„Navigatsioonist kaasaegses lennunduses”

Julia Berdnikova
Navigatsioonisüsteemide lektor
Eesti Lennuakadeemia

01.02.2025

ERAÜ 27. Talvepäev Tartus

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Navigatsioon

- Visuaalne (*visual navigavtion*)
- Astronavigatsioon (*Celestial navigation*)
- Instrumentaalnavigatsioon (*on-board, radio, space-based and relative*)

Visuaalne navigatsioon

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https://www.luxaviation.com/wp-content/uploads/2020/02/jets-charter-our_fleet-1.jpg
https://fly8ma.com/visual-flight-rules-what-is-vfr/

Astronavigatsioon

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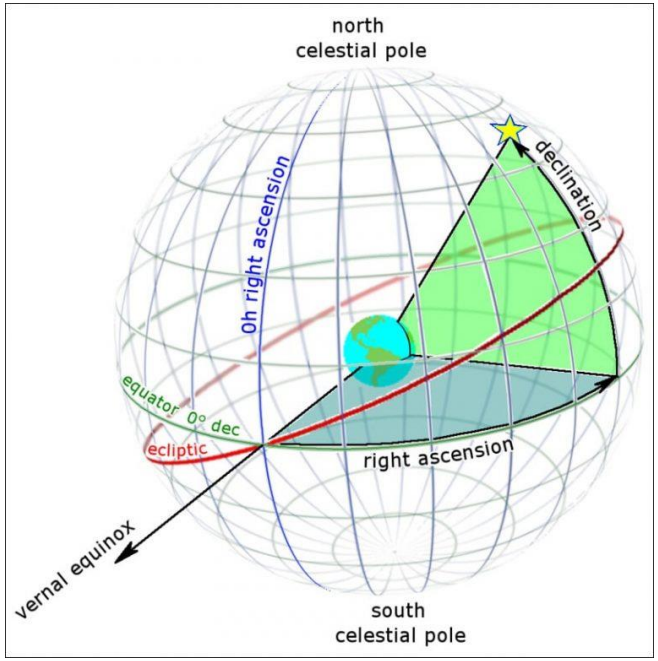

Part 1: The Celestial Sphere | Imaging the Universe - Physics and Astronomy | The University of Iowa
180423-N-DL434-149 (27894845758) - Celestial navigation - Wikipedia
Using Stars To Navigate: Beginners Guide to Celestial Navigation | Below The Stars

Arvutuslik navigatsioon (Dead reckoning)

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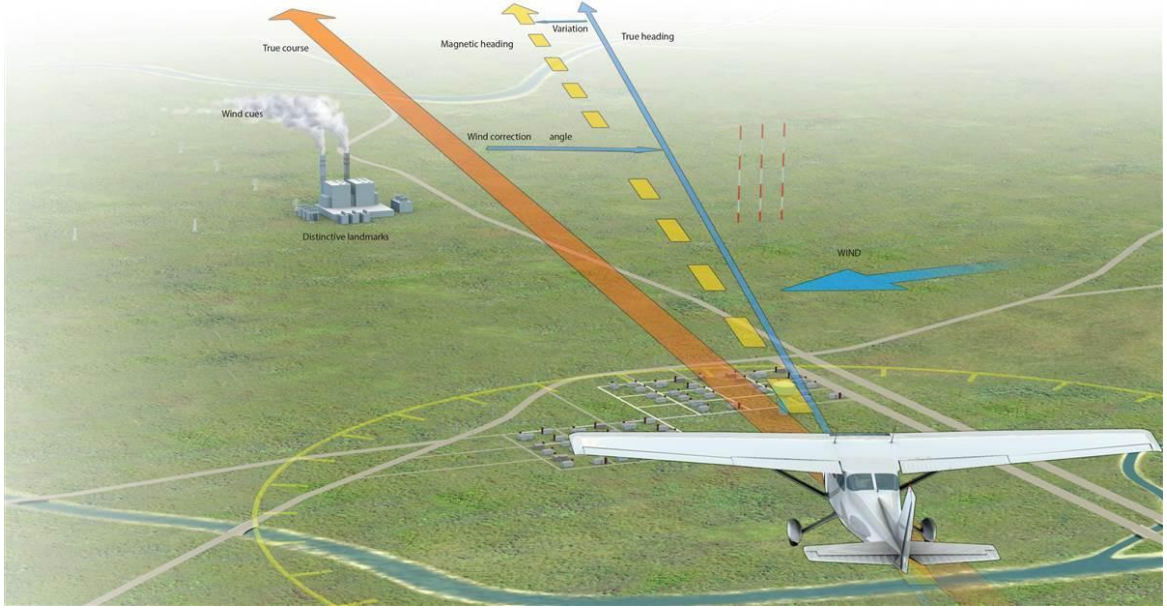
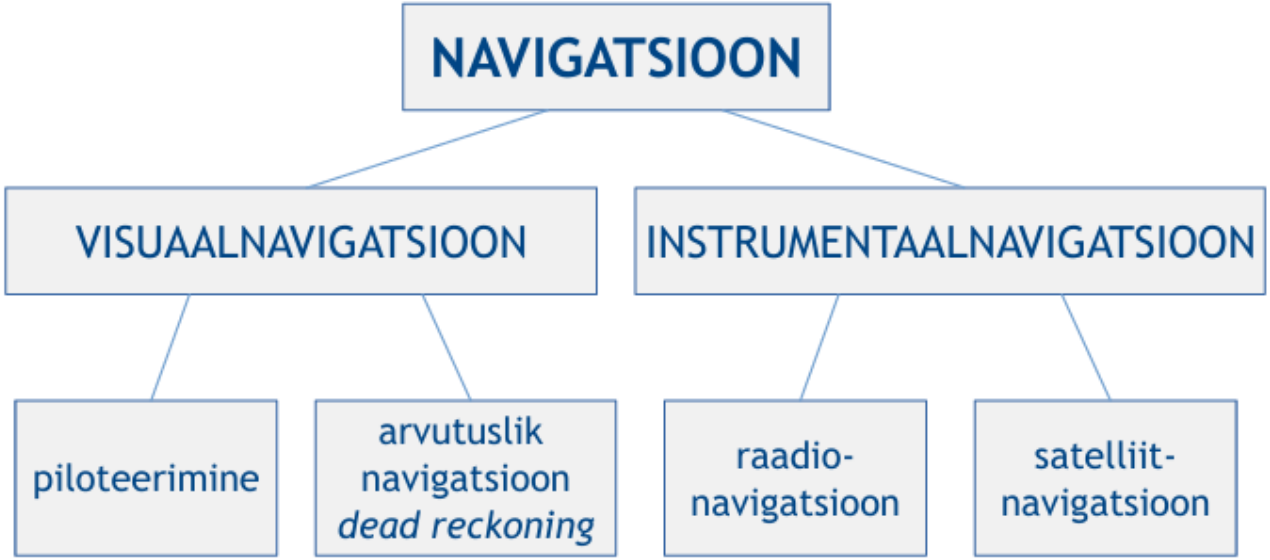


Pilotage - navigation by reference to landmarks or checkpoints.

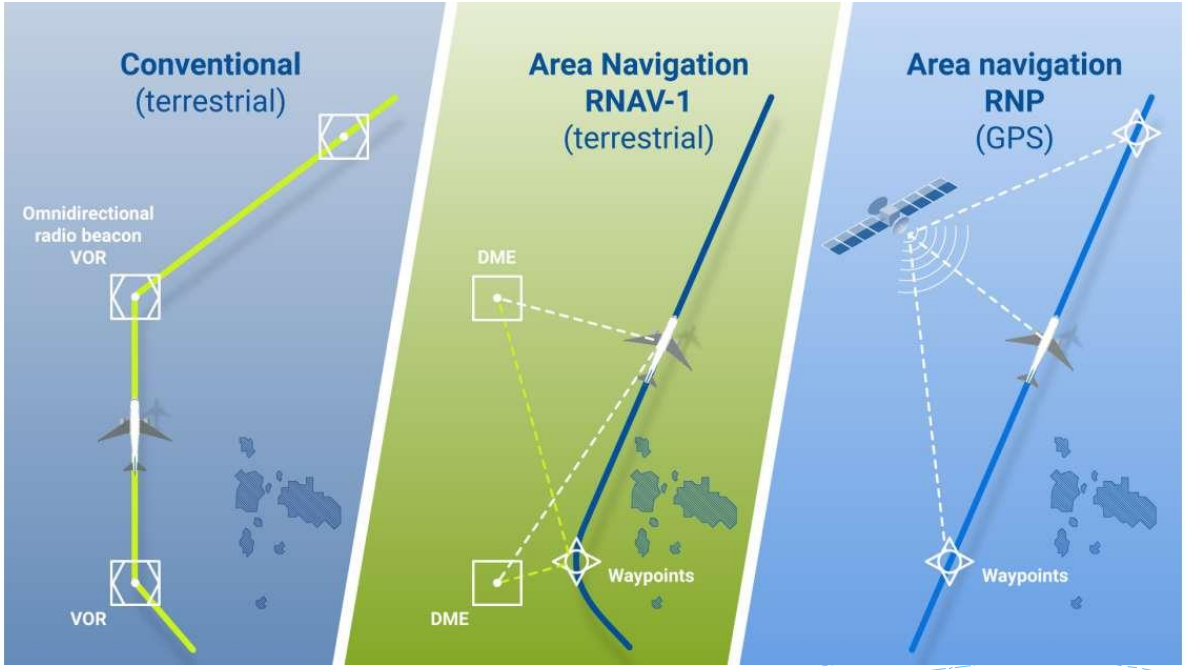
Dead reckoning is navigation by means of computations based on time, airspeed, distance, and direction.

Technique -Pilotage and dead reckoning - AOPA

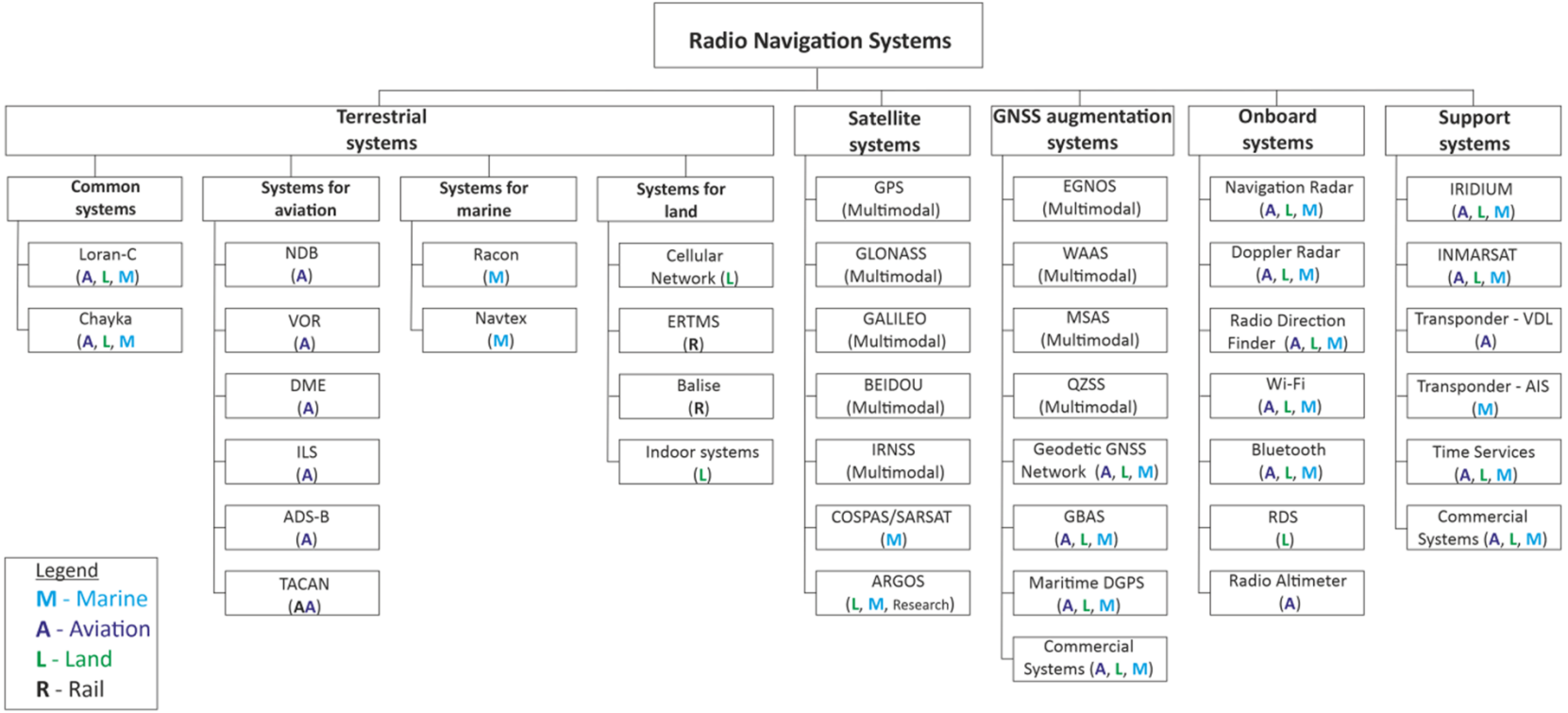

NAVIGATSIOON
VISUAALNAVIGATSIOON
INSTRUMENTAALNAVIGATSIOON
piloteerimine
arvutuslik navigatsioon *dead reckoning*
raadio-navigatsioon
satelliit-navigatsioon

Raadionavigatsioon

Raadionavigatsioon on vee-, õhu- või kosmosesõiduki kursi ja asukoha määramine raadioseadmete abil.



https://www.dfs.de/homepage/en/environment/aircraft-noise/area-navigation/pbm-konzept-en-1920px.png?cid=glh.1l7w&resize=6614ff%3A1200x630c6

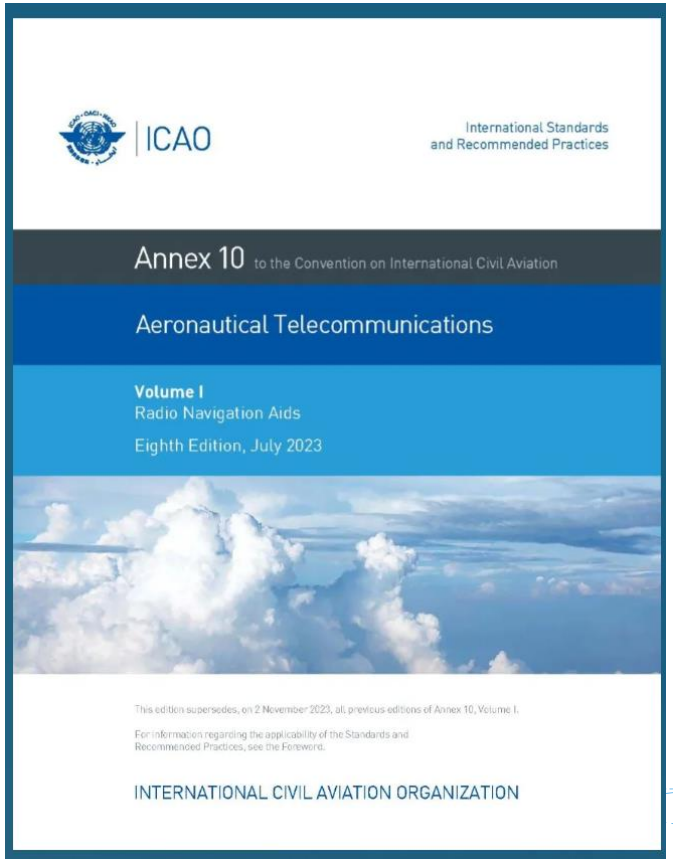


Specht C. Radio navigation systems: definitions and classifications. *Journal of Navigation*. 2021;74(5):945-954. doi:10.1017/S0373463321000369

Lennuliikluse ajaloost:

- 1910–30 Raadiosaatjad
- 1930-40 VOR
- 1940-50 ILS
- 1950-60 DME
- 1970-80 Cockpit
- 1970-00 GNSS

Tänapäevased:



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„Tehnilised nõuded sagedusloa alusel kasutatavatele raadioseadmetele“

Lisa 3 Lennuside

https://www.riigiteataja.ee/akt/103042024005

NDB (*Non-Directional Beacon*)

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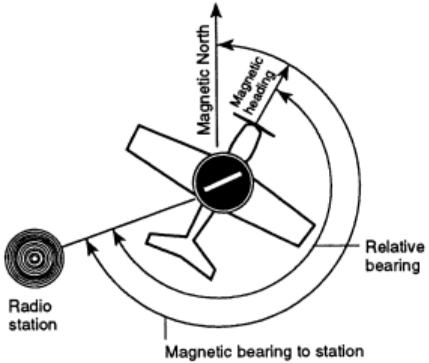
NDB on raadiomajaks, mis on häälestatud valitud raadiosagedusele.
Raadionavigatsioon lennukis toimub suunamääramisega ADF (*Automated Direction Finder*)



- High-power >2kW
- Medium-power 50-2000W
- Low-power <50W

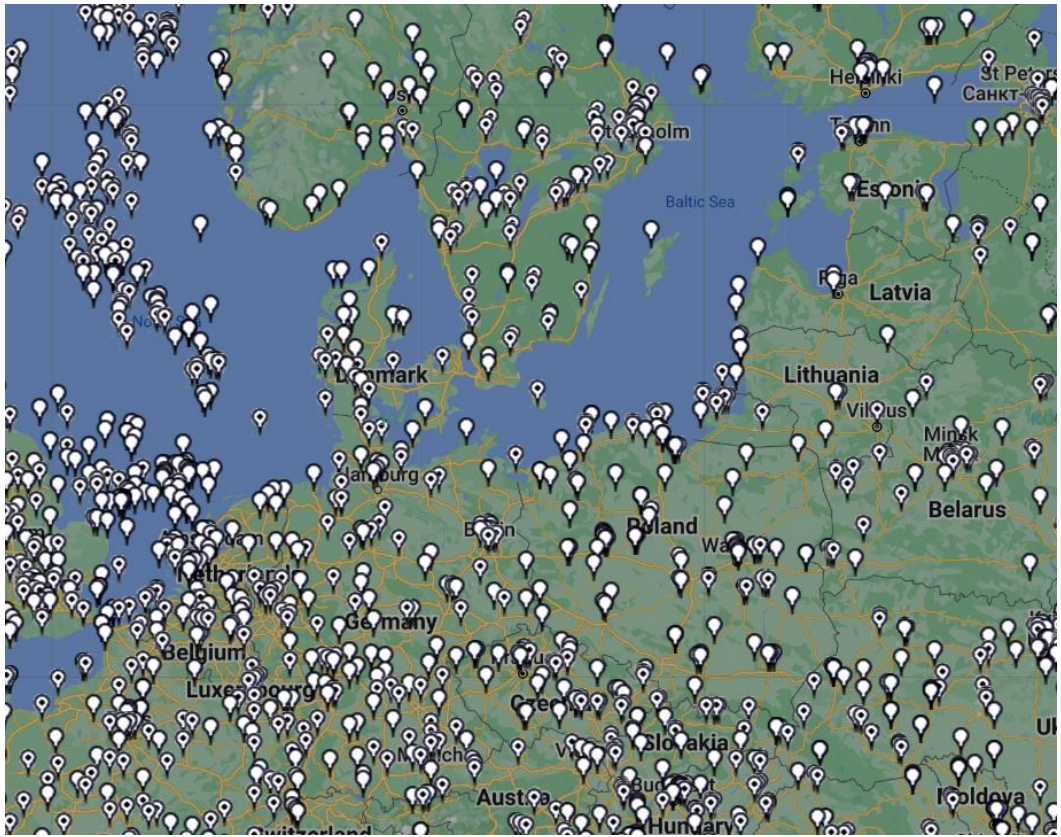
Tartu NDB

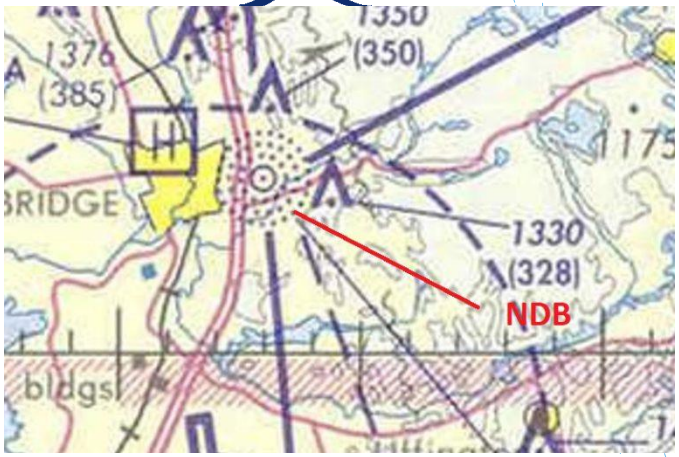
Estonia

397 KHz (UM ..- --)

Frequency	**190-1750kHz (255- 526,5 kHz)**
Power	up to 5000W
Radiation area	360°,toroid
Nav. unit	bearing
Accuracy	±5°
Range	up to 500km
Polarization	vertical
Identification	2-3 morse code 7times/min.

NDB asukohad





- On the track - indicates interest points on flight corridors.
- Approach

www.airnav.eu/index.php?stranka=NDBen

https://storage.ning.com/topology/rest/1.0/file/get/3689405976?profile=original

https://rxx.classaxe.com/en/rww/signals

VOR (VHF Omni Directional Radio Range)

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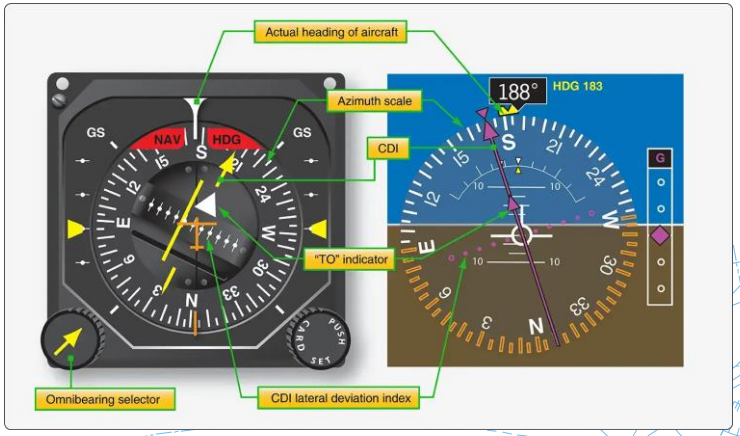
The VHF omnidirectional radio range (VOR) is an omnidirectional (360° of azimuth) range station which operates in the very high frequency (VHF) band of the radio spectrum.
The VHF radio signal includes the station's Morse code identifier and electromagnetic signals ("radials“) that allows the airborne receiving equipment to calculate the magnetic bearing from the station to the aircraft.

- *CVOR conventional VOR ("classic")*
- *DVOR doppler VOR ("Doppler")*

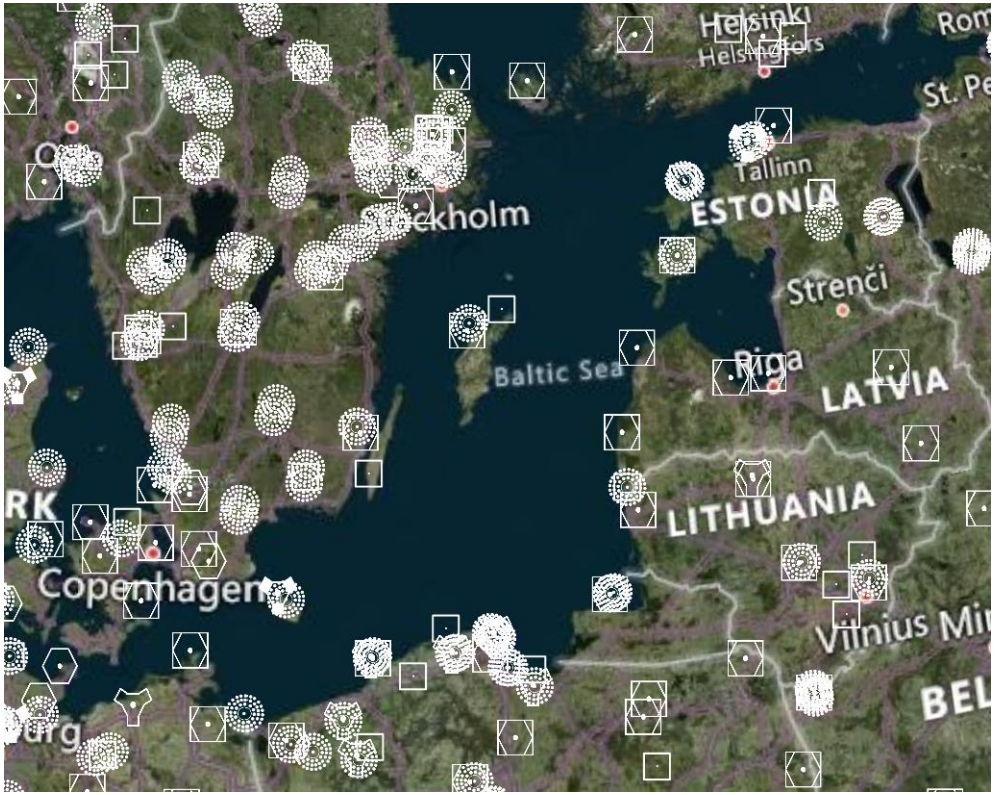
Frequency	**108-117,95MHz**
Frequency shift	50kHz
Power	
Antenna	Omnidirectional circular array
Radiation area	360°
Nav. unit	azimuth/radial
Accuracy	CVOR ±2°, DVOR ±0,2°
Range	300-400km
Polarization	horizontal

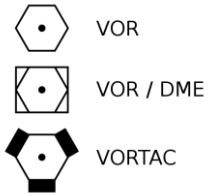
Signal phase differences



https://www.aircraftsystemstech.com/2017/05/vor-navigation-system.html
https://nats.aero/blog/wp-content/uploads/2015/05/VORphoto1.jpg

VOR asukohad



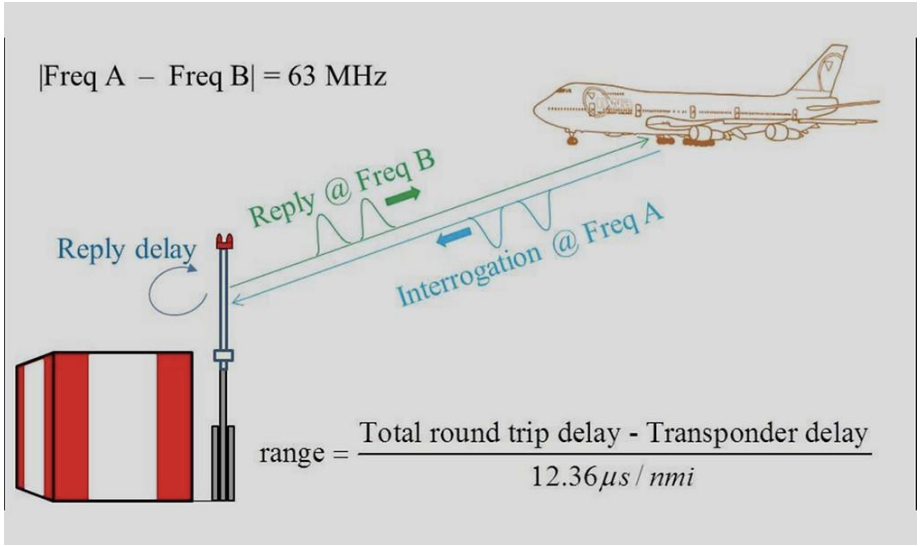


https://upload.wikimedia.org/wikipedia/commons/thumb/c/c6/Icons_of_VOR's.svg/635px-Icons_of_VOR's.svg.pn

http://climateviewer.org/history-and-science/transportation/maps/icao-flight-navigation-aids-vor-ndb/

DME (Distance Measuring Equipment)

Frequency	**960-1215MHz**
Frequency shift	1 MHz
Power	100W-2kW
Antenna	Omnidirectional
Area	360°
Nav. unit	slant range
Precision of DME/N	0.25 nmi + 1.25% of measured distance
Range	cca 370 km
Polarization	vertical
Frequency stability	2.10^{-5}
Identification	morse code at 1350 MHz



VOR / DME (Distance Measuring Equipment)

https://www.airnav.eu/index.php?stranka=DMEeng

https://www.studyaircrafts.com/dme

https://qph.cf2.quoracdn.net/main-qimg-105fa8e001d6aaaba24e7f89eb749656-lq

ILS (Instrument Landing System)

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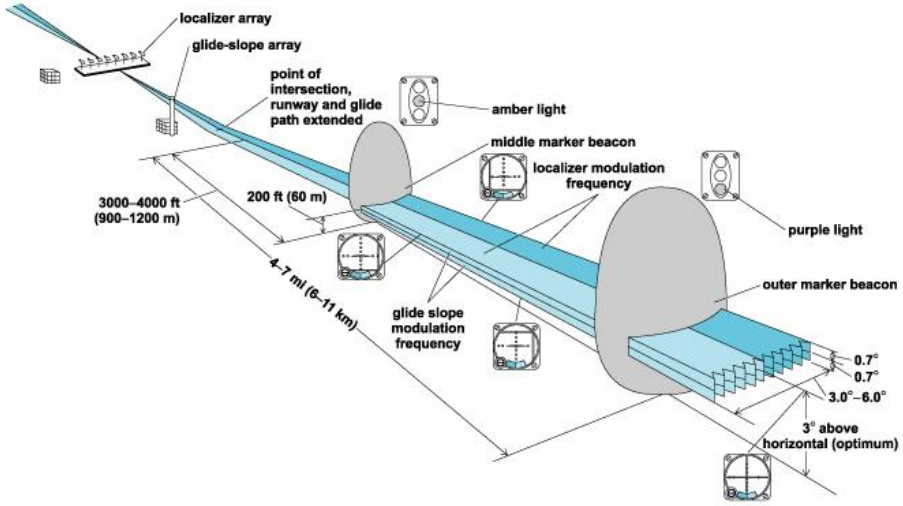
Instrumentaalmaandumissüsteem, mis koosneb kolmest seadmest:

Frequency 108–111,975 MHz

- Kursimajakas (LOC – *Localizer*) – lennuraja telgjoone pikendus õhku
- Glissaadi ehk lauglemisnurga majakas (GS - *Glide Slope*) – laskumisnurk
- Kaugusemõõtja (DME) - annab õhusõidukile kauguse majakast



https://www.aai.aero/sites/default/files/ils_1.jpg
https://www.eans.ee/tegevused/tehnika/navigatsioon

ILS (Instrument Landing System)

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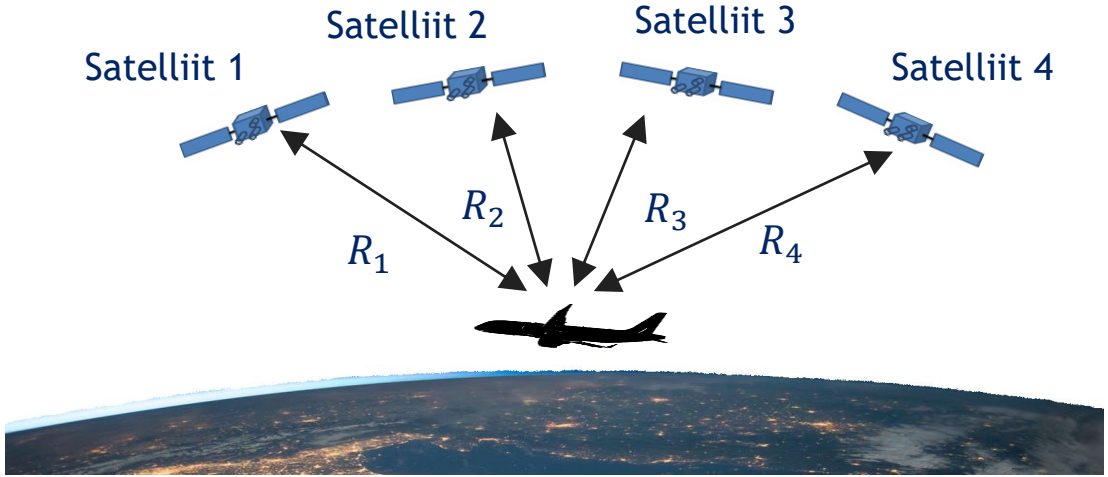
Pilt: EANS

Satelliitnavigatsioonisüsteem

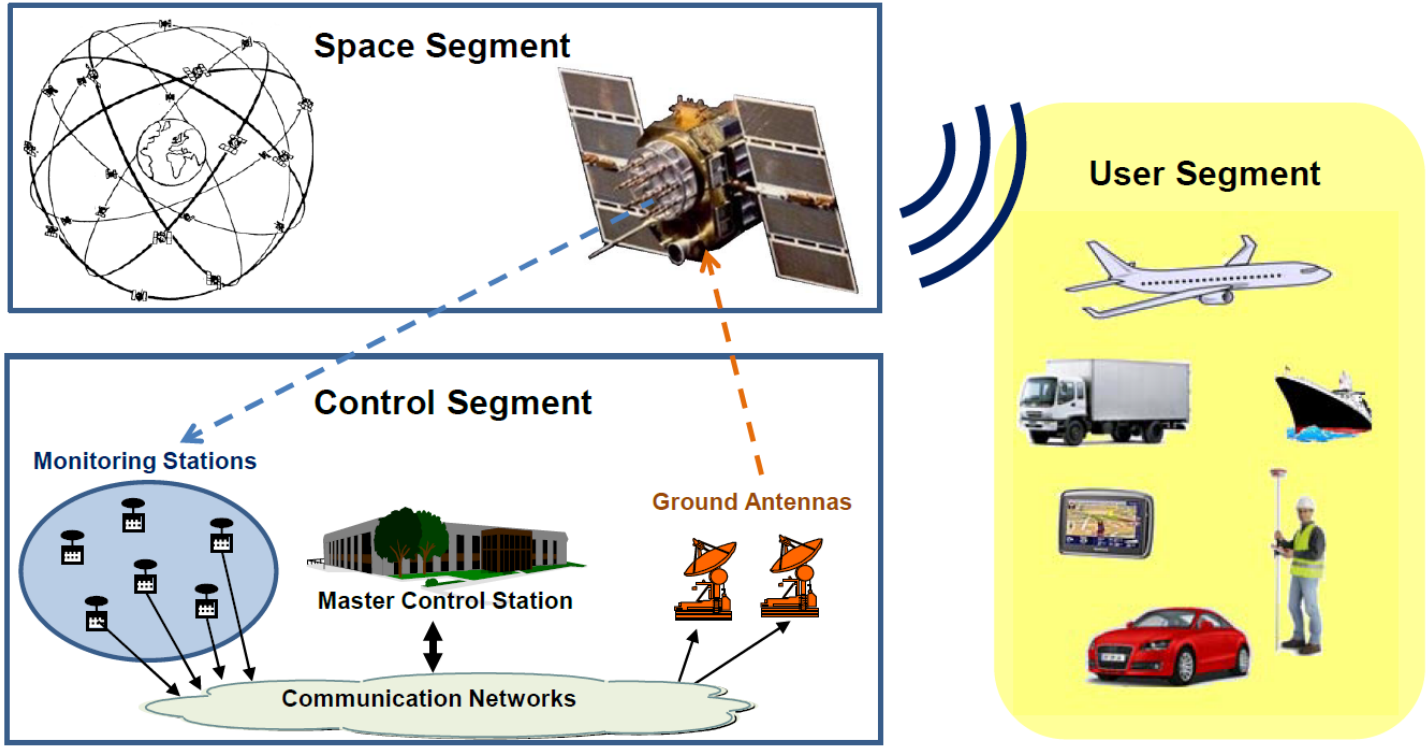
- GPS
- GLONASS
- Galileo
- BeiDou



Regionaalsed:

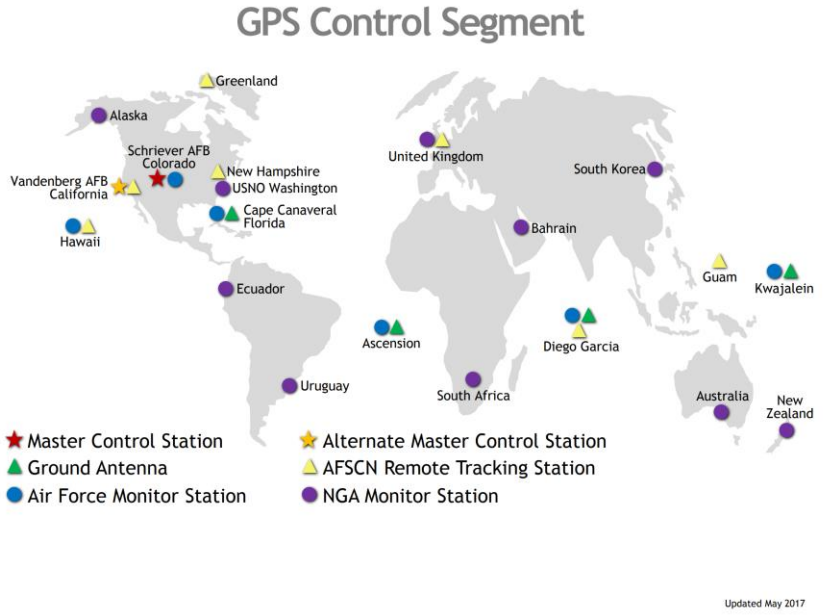
- NavIC (*Navigation with Indian Constellation*)
- QZSS (*Quasi-Zenith Satellite System*)

GNSS Overview
Segments



Source: ESA GNSS Data Processing Book

GNSS: Control segment



https://gssc.esa.int/navipedia/

GNSS: Control segment

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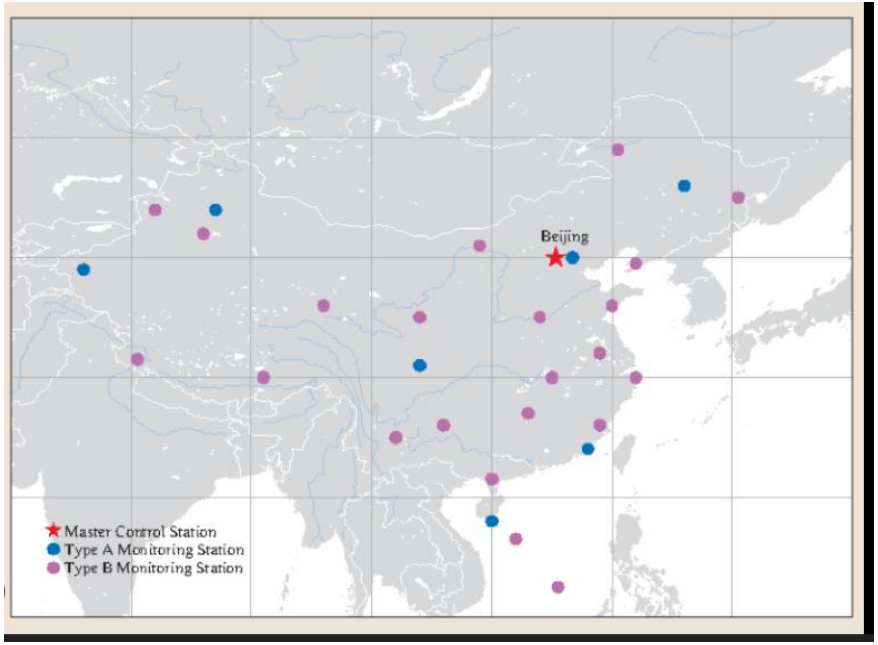

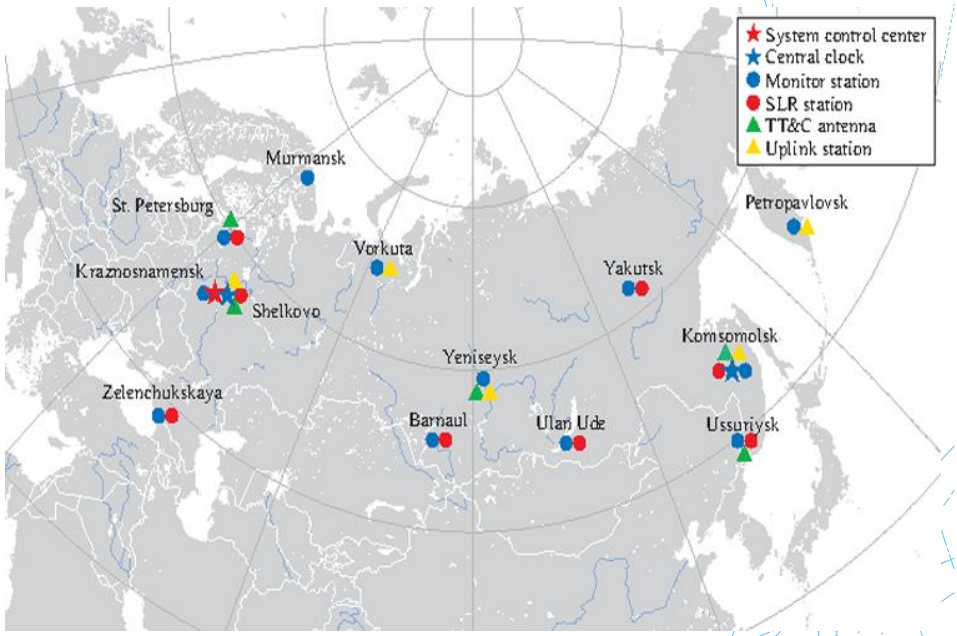

Source: Springer Handbook of Global Navigation Satellite Systems

https://gpsbeam.com/russian-glonass-global-navigation-satellite-system/

Sagedusala

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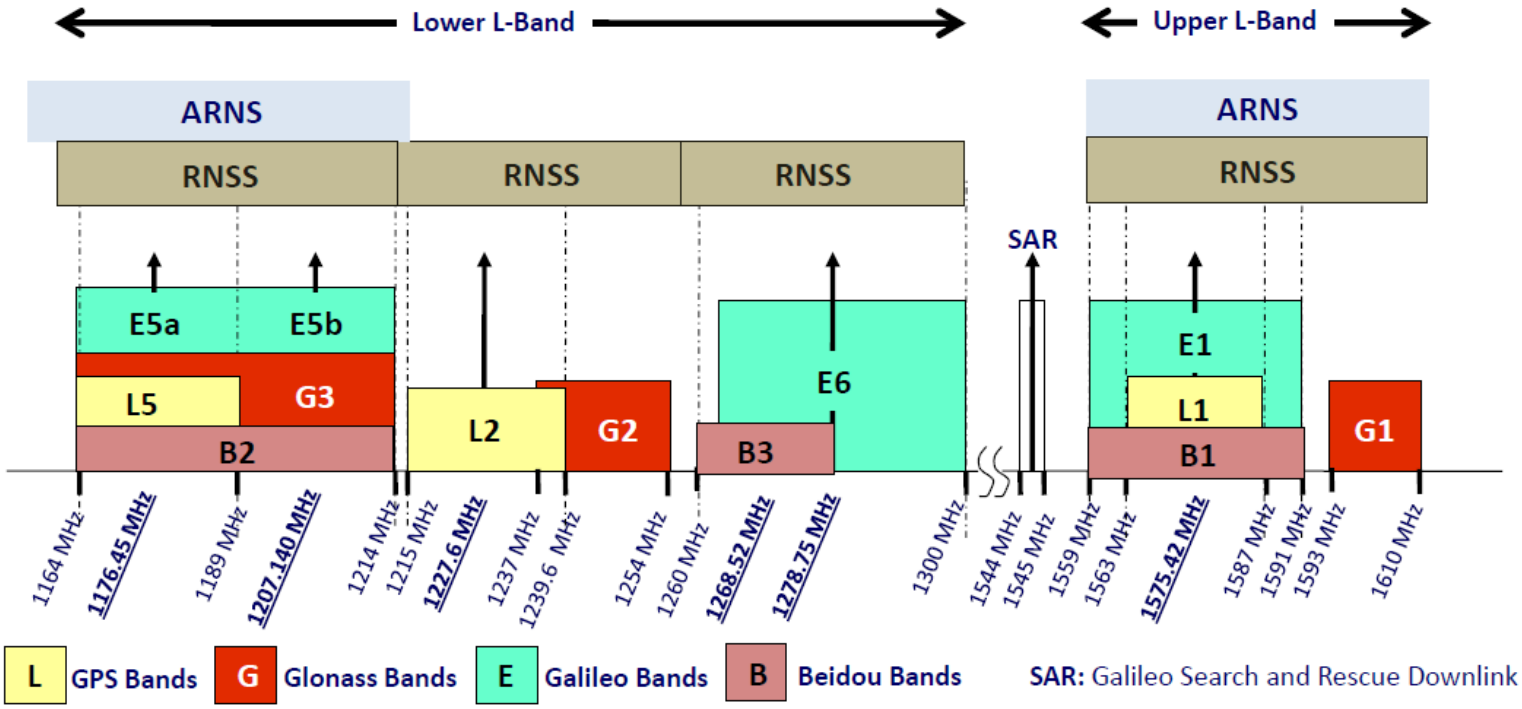

ARNS: Aeronautical Radio Navigation Service

RNSS: Radio Navigation Satellite Service

GNSS spekter

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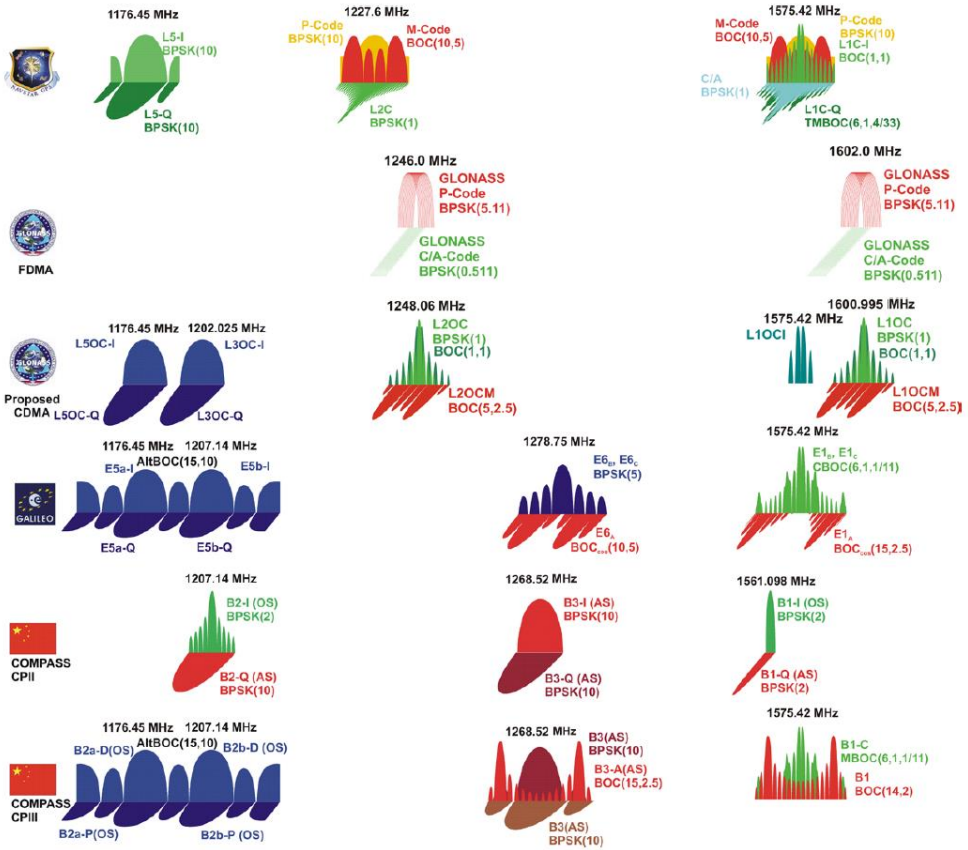

Source: ESA GNSS Data Processing Book

Annex 10: Volume I, Radio Navigation Aids

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GPS Standard Positioning Service (SPS)

3.7.3.1.1.1 *Positioning accuracy*. The GPS SPS position errors shall not exceed the following limits:

	Global average 95% of the time	Worst site 95% of the time
Horizontal position error	9 m (30 ft)	17 m (56 ft)
Vertical position error	15 m (49 ft)	37 m (121 ft)

GNSS mured

- GNSS errors
- GNSS Jamming
- Denial-of-Service GNSS Spoofing
- Deception GNSS Spoofing

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GNSS Augmentation systems (lennundus)

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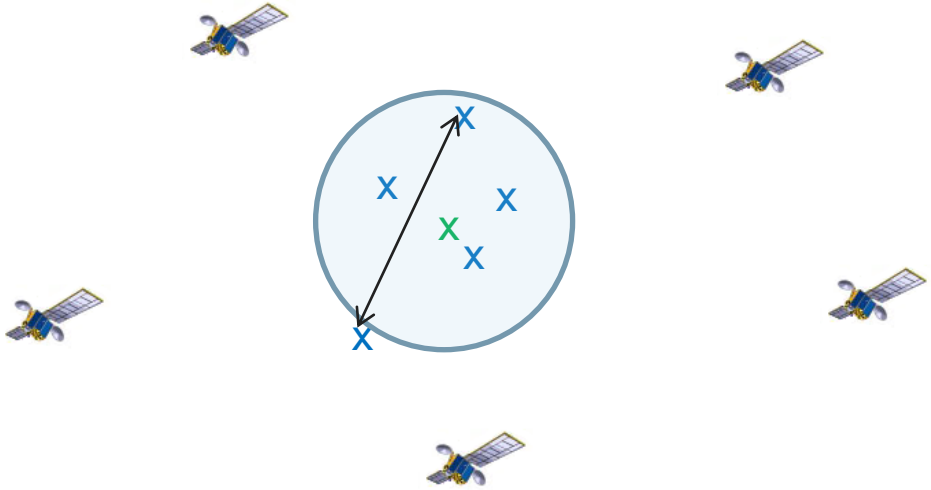
- ABAS - Aircraft-Based Augmentation System
  - RAIM - Receiver Autonomous Integrity Monitoring
  - AAIM - Aircraft Autonomous Integrity Monitoring

- GBAS - Ground Based Augmentation System
- GRAS –Ground-based Regional Augmentation System
- SBAS - Satellite-Based Augmentation System
  - EGNOS - European Geostationary Navigation Overlay Service
  - WAAS - Wide Area Augmentation System

RAIM *Receiver Autonomous Integrity Monitoring*



GNSS Augmentation systems:
SBAS (Satellite-Based Augmentation System)

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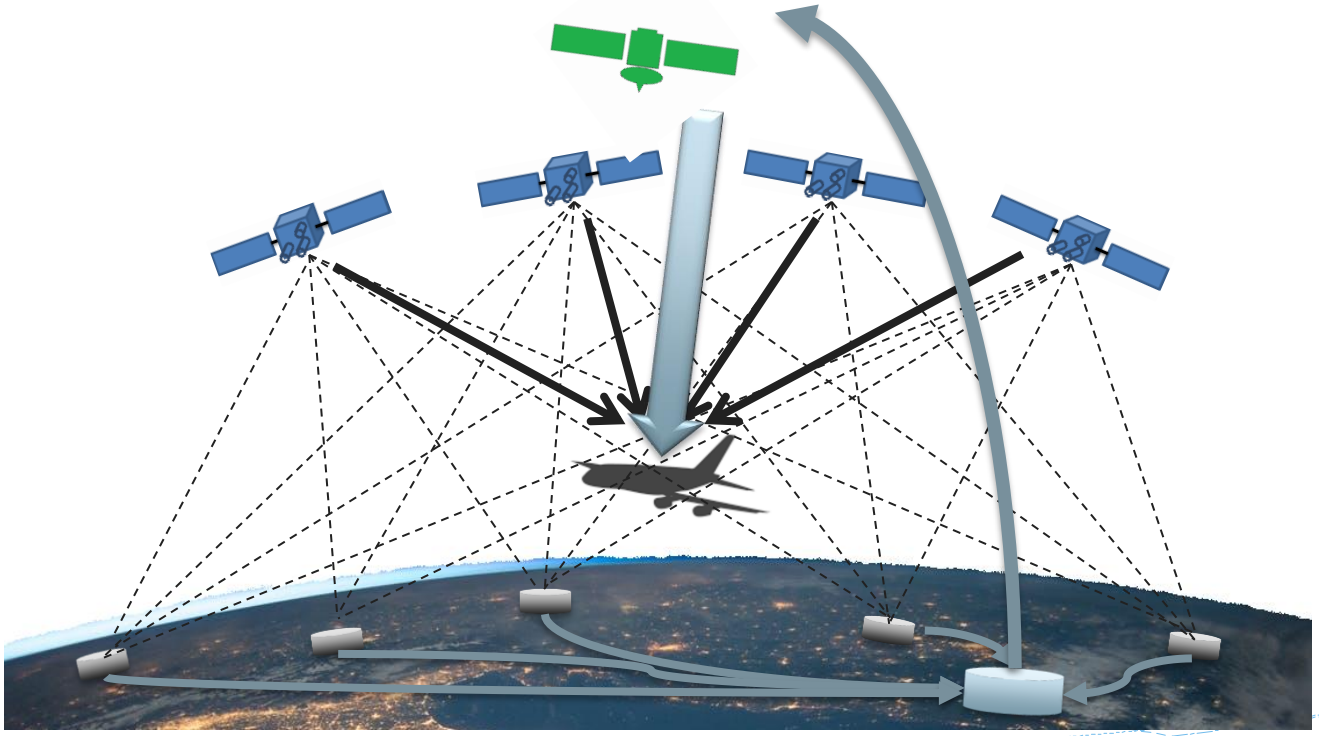

GNSS Augmentation systems:
SBAS (Satellite-Based Augmentation System)

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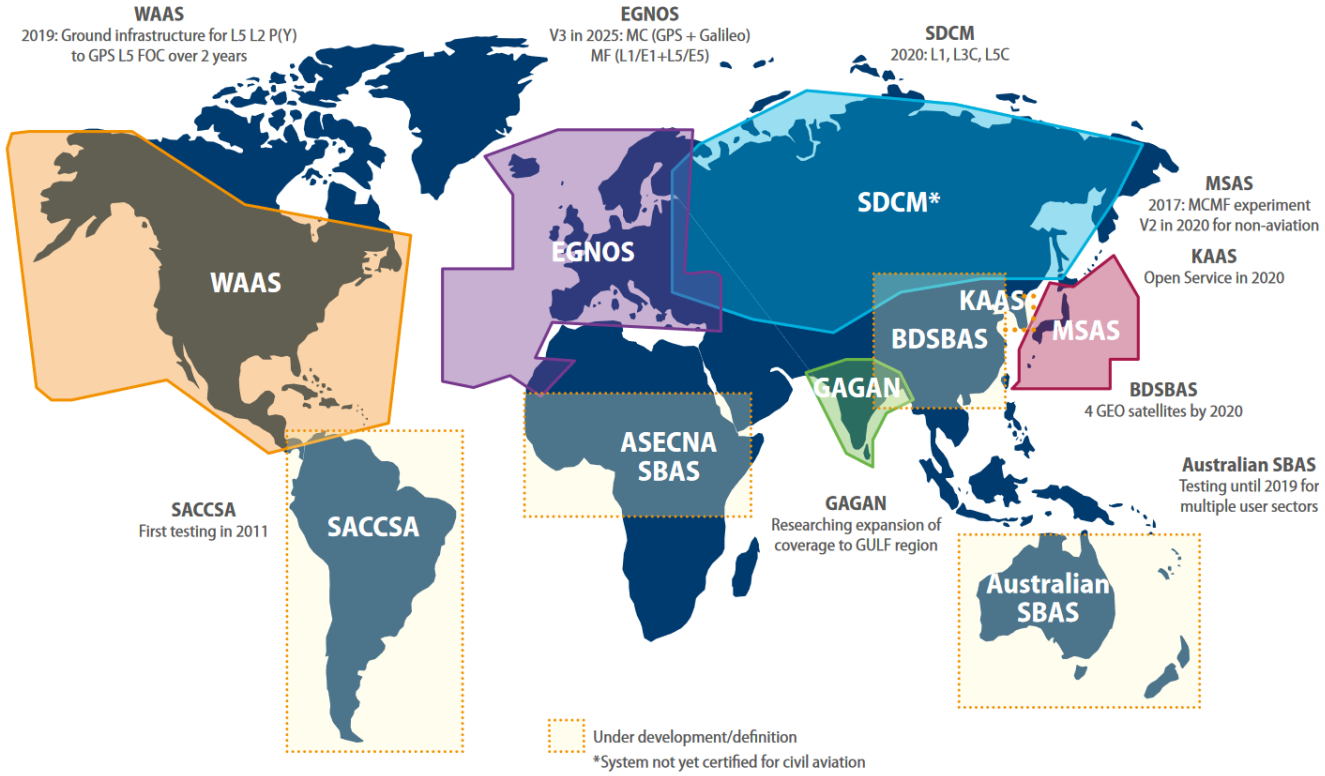
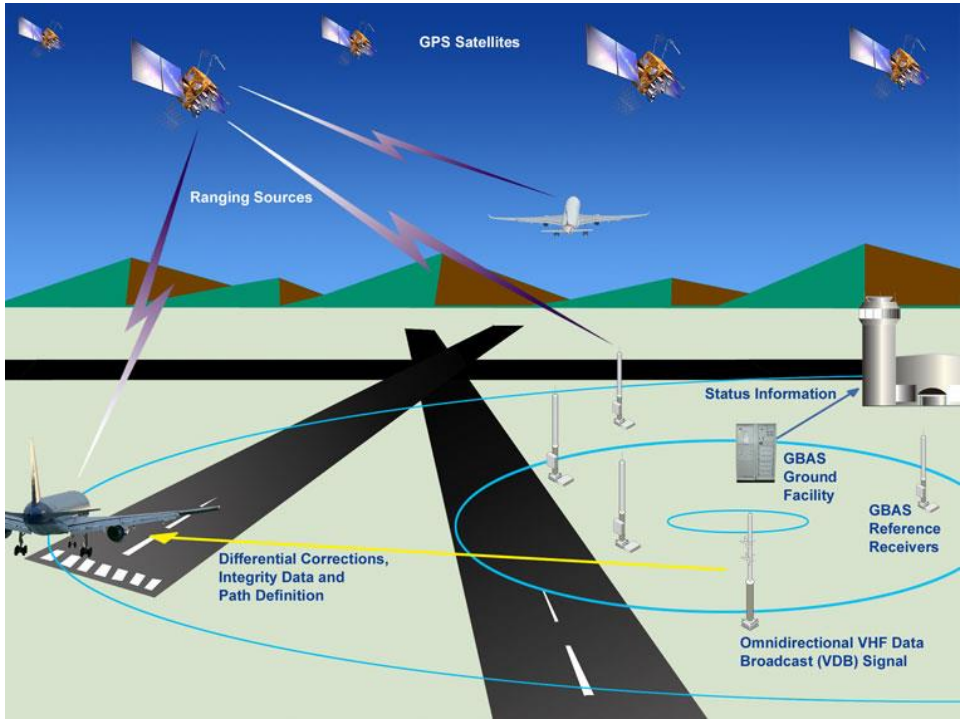
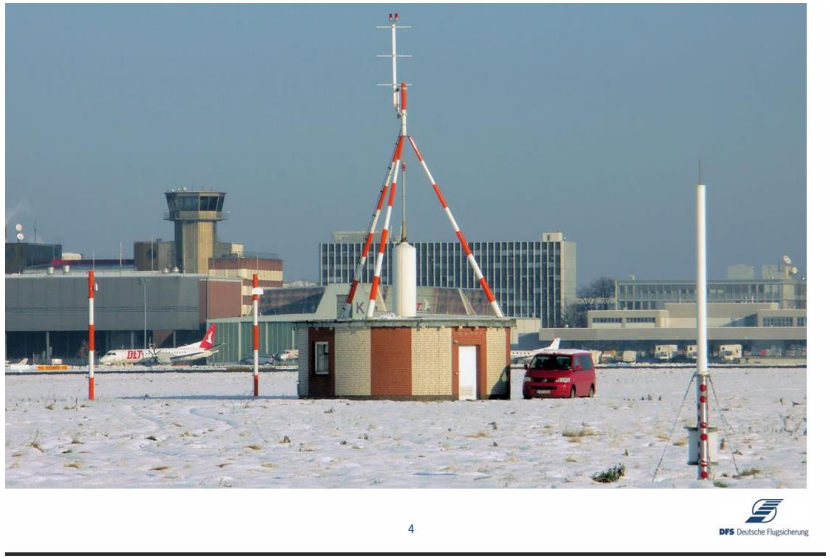


https ://www.gsa.europ a.eu/sites /defau lt/files / broch ure_o_2017_v6.pdf

GNSS Augmentation systems GBAS (Ground Based Augmentation System)





Satellite Navigation - GBAS - How It Works | Federal Aviation Administration

GBAS Operational Implementations DFS experiences and capabilities

Tänapäevane navigatsioon

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- **Piirkondlik navigatsioon**

*Area navigation (**RNAV**) specification. A navigation specification based on area navigation that does not include the requirement for performance monitoring and alerting, designated by the prefix RNAV, e.g. RNAV 5, RNAV 1.*

- **Nõutud navigatsioonitäpsus**

*Required navigation performance (**RNP**) specification. A navigation specification based on area navigation that includes the requirement for performance monitoring and alerting, designated by the prefix RNP, e.g. RNP 4, RNP APCH. RNP has been overtaken by the concept of PBN.*

- **Suutlikkusel põhinev navigatsioon**

*Performance-based Navigation (**PBN**). Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.*

Performance-based navigation
RNAV and RNP systems

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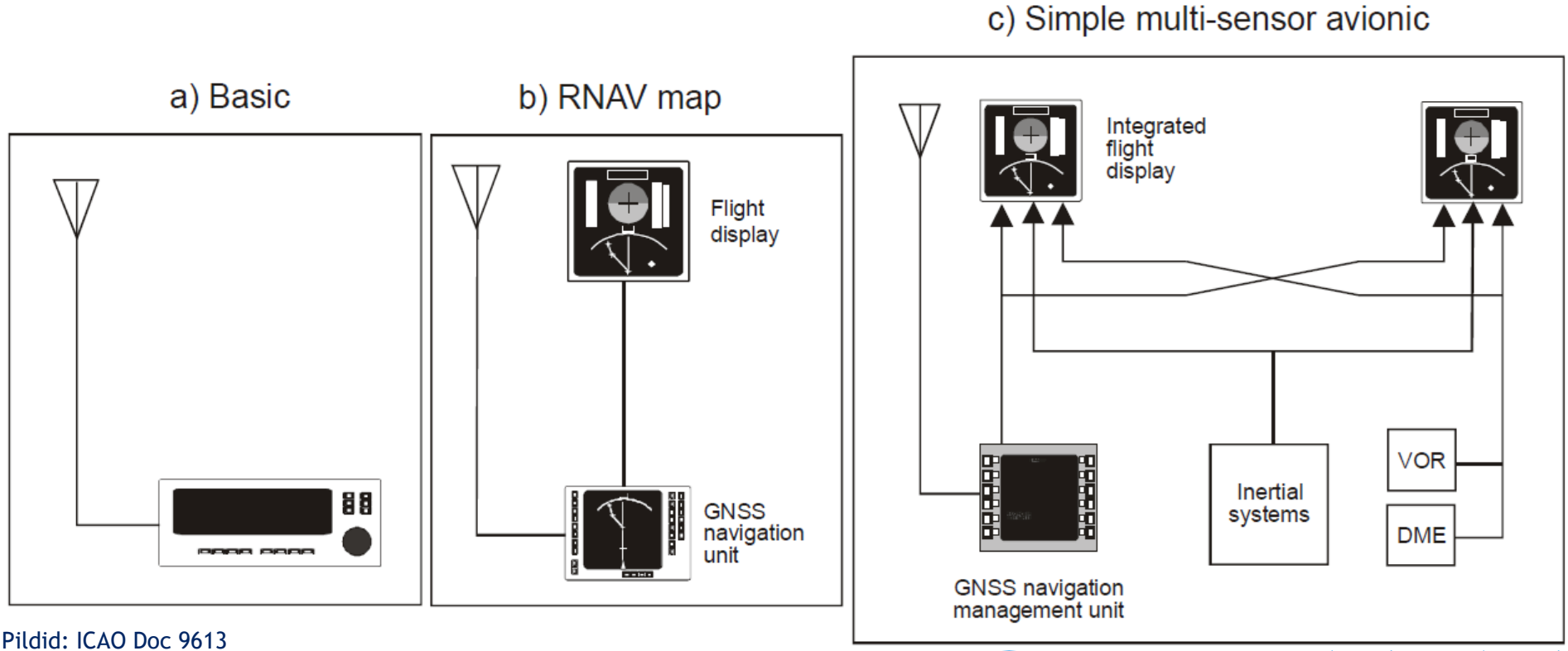
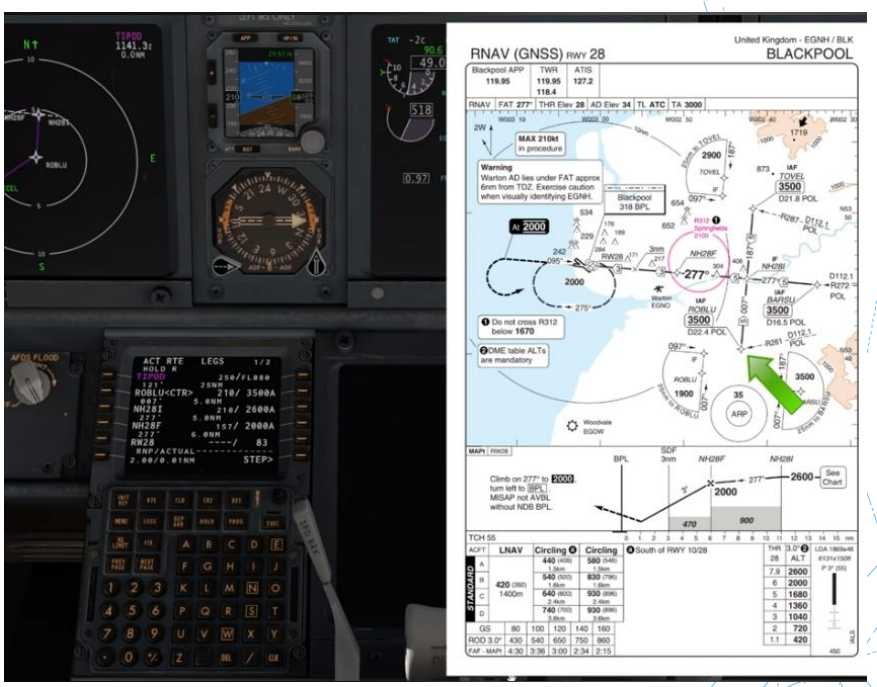


Pildid: ICAO Doc 9613

Piirkondlik navigatsioon RNAV

Area Navigation is Enabled:

- Through the use of a navigation computer
- Waypoints (co-ordinates) are input into computer
  - Manual entry permitted but limits capabilities
  - Automatically with an integrated database
- Pilot creates route (series of waypoints) according to the flight plan
- Computer estimates position using navigation sensors fitted and compares estimation to defined route
- Deviation between the position and defined path will create guidance information



Video https://youtu.be/Sb7ZPFZnJQw?feature=shared

GNSS lennunduses

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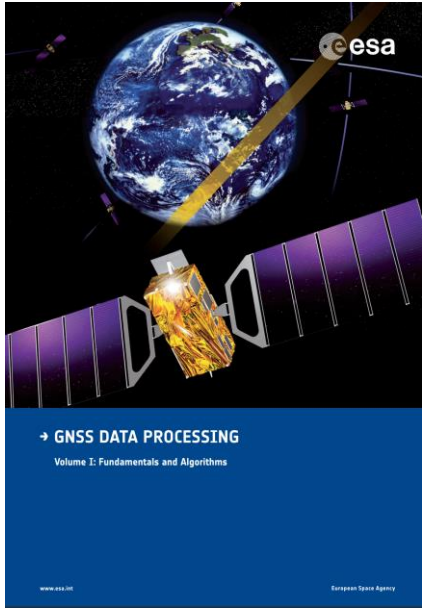

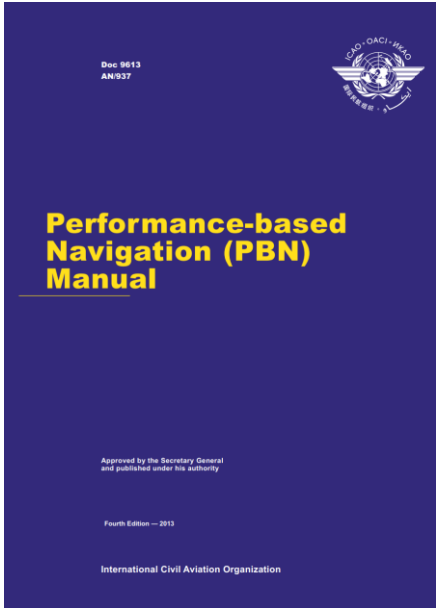

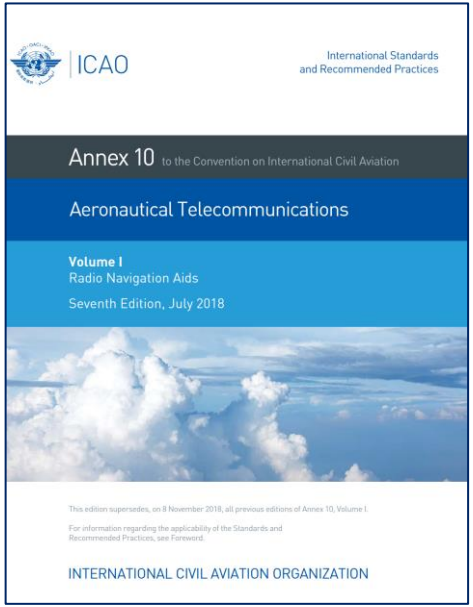

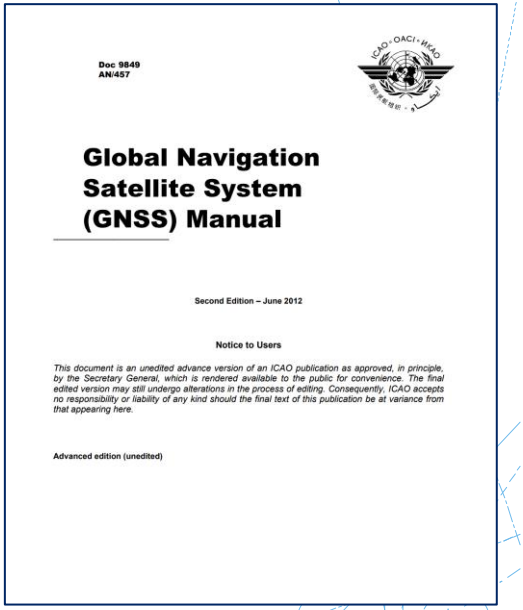

Air Traffic Safety Electronics Personnel (ATSEP)

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ATSEP.BAS.NAV NAVIGATION

ATSEP.BAS.NAV	**NAVIGATION**		
ATSEP.BAS.NAV_1	**INTRODUCTION**		
ATSEP.BAS.NAV_1.1	**Purpose and Use of Navigation**		
ATSEP.BAS.NAV_1.1.1	Explain the need for navigation in aviation	2	Positioning, guidance, planning
ATSEP.BAS.NAV_1.1.2	Characterise navigation methods	2	e.g. historical overview, visual, celestial, electronic (on-board, radio, space-based and relative)
ATSEP.BAS.NAV_2	**THE EARTH**		
ATSEP.BAS.NAV_2.1	**Form of the Earth**		
ATSEP.BAS.NAV_2.1.1	State the shape of the Earth and its parameters	1	Oblate spheroid e.g. diameter, gravity, rotation, axis, magnetic field
ATSEP.BAS.NAV_2.1.2	Explain the Earth's properties and their effects	2	Polar axis, direction of rotation
ATSEP.BAS.NAV_2.1.3	State the accepted conventions for describing 2D position on a globe	1	Meridians, parallels of latitude, equatorial plane
ATSEP.BAS.NAV_2.2	**Coordinate Systems, Direction and Distance**		
ATSEP.BAS.NAV_2.2.1	State the general principles of reference systems	1	Geoid, reference ellipsoids, WGS 84 Latitude and longitude, undulation
ATSEP.BAS.NAV_2.2.2	Explain why a global reference system is required for aviation	2	-

https://www.easa.europa.eu/en/downloads/120929/en

GNSS simulatsioonid Lennuakadeemias

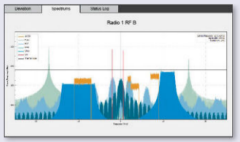
Technical Specifications

GSG-8 Key Features

- All-in-view satellites simulation
- 1000Hz simulation iteration rate
- Low-latency HIL
- Live sky time synchronization
- On-the-fly scenario reconfiguration
- 6 Degrees of Freedom (DoF) receiver trajectories
- Flexible licensing
- In-field upgradability
- High-end performance (precision, resolution, ultra-high dynamic motion)
- Simulate hundreds of satellites in real time, using off-the-shelf graphics cards (GPU)
- Multi-vehicle simulation
- Comprehensive and intuitive API (Python, C# and C++ open source client)
- Scalable and highly flexible architecture using software-defined radios
- IQ file generation and playback

Advanced Jamming and Spoofing

- In-band and out-of-band jamming signals with no additional hardware
- Spoofing for all licensed GNSS signals
- Set power level, interference signal type, spoofing signals, location, antenna pattern and trajectory for each transmitter
- Complete jamming and spoofing control through the Skydel GUI and/or API
- GSG-8 calculates the necessary parameters based on transmitter location: Power levels, distance and time-of-flight



JAMMER SPECTRUM IN SKYDEL GUI

Signal Propagation and Errors Simulation

- Multipath
- Additive pseudorange ramps
- Satellite clock error modification
- Navigation message errors
- Multiple ionospheric/tropospheric models
- Antenna pattern models
- Relativistic effects
- Pseudorange/ephemeris errors

Signals

- GPS: L1 C/A, L1 P and L1C, L2 C and L2 P, L5
- GLONASS: L1 C/A, L2 C
- Galileo: E1, E5a, E5b, E5 AltBOC, E6
- BeiDou: B1I, B2I, B3I, B1C, B2a
- NavIC: L5
- QZSS: L1 C/A, L1 C and L1S, L2C, L5
- SBAS: WAAS,EGNOS,MSAS,GAGAN,SDCM.
- Custom signals

Signal Specifications

- Pseudorange Accuracy - ± 0.001m
- Pseudorange Rate - ± 0.001m/s
- Inter-channel bias - zero
- Spurious transmission < -45 dBc
- Harmonics < -45 dBc
- Phase noise: < 0.003 rad RMS
- Signal Dynamics
  - Maximum relative velocity: 1,500,000 m/s
  - Maximum relative acceleration: No limits
  - Maximum relative jerk: No limits
- 1000 Hz iteration rate
- RF Signal Level (GNSS)
  - Power Accuracy: +/- 0.5dB
  - Output reference power:
  - -80 to -50 dBm, 0.1dB resolution
  - Dynamic range (relative to reference power):
  - -45 to +30 dB
  - Total range: -125 to -20 dBm
- RF Signal Level (Jamming): +0 to +110 J/S (with signal
- (S) reference power at -130dBm)

Skydel Plugins

- SKY-PLG-RTK – RTCM message generation via virtual basestation.

Eesti Lennuakadeemia
Estonian Aviation Academy

Aitäh!

Küsimused?