Radio - Navigation

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01 Basic Radio Propagation Theory

Basic principles

NON = without modulation NDB
A1A = keyed morse code modulation, NDB
A2A = Amplitude modulated Morse code, NDB
A3E = Amplitude modulated speech, VHF
(A)mplitude sp(3E)ch

A1A

M	1	Type	Modulation main carrier
S	2	Nature	Signal
I	3	Type	Information

- phase: fraction of one wavelength expressed in degrees from 000° to 360°
- phase difference: angular difference
- pulse power of a radar pulse string
  ↳ peak power
- Modulation: adding of low frequency (deep slow voice) onto high frequency carrier wave

- Pulse modulation used in Radar
  ↳ burst of high energy
  → peak pulse power

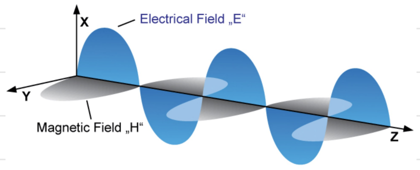
$$\boxed{\lambda = \frac{c}{f}} \qquad c = 3 \cdot 10^8 \left[\frac{m}{s}\right]$$

- Single Side Band (SSB)
  ↳ HF two-way communication
  → used to receive meteorological information (HF-VOLMET)

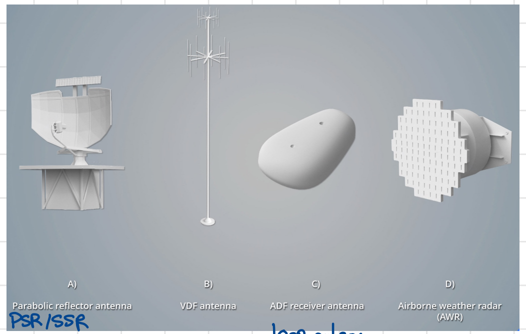
	Frequency Band	Frequency Range	Wavelength	Uses
V	Very low frequency (VLF)	3 - 30 kHz	100 - 10 km (myriametric)	Very long range navigation
L	Low frequency (LF)	30 - 300 kHz	10 - 1 km (kilometric)	Decca, NDB, Loran-C and LW/MW broadcasting stations
M	Medium frequency (MF)	300 - 3000 kHz	1 km - 100 m (hectometric)	NDB and radio range broadcasting stations
H	High frequency (HF)	3 - 30 MHz	100 - 10 m (decametric) Surface Sky wave	HF radio telephony
V	Very high frequency (VHF)	30 - 300 MHz	10 - 1m (metric) Direct wave	VHF radio telephony, VDF, VOR, marker beacon and ILS
U	Ultra high frequency (UHF)	300 - 3000 MHz	1 m - 10 cm (decimetric)	ILS glide path, DME and surveillance radars
S	Super high frequency (SHF)	3 - 30 GHz	10 - 1 cm (centimetric)	Surveillance radars, Doppler, aerodrome surface movement radar, airborne weather radar and radio altimeter
E	Extremely high frequency (EHF)	30 - 300 GHz	1 cm - 1 mm (millimetric)	Aerodrome surface movement radar

Antennas

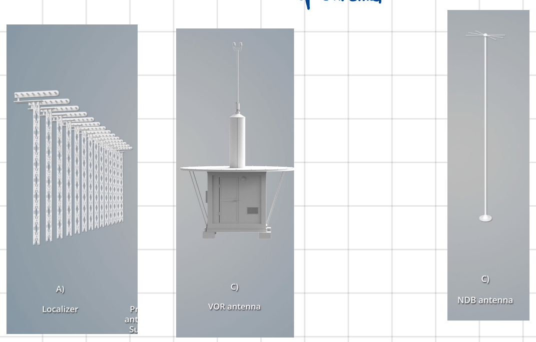
- flat plate antenna generates less side lobes than parabolic reflector
- PSR Primary Radar System
  - One directional antenna for TX and RX



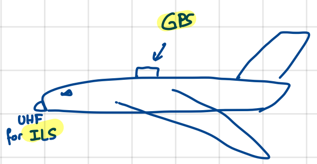
- Dipole length should be ½ wave length



- Directional antennas:
  - Loop
  - Parabolic
  - Slotted planar
  - Helical
- Omnidirectional antennas:
  - Sense
  - Dipole

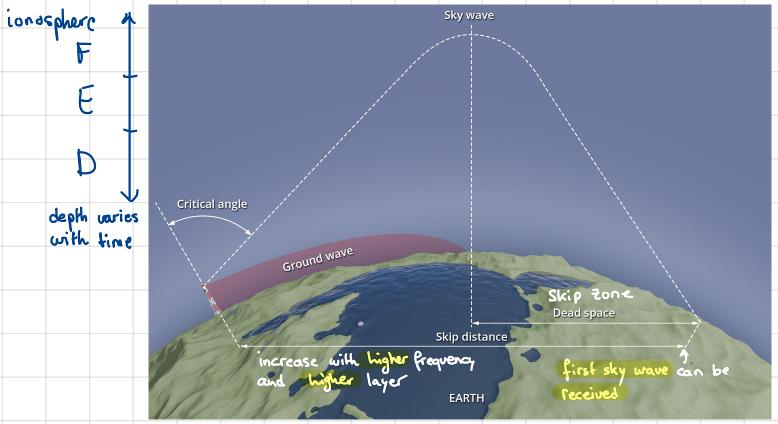


- Antenna shadowing
  → block signal with airframe when orbit
- Slotted antennas
  → narrow beam, eliminates lateral lobes
- GPS use helical antennas → signal has circular polarization



wave propagation

- fading Twilight/night Effect
  - beginning to end twilight
  - mostly at night combination of sky and ground waves
- MF Most Fading
- VLF Very Least Fading



- VLF ground wave only
- VHF limited range because of Earth's curvature
  Line of sight propagation
  Space waves No sky wave under normal conditions
- MF: daytime ground wave
  nighttime ground wave and sky wave
- HF daytime sky wave, night time sky wave } ground wave is very small
  - uses refraction from ionospheric layers

- Refraction change of speed
- Doppler effect

  □ TX → □ RX ($f \uparrow$) → □ TX ($f \downarrow$)

- Used in VOR, GPS and MTS and turbulence mode of AWR

- Multipath interference in ground-based radar system is caused by echoes from targets caused, for example, by ground reflection

02 Radio Aids

Ground direction finding (DF)

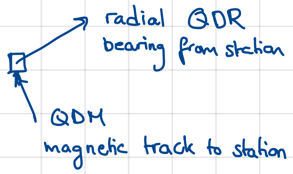
VHF Direction Finder

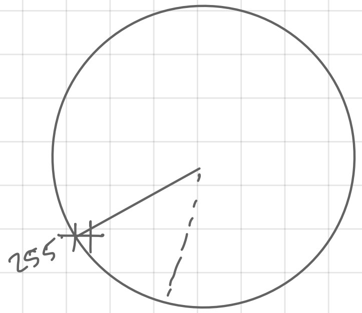
- VDF used to provide position in absence of radar
  ↳ 30 - 300 MHz = 10 m to 1m (metric)
  → doesn't take into account the wind
  - Variation at the station
  - Multipath may result in bearing errors
  - ATC can use auto-triangulation from different VDF position to find aircraft's position
- Class letter associated with VDF bearings relates to accuracy of angle in degrees
  - Class A ± 2°
  - Class B ± 5°
  - Class C ± 10°
  - Class D

$$\boxed{\text{Range [NM]} = 1.23 \cdot \left(\sqrt{H_{1\,ft}} + \sqrt{H_{2\,ft}}\right)}$$

RB = 122 MH = 85

MB = MH + RB
= 85 + 122
= 207





Non-directional radio beacon (NDB)/ Automatic direction finding (ADF)

- Considered established during approach with ADF
  1) within half full scale deflection for the ILS and VOR
  2) within $\boxed{\pm 5°}$ of the required bearing for the NDB
- Identify NDB → for A2 modulation, use the ADF function
  ↳ if failure no warning
- BFO circuit → makes the NDB ident audible by imposing a tone on the carrier wave to identify $\boxed{\text{NON/A1A}}$
  → Amplitude and frequency stay the same
  → $\boxed{\text{Activated automatically}}$

- Magnetic variation
  - NDB aircraft position
  - VOR beacon position

- highest interference for an ADF → interference during the night
- Locator
  - Low power NDB used for approach
  - Low range = 10 - 25 NM
  - LF/MF
  - Differ from NDB because different 1) Operational use 2) Transmission power

- ADF indication in the cockpit is relative bearing on a fixed card indicator
- With an A2A modulated wave you can hear the wave in ADF mode
- ADF → you can hear commercial radio station $\boxed{190 - 1750 \text{ kHz}}$
  hecto - kilometric
- Factor to affect most NDB/ADF:
  - static interference
  - night effect → change in direction of the plane of polarization due to reflection in ionosphere
    → Skywave distortion of the null position and is maximum at dawn/dusk
  - absence of failure warning system

- Coastal refraction affect mainly NDB
  - max inland and bearing crosses coast at acute angle
- Mountain effect → caused by $\boxed{\text{diffraction}}$ and affects NDB
  → caused by reflections onto steep slopes of mountainous terrain + big error on bearing

- Quadrantal errors → caused by signal bending (refraction) by aircraft metallic surfaces
  ↳ and is compensated for
- "Hunting" needle → ground wave contaminated by sky wave

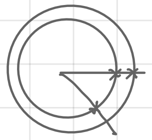
- NDB range depends on (daytime):
  - power output
  - nature of earth surface over which ground wave travels

- At night → range increases, accuracy decreases

VHF omnidirectional radio range (VOR): conventional VOR (CVOR) and Doppler VOR (DVOR)

VOR

- Principle in VOR bearing measurement → phase comparison
- Same radial: unequal phase ref, unequal variable signal
- Different radial: equal phase ref, unequal variable signal
- Established on VOR approach ⇒ Half full-scale deflection

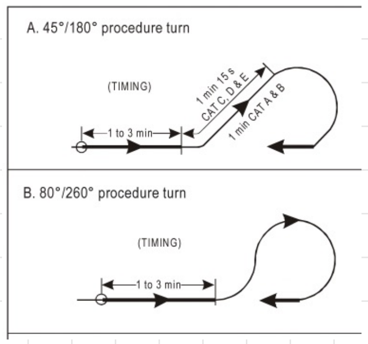


Principle

- Radial determined by phase difference between variable signal and reference signal
- 108 to 117.95 MHz (VHF), metric
- Rotation of the variable signal 30 Hz
- Full scale deviation 10°
- Navigation, voice (ATIS) and identification modulation signal found on VOR freq

Presentation and interpretation

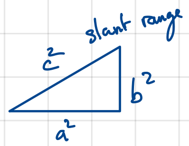
- A VOT is a test VOR
- Terminal VOR (TVOR)
  - Limited range / shorter range part of approach and departure at major aerodrome
  - odd decimal (109.25, 108.20) not to confuse with ILS
- Doppler VOR (DVOR)
  - Up to 75 NM from terminal area
  - Doppler effect received as a frequency modulated signal
- RMI
  - Tail indicates current radial



Errors and Accuracy

- Scalloping
  - negative effect on the accuracy of navigation
- Mountain effect concerns both VOR and NDB
- VOR used beyond published range
  - interference from other transmitter
- Integrity improved by using automatic ground monitoring system

Distance-measuring equipment (DME)

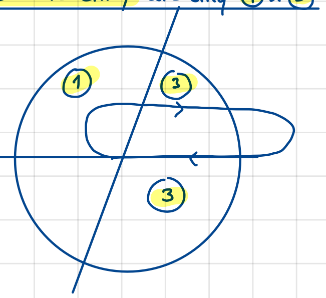


- pulse pair is unique to that aircraft
- rho-theta from terminal VOR/DME
- VOR/DME colocated → DME freq is UHF paired with VOR VHF frequency
  300 – 3000 MHz
  - ident every 40 seconds
    ↳ DME morse code ident has higher pitch and broadcasts 1 every 40 s

- TACAN can provide DME distance
- The TX doesn't lock on its own signal as DME ground transmits on different frequency

- Display counter rotating throughout their range
  → airborne receiver conducting range search

DME arc entry are only ① & ③



Instrument Landing System (ILS)

- Principles
  - Localiser (LOC)
    - located 300 m at end of RWY
    - VHF space waves 108.10 – 111.975 MHz
    - only frequencies with odd number in first decimal (108.1, 108.15, 108.3)
  - Glide path (GP)
    - located on non-approach end of RWY, 300 m behind threshold
    - operates in the UHF band
    - selected automatically by ILS/LOC frequency
    - Intercept 3 – 10 NM from threshold

- DDM (Depth of Modulation) increase linearly with angular displacement

- Side lobes
  - Produced by both LOC and GP
  - Give rise to false centre-line and false GP indication

- Back beam may be used as non-precision approach on reciprocal RWY
  - Using HSI → must set course arrow to localizer front-beam
- False beam only found above the correct GP

- FM-immune filter makes the LOC only receive less radio/television signals

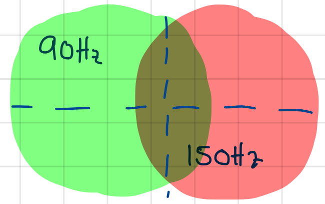
Marker beacons

- Operate on 75 MHz carrier frequency
- Outer marker — Blue
  - low frequency modulation 400 Hz
  - 2 dashed per second continuously
  - 6500 m from threshold
- Middle marker — Amber
  - medium frequency modulation 1300 Hz
  - continuous series of alternate dots and dashes
  - 1000 m (0.6 NM) from threshold
  - Indicates the position for missed approach decision during CAT I
- Inner marker — White
  - high frequency modulation 3000 Hz
  - 6 dots per second continuously

Presentation and interpretation

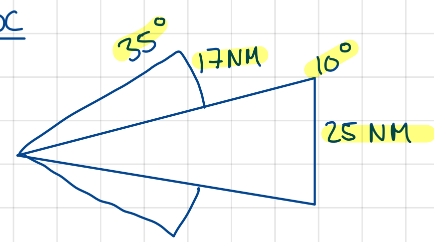
- ILS identification 2-3 letter Morse Code
- Full scale deflection CDI 2.5°
  GP 0.7°

- 90 Hz and 150 Hz amplitude modulated on LOC and GP

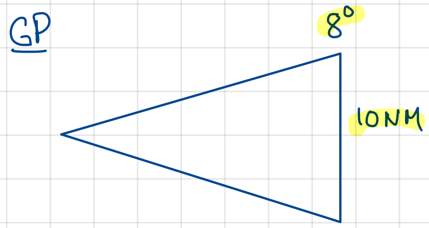


Coverage and range

LOC



GP



Errors and Accuracy

- Facility performance categories
  - CAT I down to 200 ft above RWY THR
  - CAT II down to 50 ft above RWY THR
  - CAT III down and along RWY surface

	DH [ft]	min RVR [m]
CAT I	≥ 200	550
CAT II	≥ 100 and < 200	300
CAT III A	< 50	200
CAT III B	< 50	> 75 and 200
CAT III C	no DH	no RVR

- ILS beam bends
  - slight curves produced by buildings or terrain, can be followed by large aircraft
  - Can be checked by flight test
- Scalloping
  - Small needle, moves fast, aircraft can't follow them

ROD = GS · 5

$$\text{Height [ft]} = \frac{\text{GS} \cdot \text{distance[NM]}}{60} \cdot 6080$$

Microwave Landing System (MLS)

- Frequency SHF band
  - 300 kHz frequency separation
  - 200 channels available worldwide

- Separate azimuth and elevation transmitters, DME facility
- Set up:
  - Select published channel
  - Select approach profile in azimuth and elevation

- The time interval between TO and FROM determine aircraft pos in coverage area
- Addition of DME/P necessary to obtain three dimensional positions
- Flight director bars → ok for curved approach
- 2D representation of a 3D segmented approach
- Time the passage of 2 scanning beams from transmitters co-located with DME
- Advantage: transmission can be interrupted to avoid reflections by stationary objects
- MMR → reduces training requirements

Coverage and range

- ± 40° of the RWY centreline
- Range = 20 NM

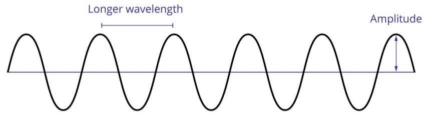
Radar

Pulse techniques

- Min range determined by pulse length
- Max unambiguous range determined by pulse recurrence frequency

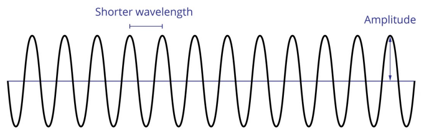
Long Range

Low frequency (Lower PRF)
Longer/Larger wavelength



Short range

High frequency (Higher PRF)
Shorter/Smaller wavelength



- PRR (Pulse Recurrence Rate)
  = number of pulse per second
- To double the range in radar increase power by 4 back and forth = 4x4 = 16
- AWR radar most commonly used in civilian aircraft
  ↳ uses primary radar principle
- All Radar = Pulse
- PRR (Pulse Recurrence Rate) = number of pulses per second
- Max range determined by pulse repetition frequency (PRF) (must wait for return to avoid ambiguity)
- Pulse length determines minimum measurable range — must be short, if object close, bounce will happen while radar not finished transmitting
- Double range, power increase by 16
- To increase range, PRF becomes lower (need more time for echo) and pulse length larger (more energy put in pulse)

Ground Radar

- Primary radar: bearing, distance of targets
  - Max range from ATC Long Range Surveillance Radar = 200 - 300 NM
  - Primary continuous wave most suited for short range operation (think of RA, uses continuous wave as well)
- Primary radar detect aircraft not equipped with SSR
  - Moving target indicator eliminates all stationary targets
- ATC use input from various sensors
  - Best screen picture with short pulse length and narrow beam
  - Aerodrome Surface Movement Radar (ASMR)
    ↳ give indication of shape and type of aircraft
  - Minimum info for controllers surveillance is: Position and any map info needed (if available) aircraft identification and level

Airborne weather radar

- Main tasks:
  - Weather detection
  - Ground mapping
  - Precipitation and turbulence detection
- Principles
  - Wavelength of about 3 cm centimetric (to reflect wet hailstones)
  - SHF band 9375 MHz (9.375 GHz)
    10 GHz optimum for large droplets and small antenna
  - Antenna stabilization → in Roll and Pitch
  - Pencil beam (3-5° width)
    → detect ground features beyond 50-60 NM (more power in narrow beam)
    → flat plate antenna pencil or conical beam with downward tilt for ground mapping

- Radar Control Panel
  - On/off switch
  - Mode switch: WX, WX+T, MAP → change shape and orientation of transmission beam down to ground (turbulence)
  - Gain-control setting: adjusts receiver sensitivity
  - Tilt/Autotilt switch: adjusts according to altitude
- Presentation and Interpretation
  - Reflection intensity: Green, Yellow, Red, Magenta
  - Azimuth-marker and range lines: relative bearing, distance to thunderstorm
- Errors, Accuracy, Limitations
  - AWR caution on ground: risk in polar area of mistaking coastal ice for real coastline
- Factors Affecting Range and Accuracy
  - Shadow area: behind heavy rain, no radar wave penetration
  - Tilt settings: altitude, thunderstorm related, greatest reflectivity from wet hail and rain
  - High tilt may miss thunderstorm
- Application for Navigation
  - Mapping mode: navigation function, large ground zone echo
  - Use of cosecant beam wich enables scanning of large ground zone up to max 50-60 NM (Short range)
  - Avoid thunderstorm: fly upwind, avoid red/magenta areas
  - Turbulence detection: heaviest near thunderstorm cell edge
  - Windshear detection: Doppler technique, inertial data, air data

Secondary Surveillance Radar and transponder

- ATC based on airborne transponder replies
- Ground ATC secondary radar provides extra information
- Airborne transponder provides coded-reply signals for ground radar, TCAS
- SSR advantages: better range, more info, lower power required, active participation
- Interrogator transmits pulse pairs
- Interrogation modes: Mode A transponder code 4-digit 4096 codes
  Mode C pressure altitude in 100ft increment
  Mode S selects aircraft address, transmits flight data
- Interrogation and reply frequency: 1030 MHz (ground)
  1090 MHz (aircraft)
- Decoding time between pulse pairs determines which mode
- Special position identification (SPI) pulse IDENT transmitted on ATC request (special pulse after normal pulse train)
- Mode S compatibility with Mode A and C required. Mode S Broadcast transmits info to all mode S transponder
- Mode S receives interrogations from TCAS and SSR
- Mode S interrogation contains aircraft address, selective call, or all-call address
- ICAO aircraft address hard-coded in Mode S transponder
- 24-bit address used in Mode S transmission for specific aircraft targeting
  ↳ aircraft identified by unique code
- Mode S: enhanced vertical tracking, 25-ft altitude increment
- SSR used for ADS-B
- ATC display system presents: pressure altitude, flight level, registration, GS
- Selector modes: OFF, STDBY, ON (Mode A), ALT (Mode A, C, S), reply lamp

06 Global Navigation Satellite Systems (GNSSs)

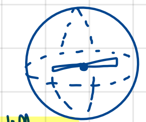
Global navigation satellite systems (GNSSs)

- Main GNSSs
  - NAVSTAR GPS (USA)
  - GLONASS (Russia)
  - Galileo (Europe, under construction)
  - BeiDou (China, under construction)
- GNSS Operation
  - Two modes: SPS (civilians), PPS (authorised users)
  - Three segments: Space, Control, User

1) Space segment (eg. NAVSTAR GPS)
- Broadcasts on UHF frequencies: L1, L2
- SPS uses L1, PPS uses L1 and L2
- Transmits ranging signal: PRN code (identification of satellites), timing, navigation
- Navigation message contains: - clock correction (correct satellite time)
  - UTC parameters
  - ionospheric model
  - satellite health
- L1 (higher frequency) transmits C/A code (only code for civilian) and P code
- L2 transmits only P code
- 2 non-identical atomic clock for time reference

2) Control Segment
- Consists of master control station, ground antenna, monitoring stations
- Monitors constellation, corrects orbital parameters, uploads navigation data
- Detects malfunctioning satellites

3) User Segment



- Provides 3D position, speed, precise time
- Receiver calculates distance by transmission and reception time difference
- Initial distance: pseudo-range (includes receiver clock error)
- 4 unknowns (x, y, z, Δt) need 4 satellites for positioning
- Synchronizes time reference with 4 satellites (multi-channel receiver)
- Calculates ground speed via SV Doppler shift or position change

NAVSTAR GPS integrity

- RAIM: consistency checks among range measurements (aircraft based) determines integrity of GNSS navigation signal using only GPS signals
- Basic RAIM needs 5 satellite (to find error)
  6 satellite to isolate faulty (which one)
- Different GNSSs have unique data and services but Compatibility and interoperability of NAVSTAR and GLONASS

Errors and Accuracy factors

- Ionospheric propagation delay → most significant error
- Dilution of Precision (DOP)
- Satellite clock error
- Satellite orbital variations (ephemeris)
- Multipath
- UERE computed from these factors
- Geometric Dilution of Precision (DOP) depends on satellite geometry (position) and number
- Satellite orbit errors due to solar winds, gravitation from Sun and Moon

IPD Errors: Ionospheric propagation delay

- Reduced by modelling or using two frequencies
- UERE represents the residual errors in receivers, which have not been corrected
- GDOP calculates position accuracy from UERE and DOP

Ground-, satellite- and aircraft-based augmentation systems

- (GBASs) Ground-based augmentation systems
  - Ground errors measured, relayed for GNSS signal correction — errors due to ionospheric and tropospheric delay
  - ICAO GBAS standard: $\boxed{\text{data link}}$ in ILS-VOR systems $\boxed{\text{VHF}}$ band (108 - 118 MHz)
  - GBAS station coverage ~20 NM
  - Guidance: terminal area, 3D final approach segment (FAS) VHF + differential position corrections
  - One station supports aircraft within coverage: approach data, corrections, GNSS integrity
  - Software coverage: ± 10° of final approach path, 15-20 NM distance, ± 35° up to 15 NM
  - FAS data unused outside this area
  - GBAS + GPS = LAAS (aircraft closer to ground station has more precision)
  - GBAS approach = GLS approach
  - Requires 4 satellite

SBAS Satellite based

- Ground equipment measure errors, relayed for navigation satellite correction
- Data link frequency = GPS signal frequency $\boxed{\text{UHF}}$
- $\boxed{\text{Geostationary satellites}}$ enable $\boxed{\text{wide area}}$ broadcast — Wide area differential GPS
  - more area than GBAS
- Pseudo-range measurements to geostationnary satellites like GPS satellites
- 2 Elements: ground infrastructure (monitoring, processing), communication satellite
- Supports 3D Type A and B approaches
- Examples: EGNOS (Europe) European Geostationary Navigation Overlay Service — 3 geostationary satellite
  - WAAS (USA)
  - MSAS (Japan) — up to 4 geostat. satellite
  - GAGAN (India)
- Improves $\boxed{\text{accuracy}}$, $\boxed{\text{integrity}}$; alerts within 6 seconds of GPS malfunction (instead of 3h)
- Able to provide approach and landing operation with vertical guidance

ABAS Aircraft based

- Uses GPS constellation redundancy or combines GNSS measurements with other navigation sensors for integrity control
- GNSS-only ABAS = RAIM
- Additional onboard sensors = AAIM measures FD, FDE
  - Typical sensors: barometric altimeter, IRS

07 Performance Based Navigation

Performance-based navigation (PBN) concept

PBN principle

- RNAV / RNP factors: — RNP: navigation performance within an airspace
  - $\boxed{\text{Accuracy}}$: Conformance of true and required position
  - $\boxed{\text{Integrity}}$: Trustworthiness of system's information; Includes timely, valid alerts
  - $\boxed{\text{Continuity}}$: Uninterrupted function capability
- Purpose: Optimize airspace utilization
- Awareness: Flight crew, ATC must know RNAV / RNP capabilities
- PBN vs conventional: PBN non-sensor specific
- Raw vs computed difference → can check validity and consistency of computed data
- Availability: System's annual usable time percentage

PBN components — memo: ISA

- NAVAID Infrastructure — Can not be based on NDB (to imprecise)
- Navigation Specification — RNAV 2, RNP 2, RNAV 5
- Navigation Application

PBN Scope

- Oceanic / Remote, En-route, Terminal Phases: Linear lateral performance / time constraints
- Approach Phase: Linear / angular laterally guided ops

Navigation specification

- RNAV vs RNP: Difference is $\boxed{\text{on-board performance monitoring/alerting required in RNP}}$
- Navigation Functional Requirements
  - RNAV / RNP Functions:
    - Lateral deviation
    - Distance / bearing to waypoint
    - GS / time to waypoint
    - Navigation data storage
    - Failure indication

- RNP and RNAV specs
  - $\boxed{\text{X means aircraft follows a lateral navigation within X NM accuracy during 95\% of the flight time}}$
  - Higher accuracy aircraft: May lack functional requirements for less accurate specs
  - RNAV 10 / RNP 4: Oceanic / remote phase
  - RNAV 5: En-route, arrival phases outside 30NM — STAR
  - RNAV 2 / RNP 2: Navigation specs
  - RNP 2: En-route, oceanic / remote phases
  - RNAV 2: En-route continental, arrival, departure phases
  - RNAV 1 / RNP 1: Arrival, departure phases — STAR
  - RNP APCH: Approach phase
  - RNP AR APCH: Approach phase authorization Required
  - RNP 0.3: All phases (except oceanic / remote, final approach); Primarly helicopters
  - RNAV 1 / RNP 1 / RNP 0.3: Enroute phases, low-level IFR helicopter flights

Use of Performance-based navigation (PBN)

- Specific RNAV and RNP System Functions
  - Fixed Radius Tracks
    - Fixed Radius Turn (FRT) → en-route
    - Fixed Radius Path — RF radius-to-fix leg based on fixed radius terminal approach
  - Flyby / Fly over
    - Fly-by waypoint requires turn anticipation to allow tangential interception of the next segment of a route or procedure
    - Fly-by → used in RNP
    - Fly-over turns are excluded
  - Offset flight path
    - lateral offset can be specified in increment of 1NM up to 20NM
  - PBN path terminator
    - Specific type of termination of the previous flight path
    - CA: Course to an Altitude
    - FA: Fix to an Altitude
    - CF: Course to a fix

Performance-based navigation (PBN) operations

PBN Principles

- Path Definition Error (PDE): Inability to specify desired path accurately — Assumed to be zero and depends on integrity of Nav database
- Flight Technical Errors (FTE): Path-following error execution by autoflight system / pilot — monitored by crew
- Navigation System Error (NSE): Navigation system accuracy / $\boxed{\Delta \text{ estimated position and actual position}}$
- Total System Error (TSE): Geometric sum of PDE, FTE, NSE
- Navigation Accuracy: Depends on TSE

On-board Performance Monitoring and Alerting

- Flight Technical Errors: Managed by on-board systems / flight crew procedure
- Navigation System Errors: On-board equipment requirement for RNP
- Path Definition Error: Managed by gross reasonableness check of nav data
- Estimate Position Error (EPE): Compared with required navigation specification depending on navigation sensor

Abnormal Situations

- Abnormal and Contingency Procedures: Use in case of loss of PBN capability
  - → Fail to engage correct approach mode
  - → Loss of satellite signal
  - → CDI > half-scale displacement

Database management

- Navigation Database: Must be valid for current AIRAC cycle

Additional Terms

- RNP: Required Navigation Performance
- ANP: Actual Navigation Performance

Requirement of specific RNAV and RNP application

RNAV 10
- Requires 2 independant LRNSs : INS, IRS / FMS, GNSS
- Navigation capability time extendable

RNAV 5
- Manual data entry acceptable

RNAV 1 / RNAV 2 / RNP 1 / RNP 2
- Fly SID / STAR : retrievable by route name, conforms to charted route
- Route modification : insertion / deletion of waypoints
- No manual entry of lat/long or place / bearing / distance

RNP APCH
- LNAV with GNSS, vertical guidance with SBAS or Baro - VNAV
- Baro - VNAV : aerodrome temperature within range if not auto - temp compensated
  - ↳ Final approach
- LNAV / VNAV and LPV minima : 3D operations
- LPV minima : requires FAS data block, SBAS
- RNP APCH not flown unless retrievable and conforms to charted procedure
- Don't fly RNP APCH in case of discrepancy

RNP AR APCH
↳ require authorization

Advance RNP (A-RNP)
Incorporates RNAV 5, RNAV 2, RNAV 1, RNP 2, RNP 1, RNP APCH not RNAV APCH

PBN PinS Approach
- Designed for helicopters, RNP APCH procedure, LNAV or LPV minima
- Includes "proceed VFR" or "proceed visually" from MAPt to landing

3D Approaches
- RNP APCH (Baro - VNAV)
- GLS (GBA Landing system)
- PAR (Precision approach radar)
- ILS
- RNP APCH (SBAS)