



National Aviation University of Ukraine
Air Navigation Systems Department

Main threats and solutions for positioning by navigational aids network

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Airplane on-board equipment for positioning

Global Navigation Satellite System
(GPS, GLONASS, GALILEO, BeiDou)

Inertial Navigation System
(IRS, AHRS)

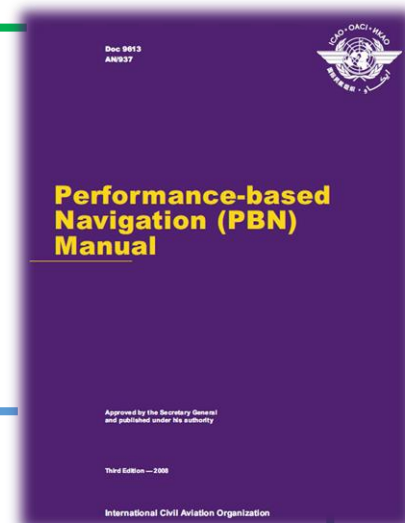
Position detection by pair of DME (DME/DME)

Position detection by pair of VOR and DME (VOR/DME)

Positioning by Navigational Aids in Flight Management System

Compatible
with PBN
(RNAV 1)

ICAO
DOC 9613

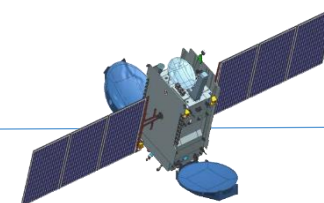
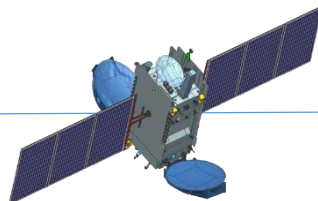
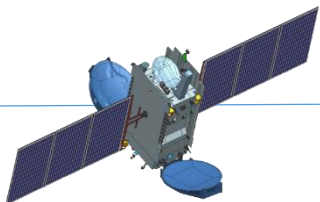


Errors of Global Navigation Satellite Systems

- large spatial variation in ionospheric delay
- **Interference from ground based radio equipment**
- **jamming of radio waves**
- Refraction from obstacles (multipath error)
- Geometric factor of the satellite segment



Treats in communication line of Global Navigation Satellite System



20180 km

Transmitter of satellite for L1 supports power in 21.9 W (13.4 dBW)
Satellite antenna gain for the worst case of user location supports 13.4 dBW
Power of navigation signal from satellite is above 26.8 dBW
Radio wave propagation in free space takes 184.4 dBW
Total atmospheric and polarization mismatch losses take 3.9 dBW
Finally, in user segment we are getting navigation signals with power level of **-158 dBW**

The power level of these signals is too small and may be easily affected by intensive noise or interference in communication channel.



Improper functioning equipment can be a source of noise that can affect communication line of navigation system by means of **interference**

Jamming



Interference and Jamming is a big problem

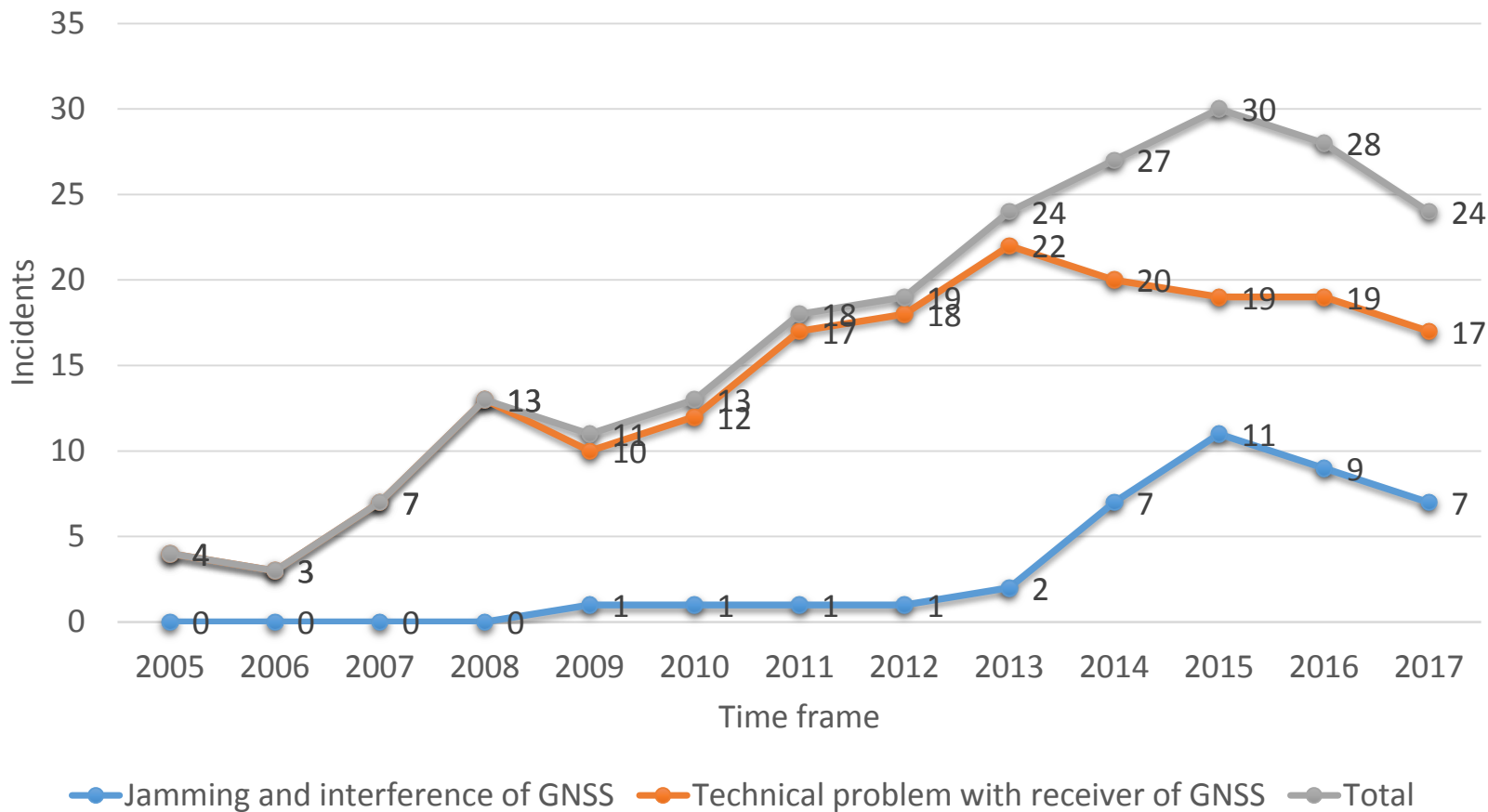
Not properly functioning electrical equipment made GPS unusable in an area of about 3 km around Moss Landing Harbor in California in 2001. A DGPS reference station in the vicinity was also affected by the interference.



In January 2007 many electronic systems suddenly stopped functioning in San Diego. Air traffic controllers and controllers of the maritime traffic service detected that their systems did not function properly. Although the apparent interference lasted for only two hours it took three days to find out that a communication exercise of the United States Navy was the cause. The exercise was intended to jam communication systems but unintentionally also jammed GPS signals.



Statistics of GNSS malfunction



NASA, ASRS



Unintentional jamming

GP-50



Platon



Scorpion - GPS



G-55



USB





Alternative to GNSS positioning tech

Global Navigation Satellite System
(GPS, GLONASS, GALILEO, BeiDou)

Inertial Navigation System
(IRS, AHRS)

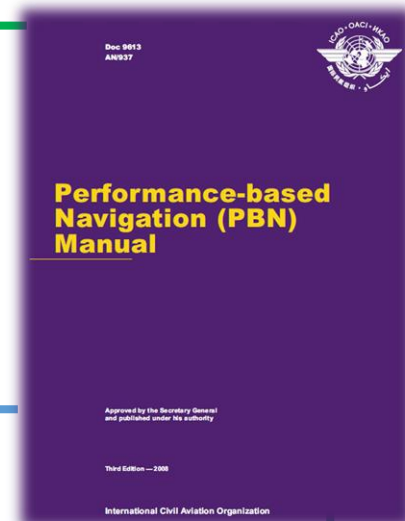
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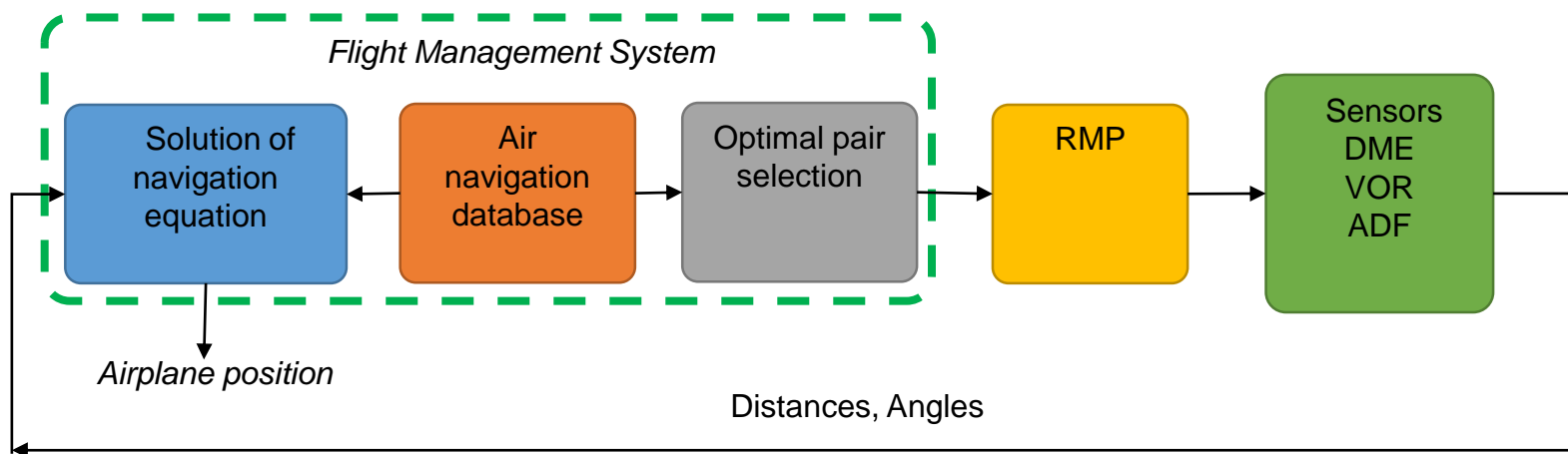
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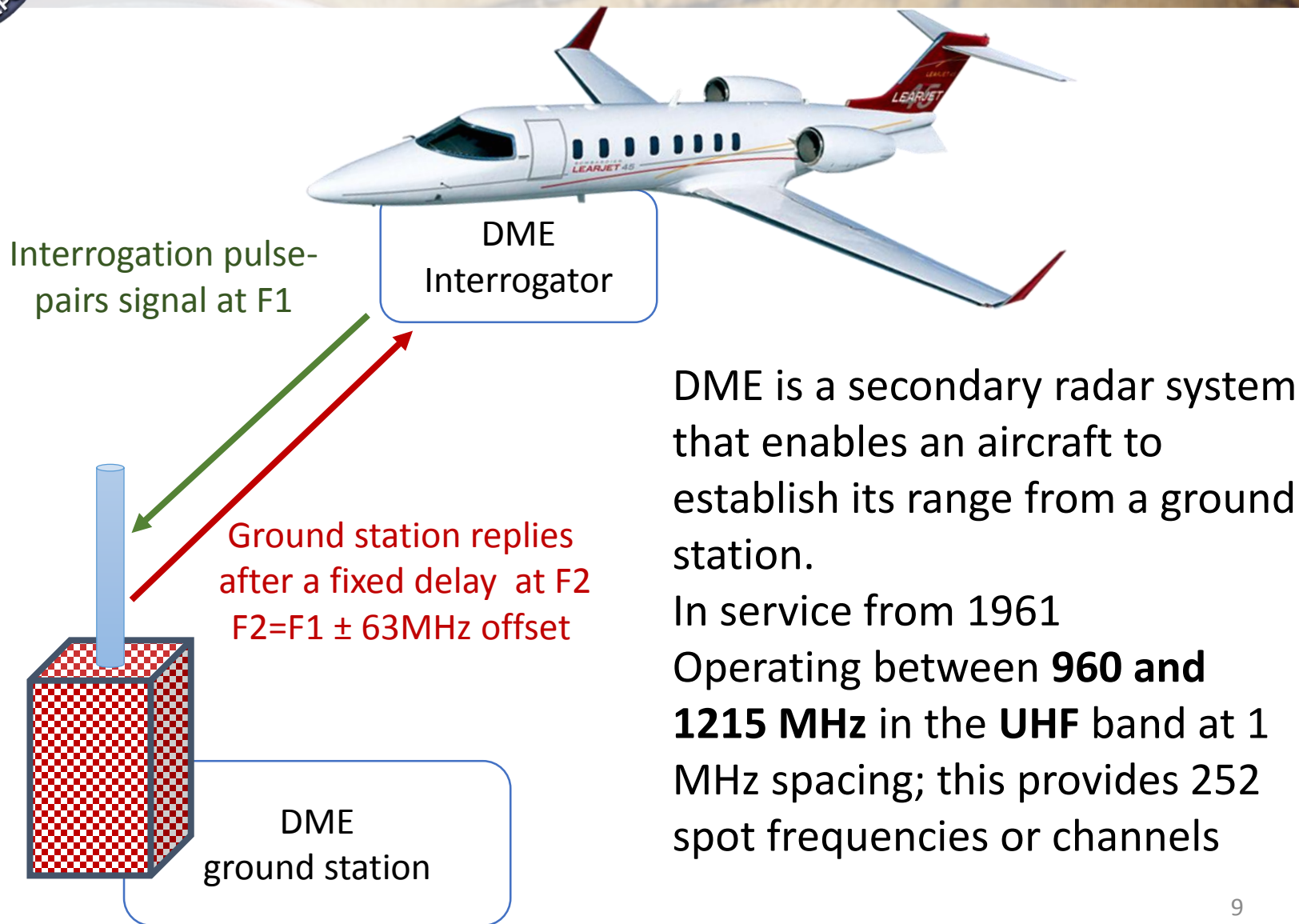


A cycle of positioning by navigational aids





Distance measuring equipment, DME

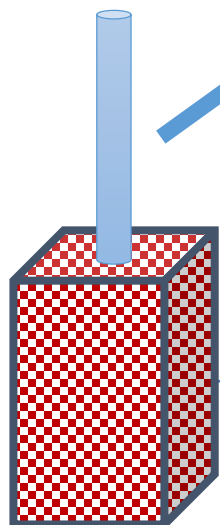
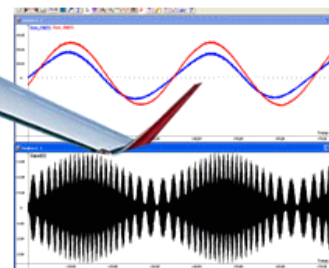




VHF Omni-directional Range (VOR)

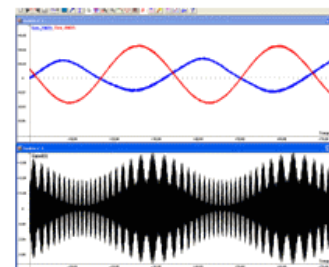
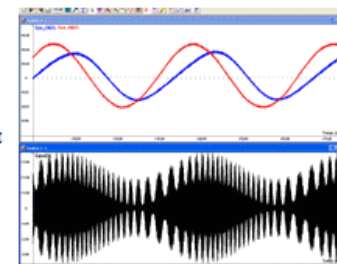
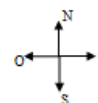
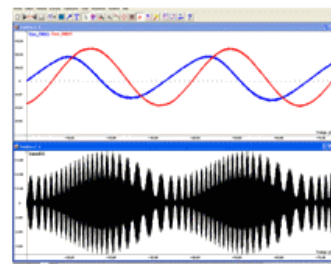


FM is a 30 Hz frequency modulated omni-directional, **reference signal** which produces constant phase regardless of a receiver's bearing from the VOR



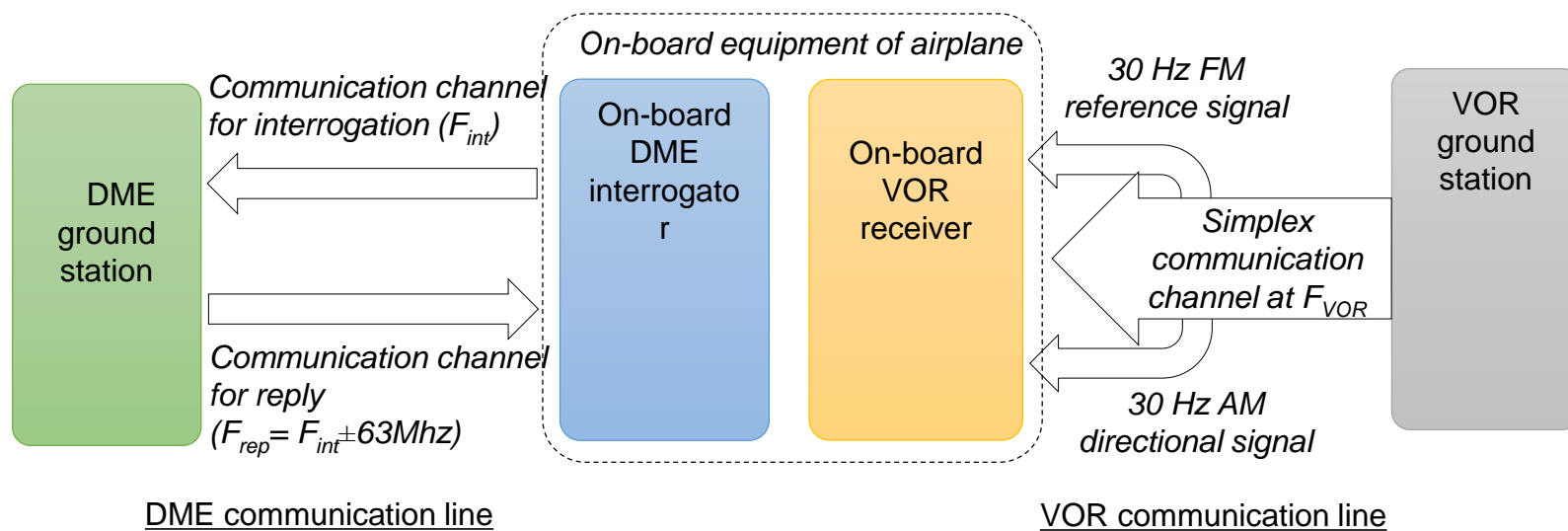
AM is a 30 Hz amplitude modulated **variable phase (directional) signal** created by the rotating transmission pattern

VOR
ground station





Communication lines of navigational aids





Threats of positioning by navigational aids

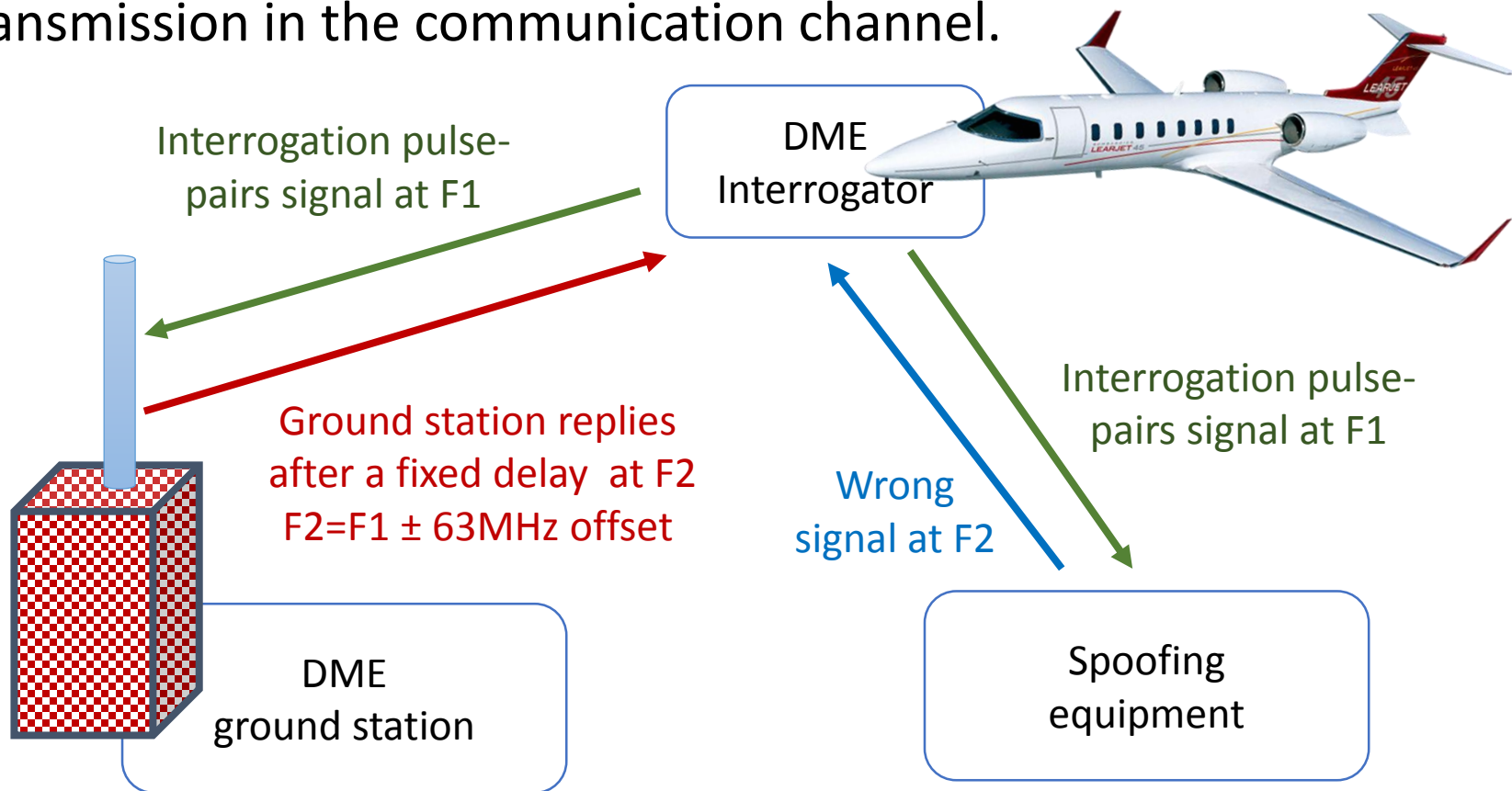
1. Radio Frequency Interference
2. Jamming and spoofing of navigation functionality
3. Air navigation Data Base error
4. Threats of positioning related to availability area



Spoofing of navigation functionality

VOR communication line is a simplex that makes this navigational aid sustainable for spoofing acts.

DME is not protected according to unencrypted data transmission in the communication channel.





Spoofing detection

- Simple comparison of predicted distance and measured is the solution.
- Big difference between them indicates abnormal data and should initiate a new measurement cycle or be a cause for changing DME frequency.
- Dead reckoning method, linear extrapolation, regression models.
- An adaptive pattern array is a possible solution in case of detected direction of jamming/spoofing source of a radio signal that can be implemented in on-board equipment of DME interrogator and VOR receiver.



Air navigation Data Base error

- Algorithms of airplane position estimation are grounded on solving a system of linear or nonlinear navigation equation with exactly known navigational aids location.
- FMS needs actual channel of DME or VOR, coordinates and other technical data
- air navigation database in FMS memory.
- The outdated database may cause a serious threat for the whole positioning process.
- Usage of not valid data may cause overloading of navigational aid pair selection process, due to multiple interrogations of unused channels and dismissing actual operation ground facility.
- database updating helps to keep navigational aids data valid to support worldwide navigation.



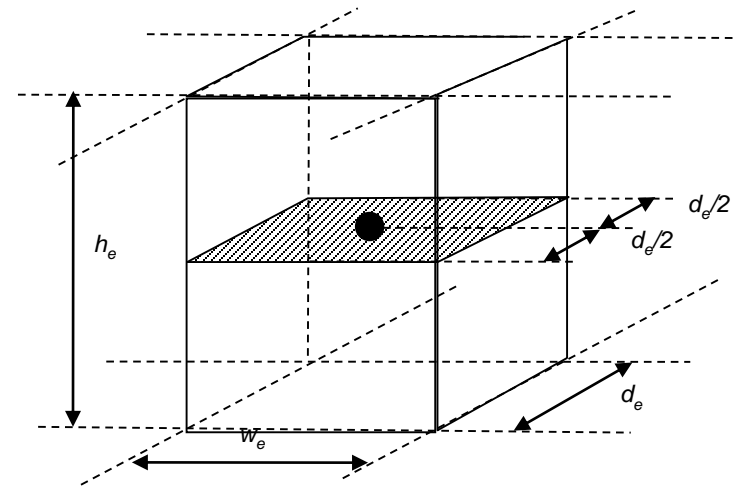
Verification

cell size :

$d_e=6.77$ km, $w_e=4.97$ km, $h_e=177$ m.

Horizontal plane includes 25354 elementary cells with 100 altitude layers within Ukrainian airspace.

Total area of Ukrainian territory is 8.5×10^5 km² and 1.5×10^7 km³ of airspace volume.

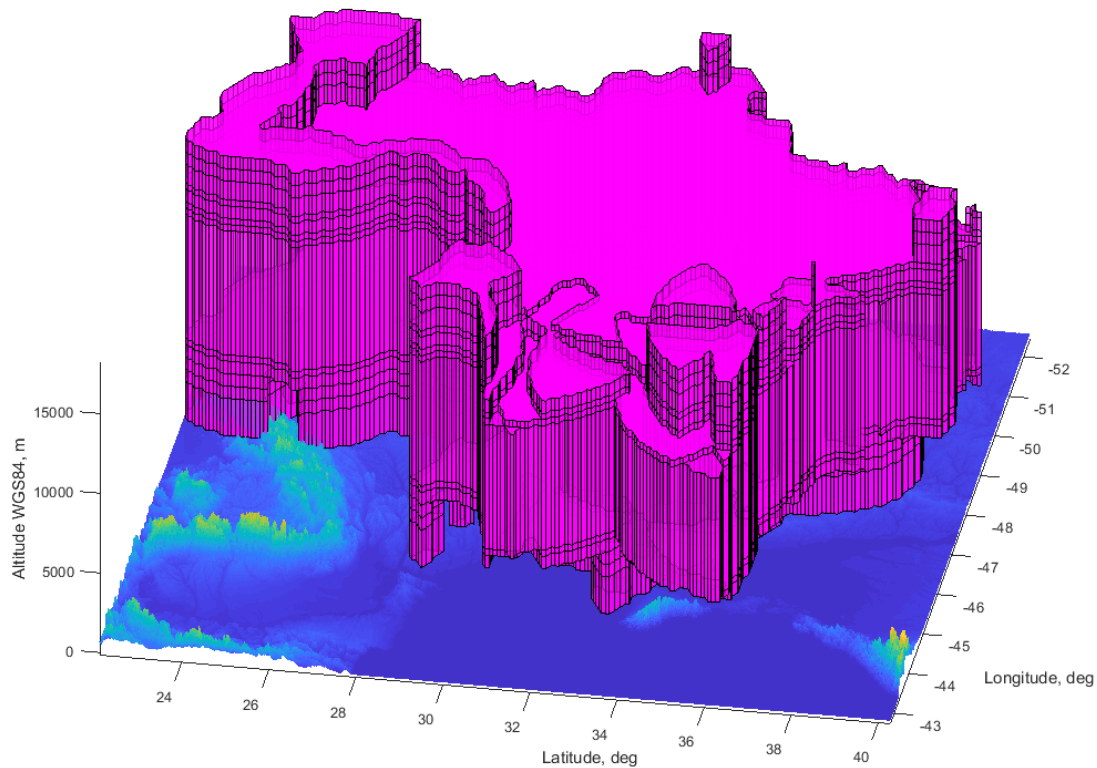


Results of performance analysis of Ukrainian airspace according to area navigation specifications for different positioning approaches in percentage of space volume

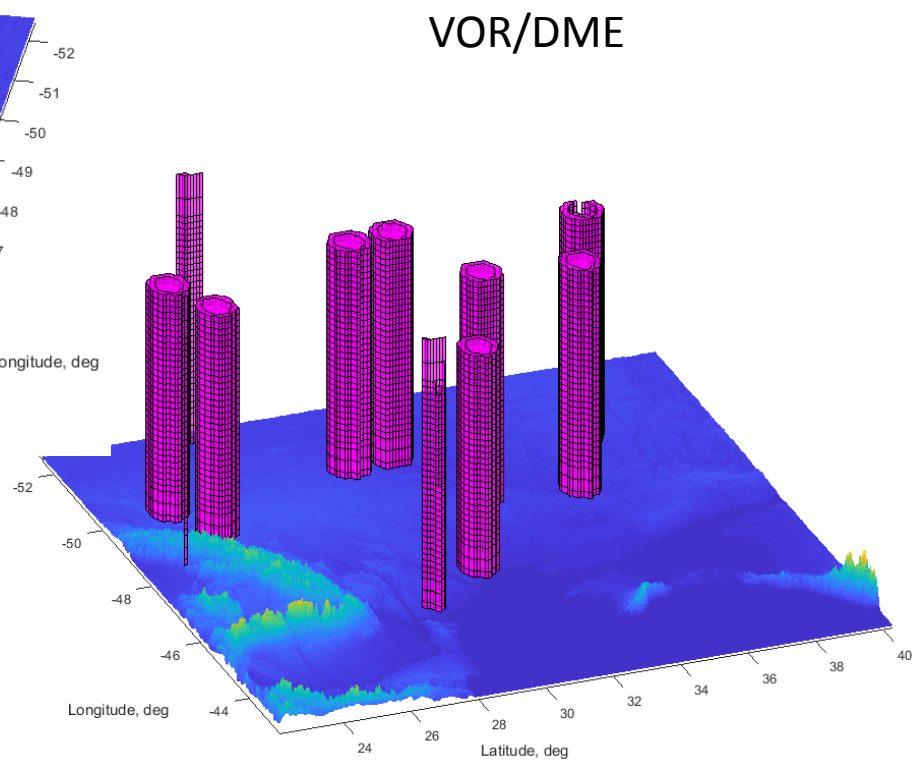
RNAV	DME/DME	VOR/DME	VOR/VOR
RNAV 1	74.6%	4.58%	0%
RNAV 2	74.78%	26.64%	0.78%
RNAV 5	74.78%	70.38%	32.5%



Verification RNAV 1

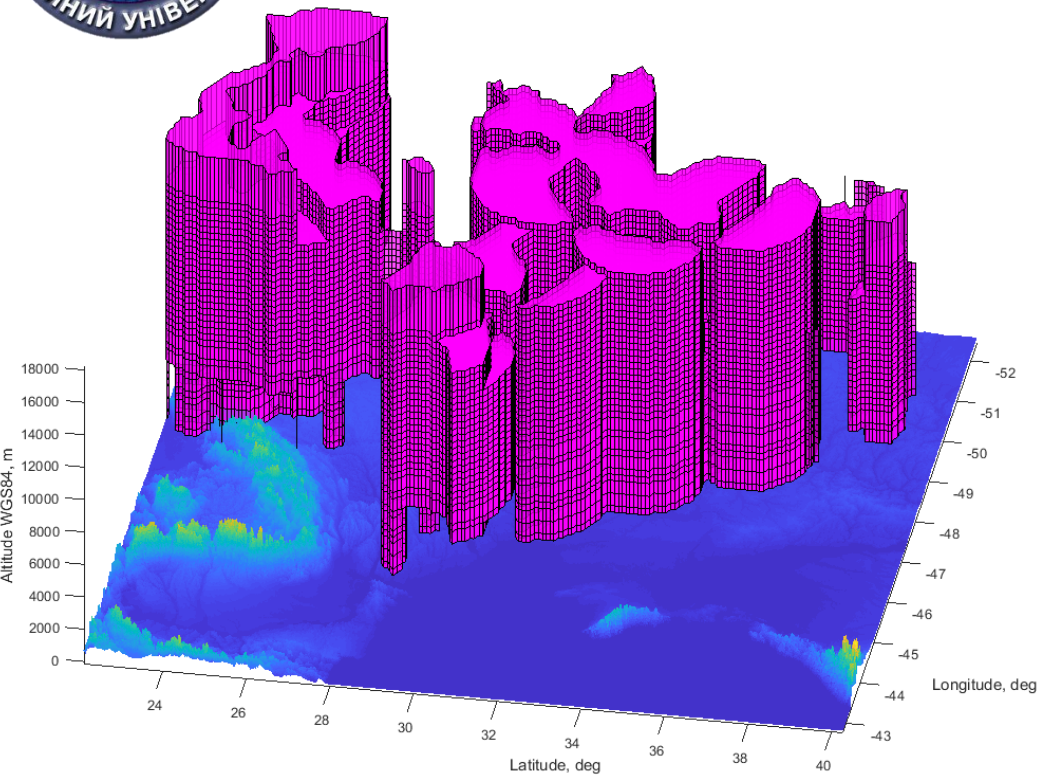


DME/DME

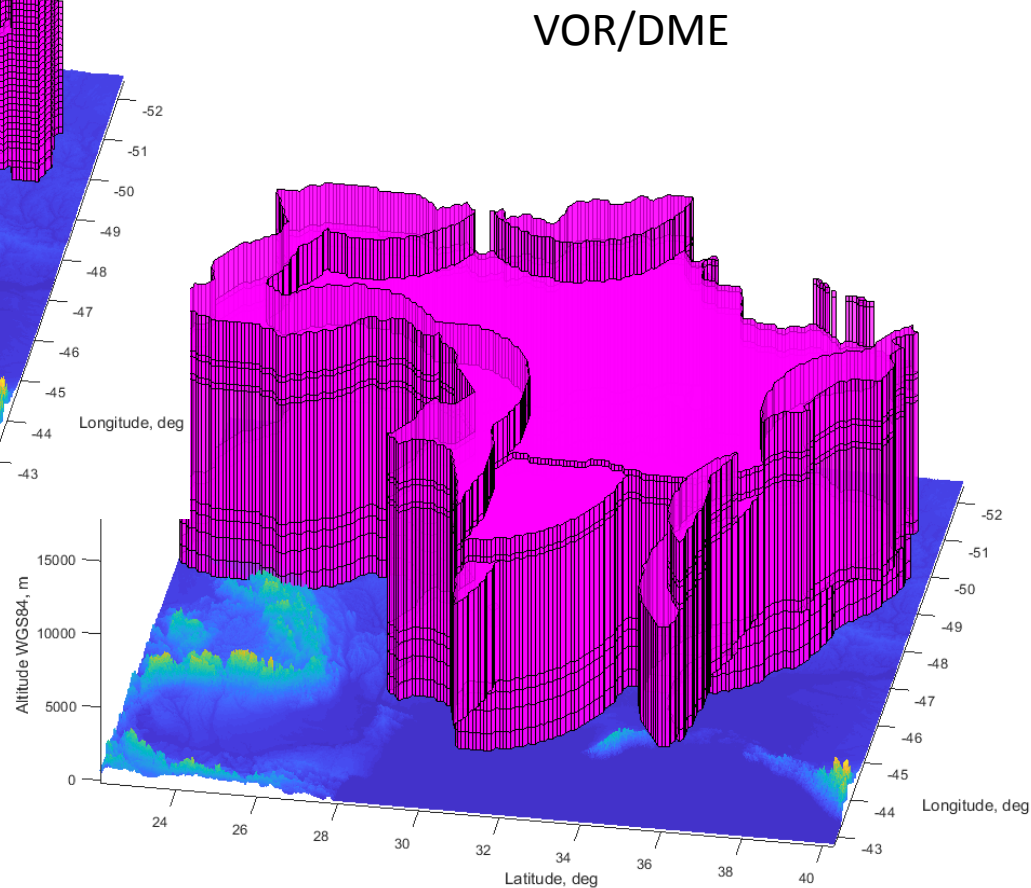




Verification RNAV 5



VOR/VOR



VOR/DME



Conclusions

- The main threats for positioning are analyzed.
- The problems of GNSS: interference and unintentional jamming are discussed.
- The main threats of positioning by alternative positioning equipment is represented at first time.
- Security of navigational aids are discussed from communication channel point of view.
- Radio Frequency Interference, Jamming and spoofing of navigation functionality, Air navigation Data Base error, Threats of positioning related to availability area.

Contacts

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