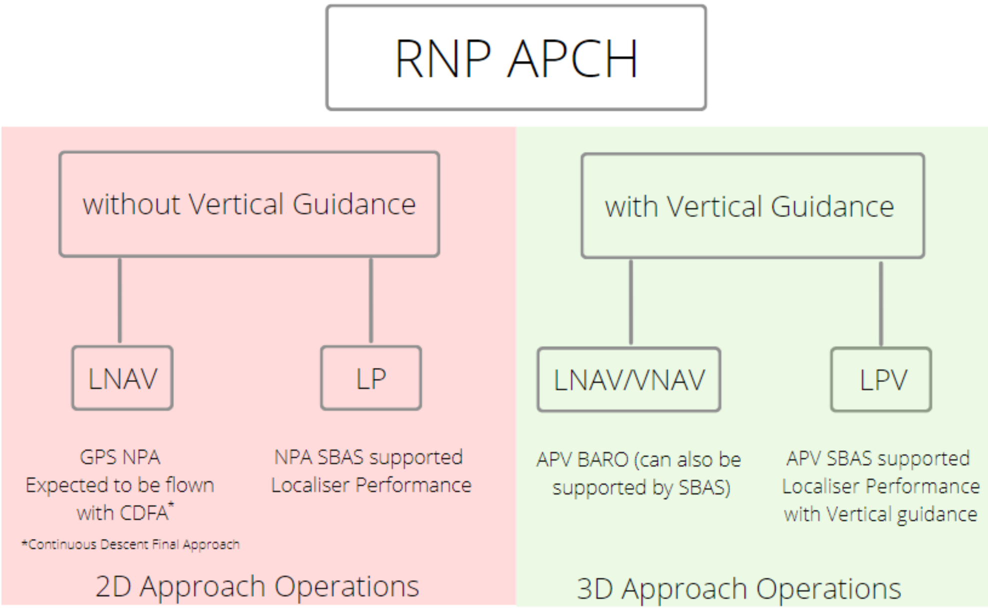
- Groundspeed or time to waypoint
- Lateral deviation
- Storage
- Failure indications
- Distance or bearing to waypoint

Unlike conventional navigation, PBN is not sensor-specific.
PBN cannot be used with NDBs.

Deviation error in linear ops defined by NM for cross-track deviation
Deviation error in angular ops defined by degrees of CDI needle deflection

Airspace concept is achieved by enhancements in [CNSA]:

- Communication
- Navigation
- Surveillance
- Air traffic management



Altitude information in LNAV/VNAV provided by Baro-VNAV or SBAS.
SBAS is required down to LPV minima.

For the Baro-VNAV a correct altimeter indication is required and operations are limited in range of temperatures. A certified temperature compensation system can be used and compensate the final approach segment (FAS). Lower temperatures make the GPA shallower than indicated (aircraft lower than indicated).

In LNAV approach the PIC is responsible for correcting the descent profile based on temperature (low temperatures when lower than ISA in particular) as it’s a 2D approach.

Manual data entry is acceptable in the FMS for RNAV5

ARINC 424 path terminator is a code defining a specific type of flight path along a segment of a procedure and a specific type of terminator of that flight path. ARINC 424 path terminators set the standards for coding the SIDs, STARs and instrument approach procedures (IAPs).

Lateral offset flightpath in RNAV/RNP can be flown from 1 up to 20 NM and is intercepted up to 45°

Most system discontinue offsets:
1. In the terminal area
2. At the beginning of an approach procedure
3. At an RNAV HOLD
4. During course change of 90 degree or more

When flying and RNP procedure or fix, apart in the absence of autopilot the flight director is required to provide the necessary level of guidance and precision during the turn

Radius to fix [RF]: use in terminal or approach procedures (defined by radius, arch length and fix)
Fixed Radius Transition (FRT): used with enroute procedures

Discontinue approach if:
1. GPS signal lost
2. CDI more than half scale deflection
3. Receiver fails to engage correct approach mode
PBN database need to be valid for at least 28 days (current cycle of AIRAC)

The FAS data block is a standard data format to describe the final approach path

INS/IRS requires about 10 minutes to initialize

PBN 3D approach

- GNSS + VNAV
- SBAS

3D approach

- RNP APCH (GNSS + baro VNAV)
- RNP APCH (SBAS)
- GLS
- PAR
- ILS

Specific Requirement RNAV and RNP specification

Choose the RNAV SID/STAR from the database
RNAV 10 requires 2 LRNS comprising 1 INS, IRS FMS or GNSS
Go around if the required RNP APCH fails to engage
Advanced RNP(A-RNP) incorporates the navigation specifications:

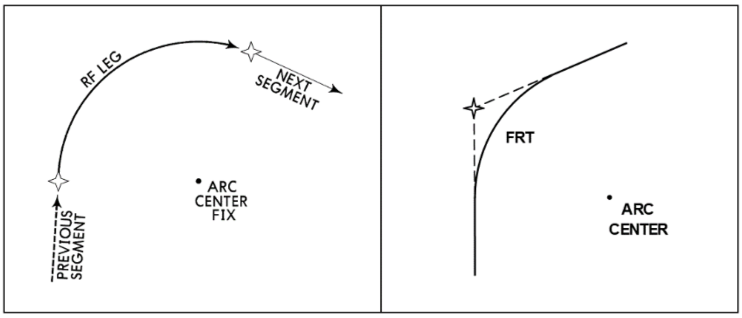
- RNAV 1 | RNP 1
- RNAV 2 | RNP2
- RNAV 5
- RNP APCH [Not RNAV APCH!]

Operators may extend their RNAV 10 navigation capability by updating [their position]

Path terminators

Fly by turn= can be used in RNP flight track
Fly over turn = cannot be used in RNP flight track

Fixed Radius Transition [FRT]



Radius to Fix Transition [RF]