Simulation Tool to Analyze RFI Counteraction Algorithms in Various Satellite Scenarios

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[3] European Space Agency

Agenda

- Harp Technologies Ltd
- Interference Detection and Cancellation (IDS) Simulator
- RFI Algorithm Assessments with the Simulator
  - Detection
  - Isolation
  - Characterization
  - Classification
  - Localization
- Conclusions

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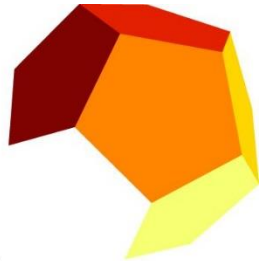
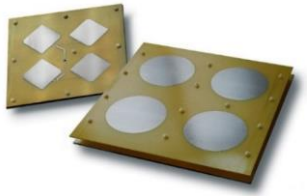
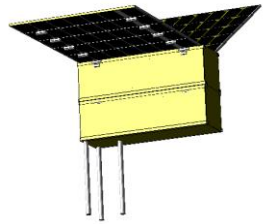
Harp Technologies Ltd

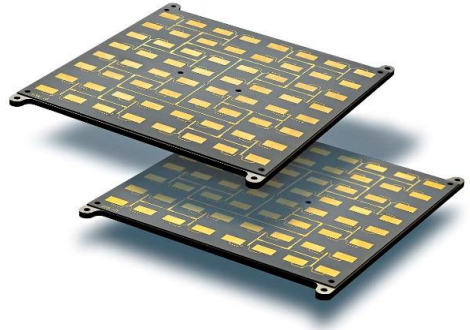
- Contract based R&D services in RF, micro- and millimetrewave technologies
- An SME established in 2007, located in Espoo, Finland
- Studies, components, sub-systems, end-to-end systems
- 13 employees (recruit open)

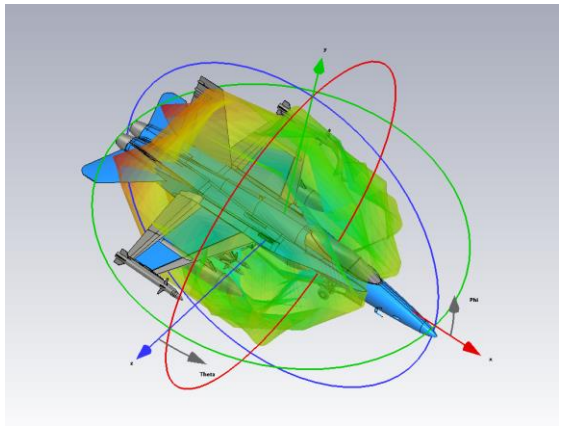


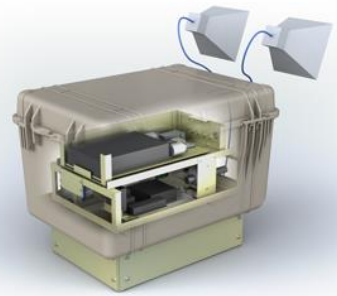
R&D examples

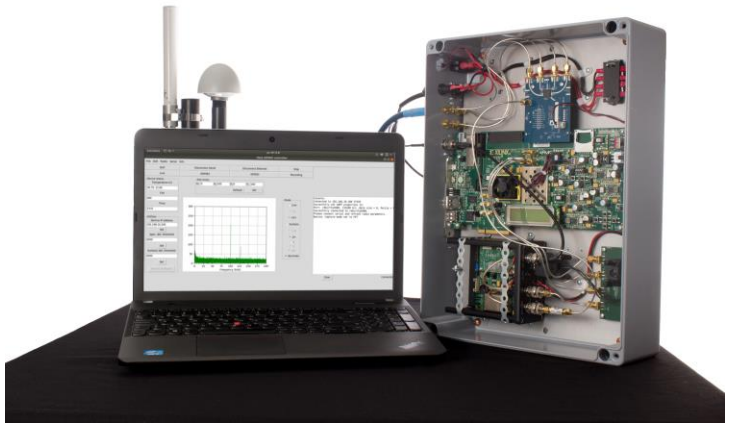












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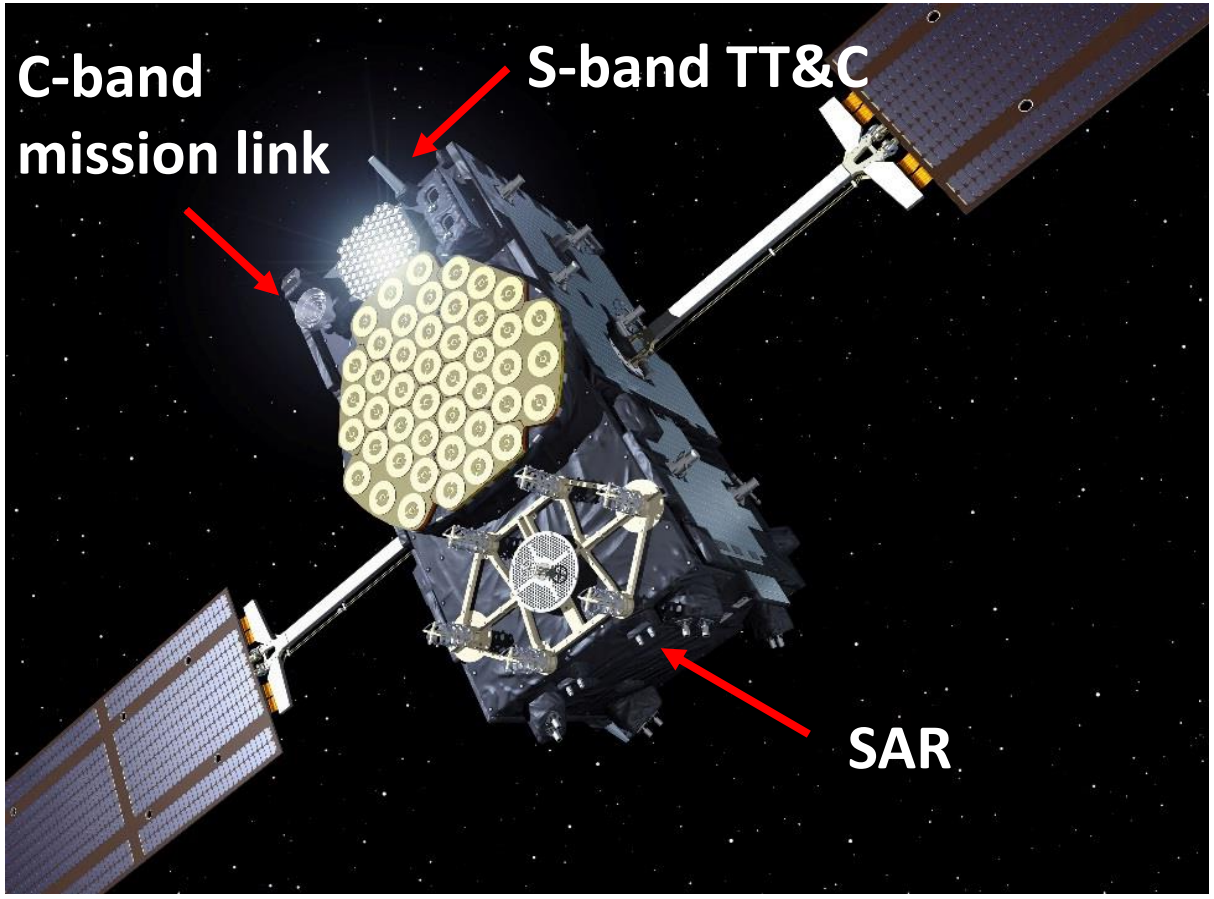
Motivation of the Activity

- RFIs are all over. They jeopardize science measurements and critical services such as GNSS.
- Specific considerations for Galileo **uplink** operations:
  - UHF-receiver for SAR service
  - S-band link for TT&C
  - C-band mission link
- RFI can be fight in many ways: detection, isolation, characterization and classificaiton, localization (DISCL).

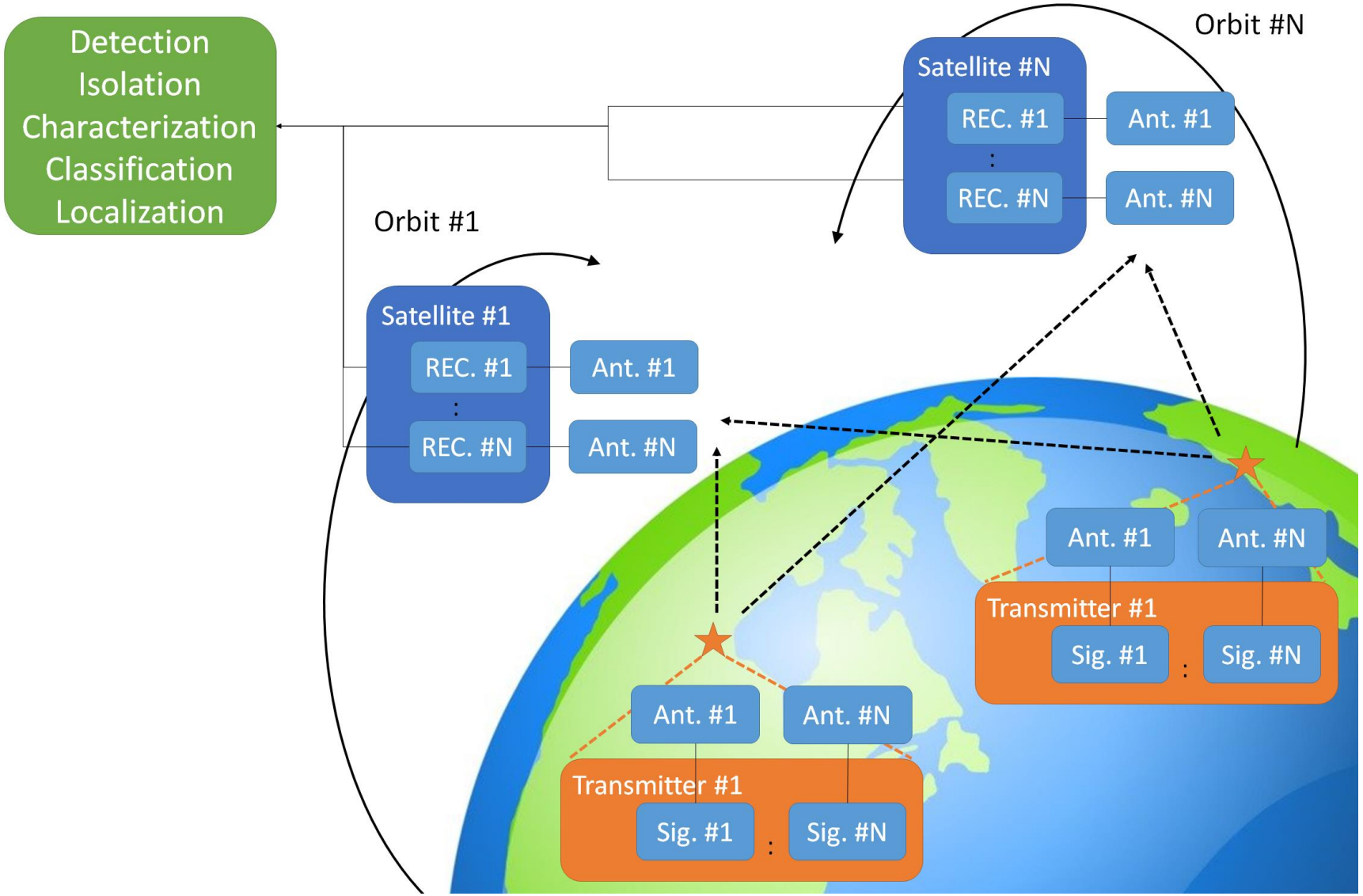


Study Goals of the Activity

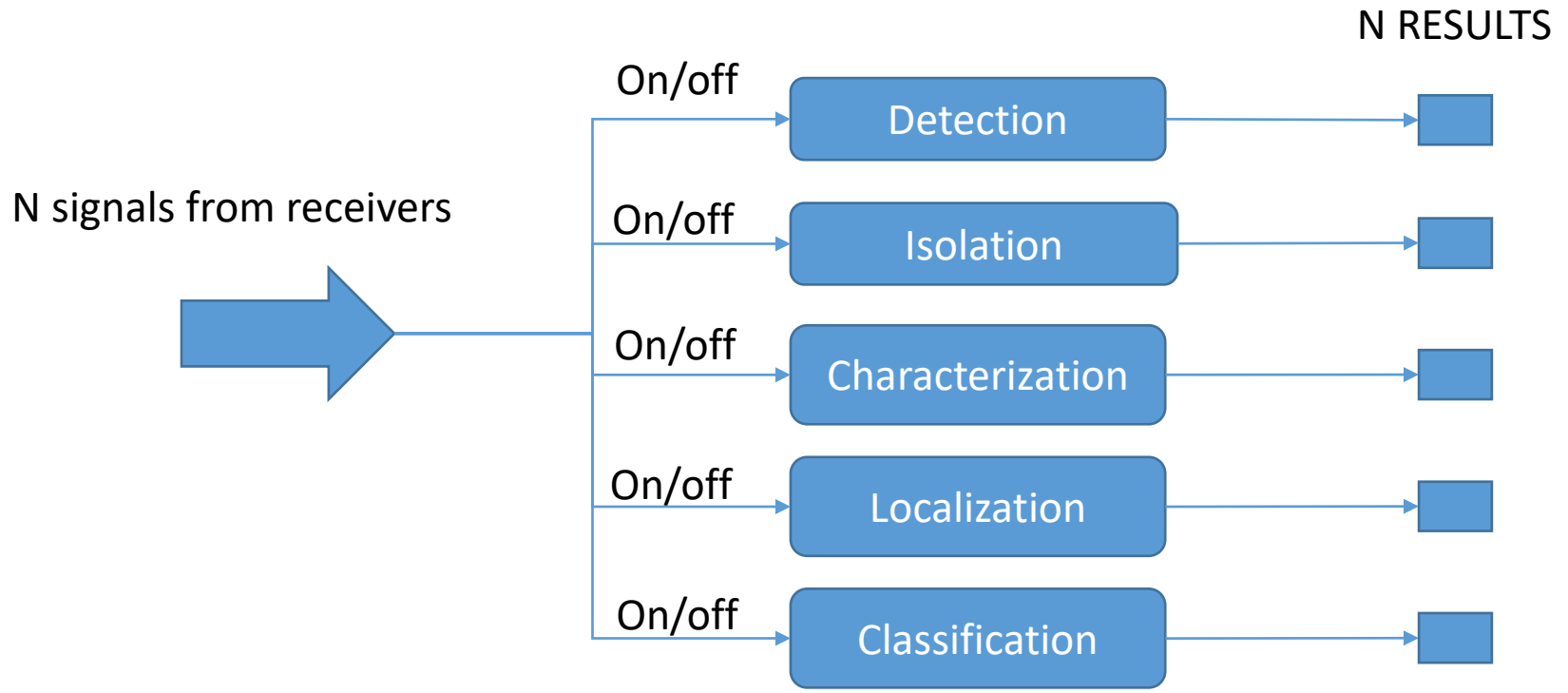
1) To **study the performance** of selected RFI detection, isolation, classification and characterization and localization techniques against of RFI signals

2) To **develop an End-to-End software simulator tool** for the simulation-based performance assessment of the above-mentioned techniques

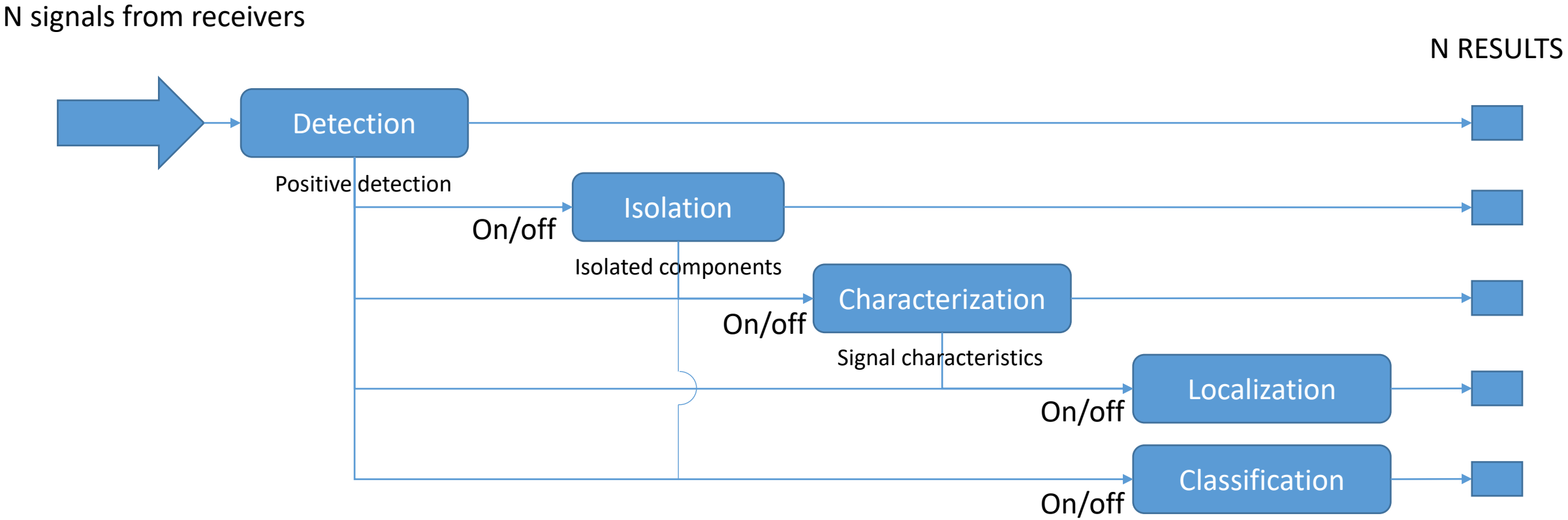
IDS Simulator – Overall Setup



Independent Algorithm Analysis Scheme



Algorithm Triggering Scheme



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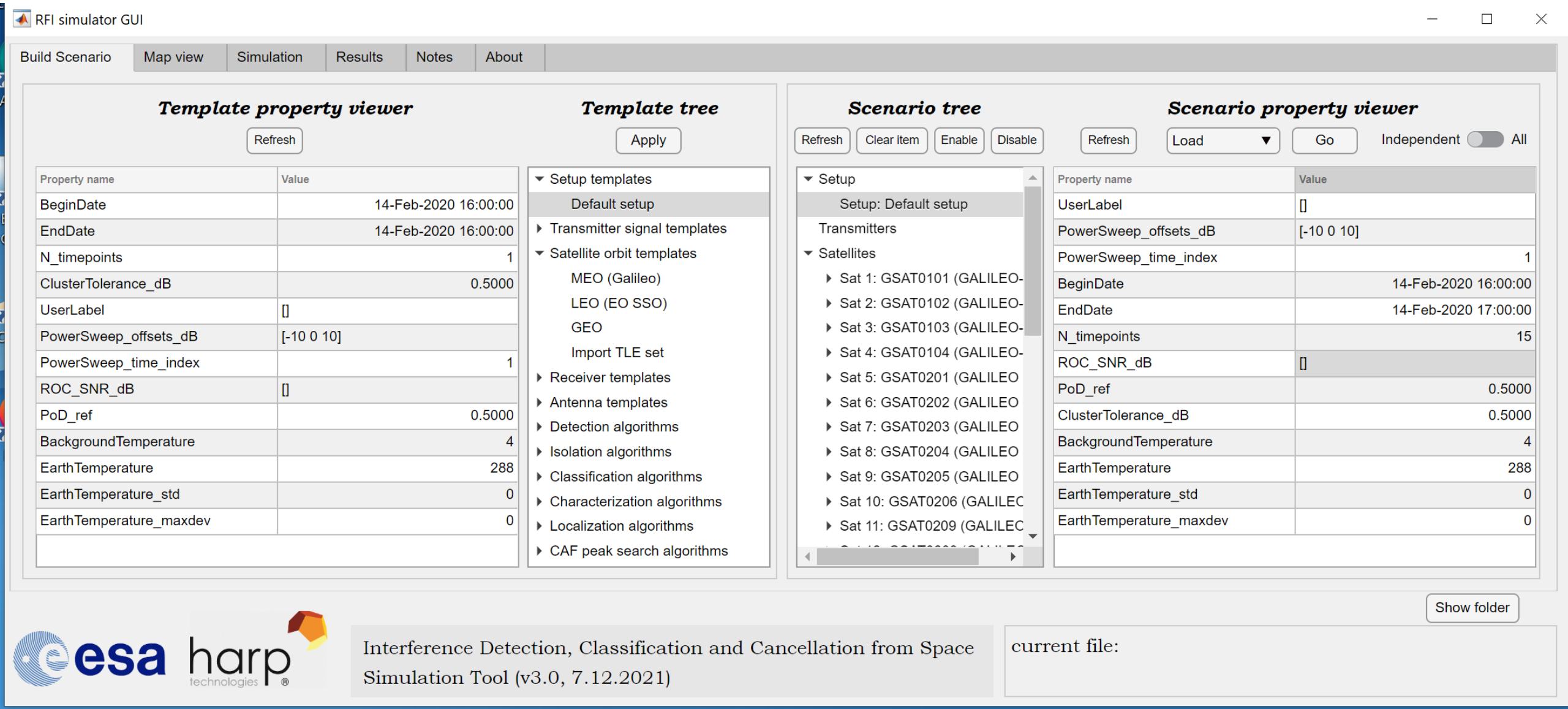

IDS Simulator – Algorithms

Algorithm class	Technique	
Detection	Energy detector	Gaussianity detector
	Power Spectral Density detector	Space-domain detector
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	Fourier Synchro-Squeezed Transform (FSST)	
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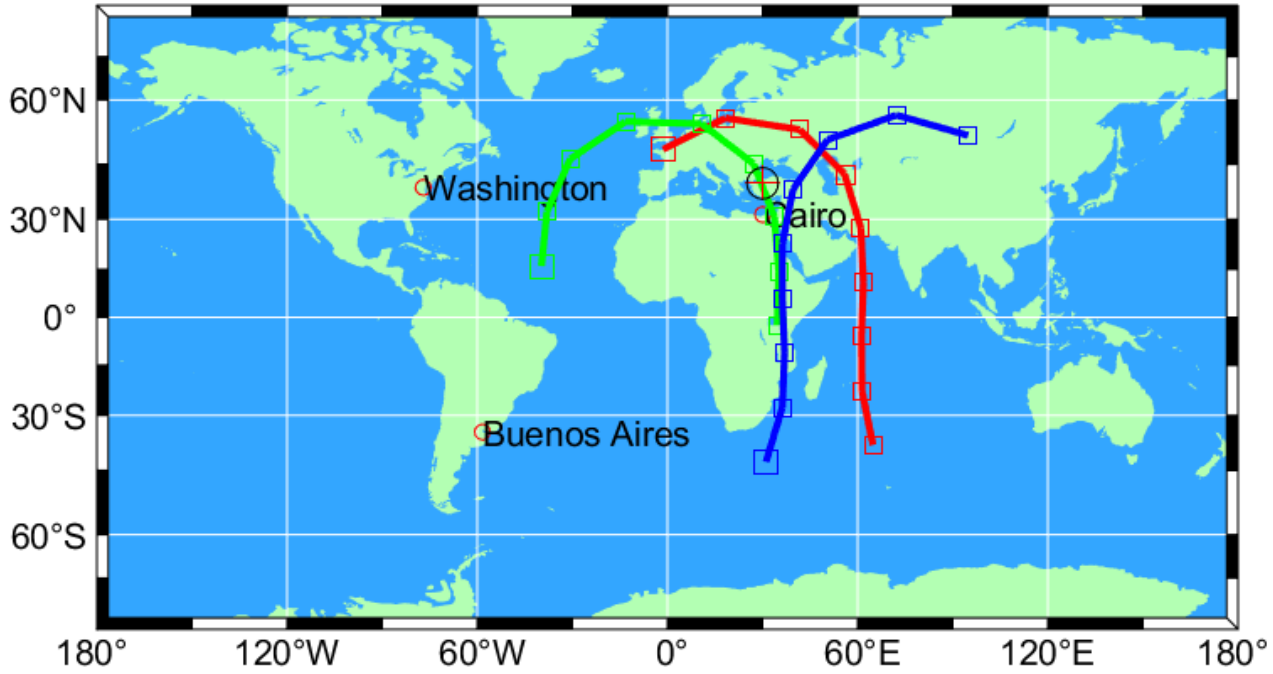
Algorithm Study Approach

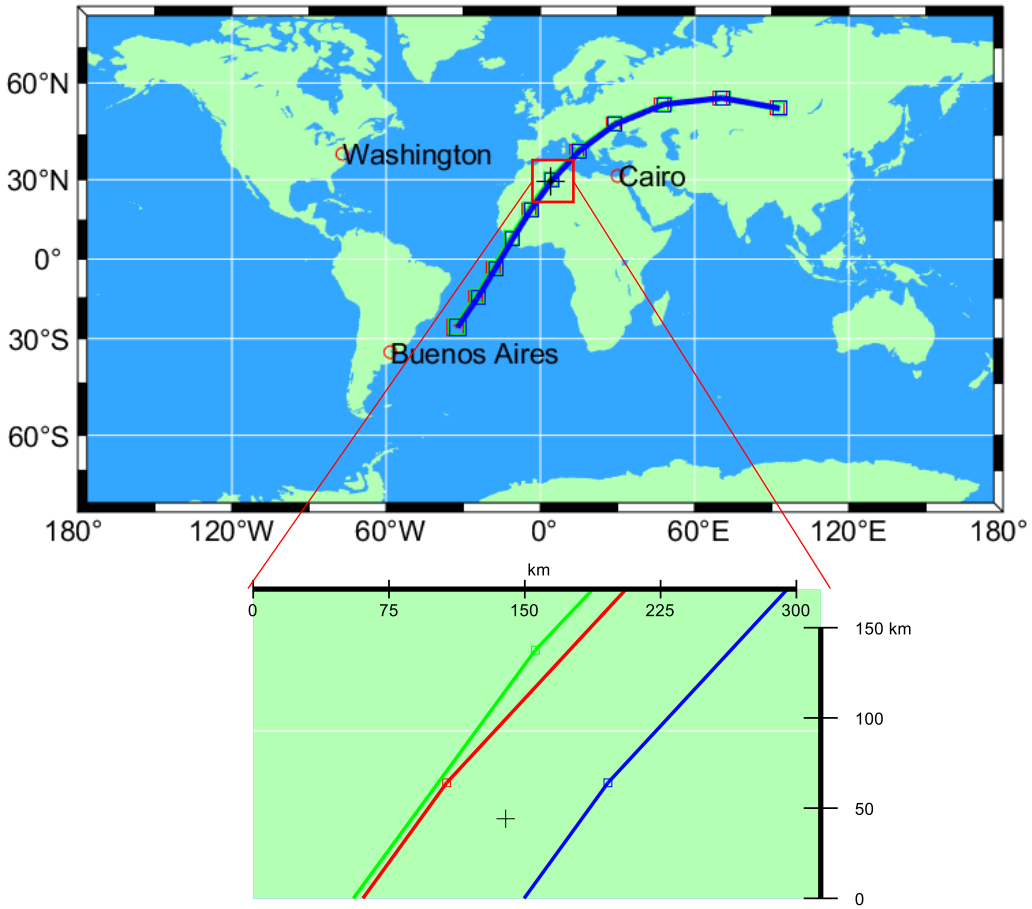
1. Algorithm description and study
   - Identification of relevant test scenario
   - Identification of relevant parameters to test
2. Algorithm implementation to IDS Simulator environment
3. Implementation verification
4. Performance testing and analysis
   - 7 reference RFI signals: DSSS BPSK, LFM, pulse, CW, NBN, WBN, FHSS
   - Galileo orbit and S-band receiver parameters
   - Other relevant scenarios: LEO satellite, tandem/triplet formations at LEO

Typical Scenarios

Three Galileo Satellites



LEO satellite triplet



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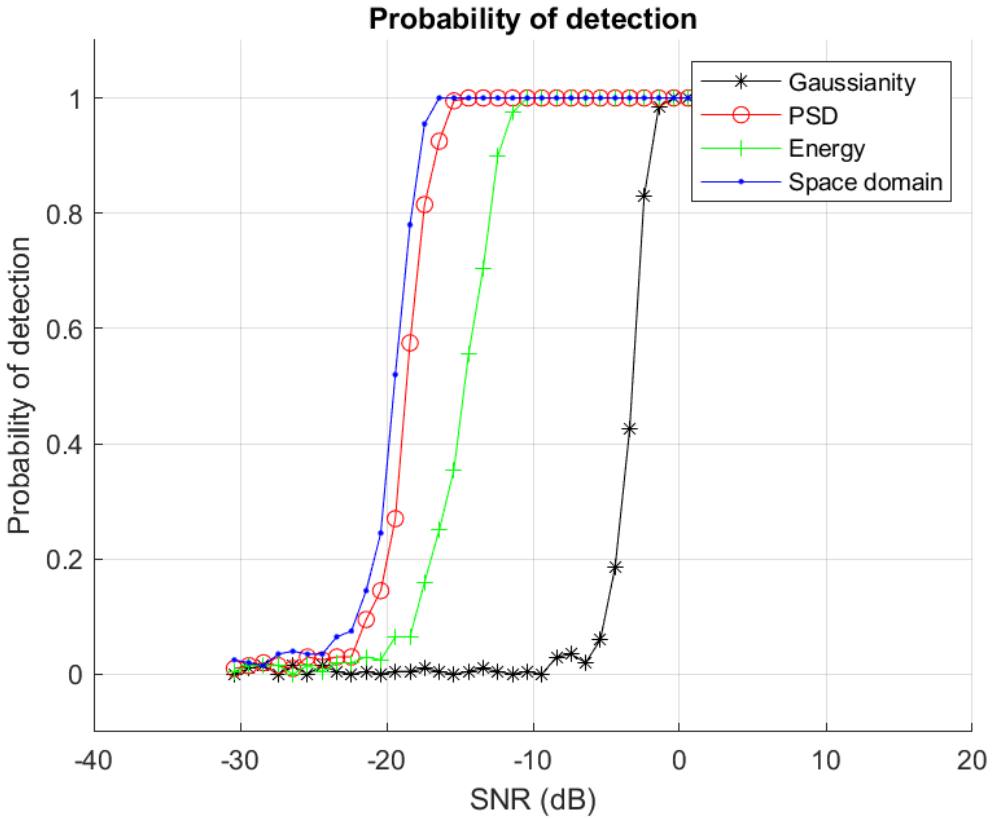
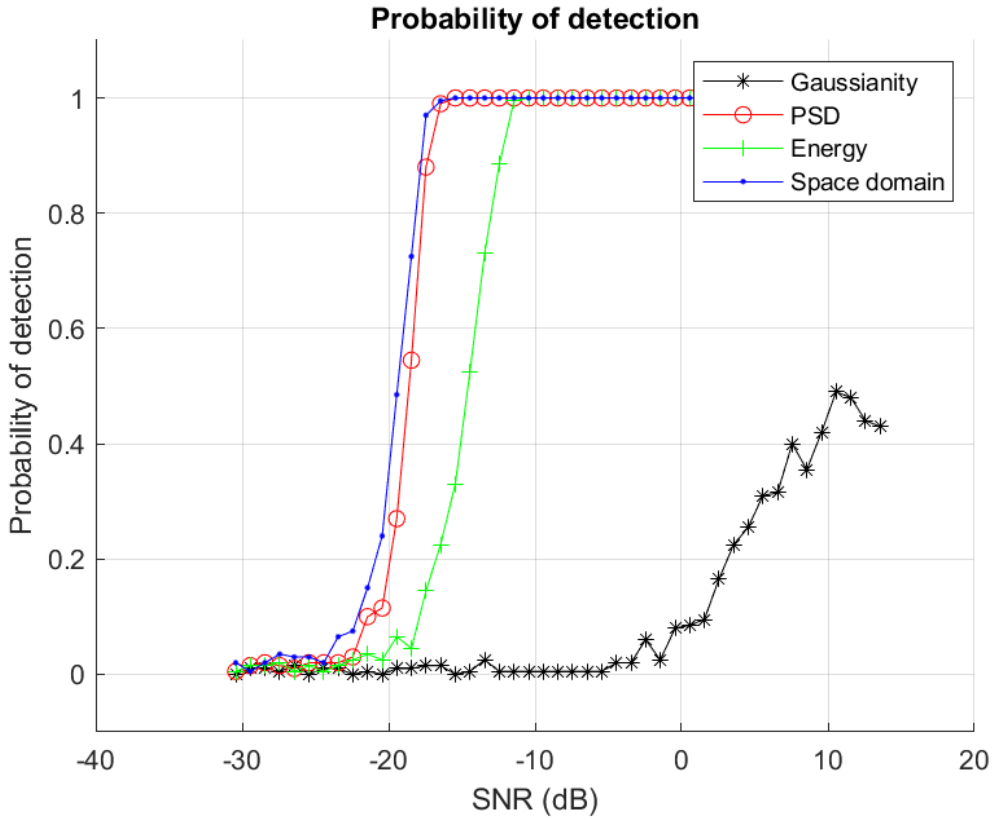
Detection, Example 1

- Probability of Detection (PoD) against two RFI signal types

RFI: DSS BPSK

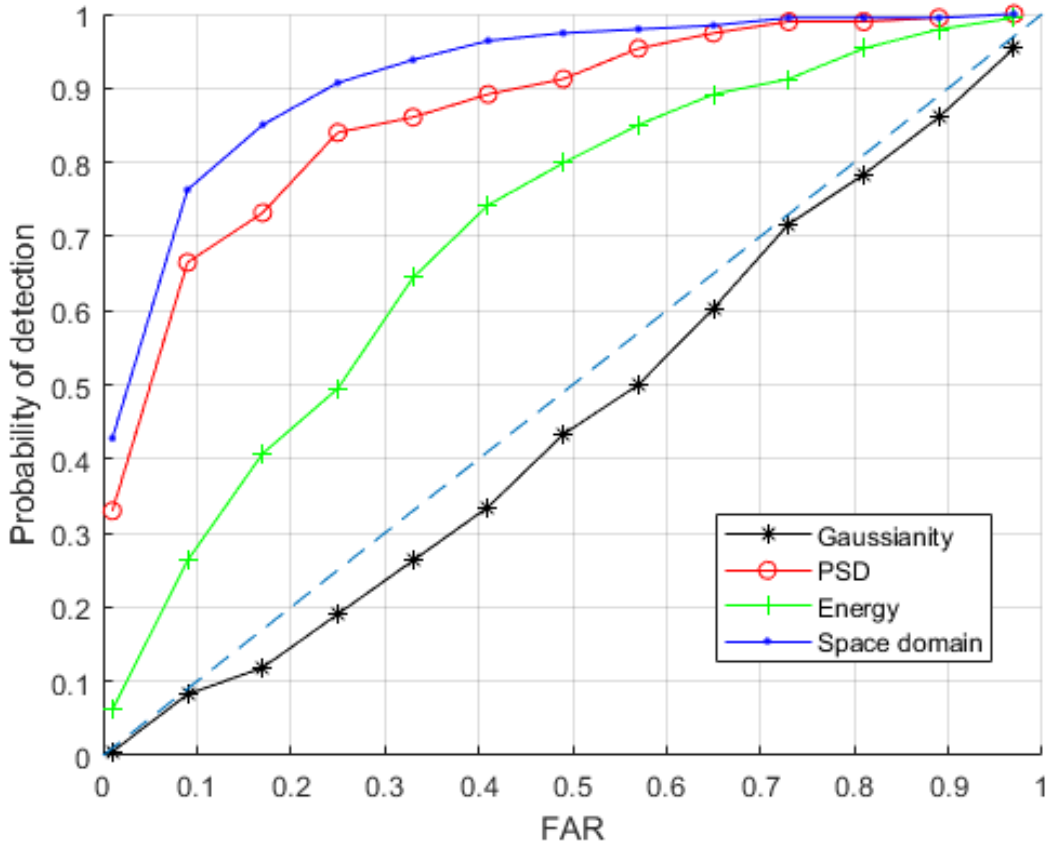


RFI: Narrow-band Noise



Detection, Example 2

- Receiver Operating Characteristics (ROC) analysis
- ROC analysis studies the PoD as a function of FAR in certain fixed SNR conditions.
- Left: ROC curvues for detection algorithms for DSSS BPSK signal at SNR = -20 dB



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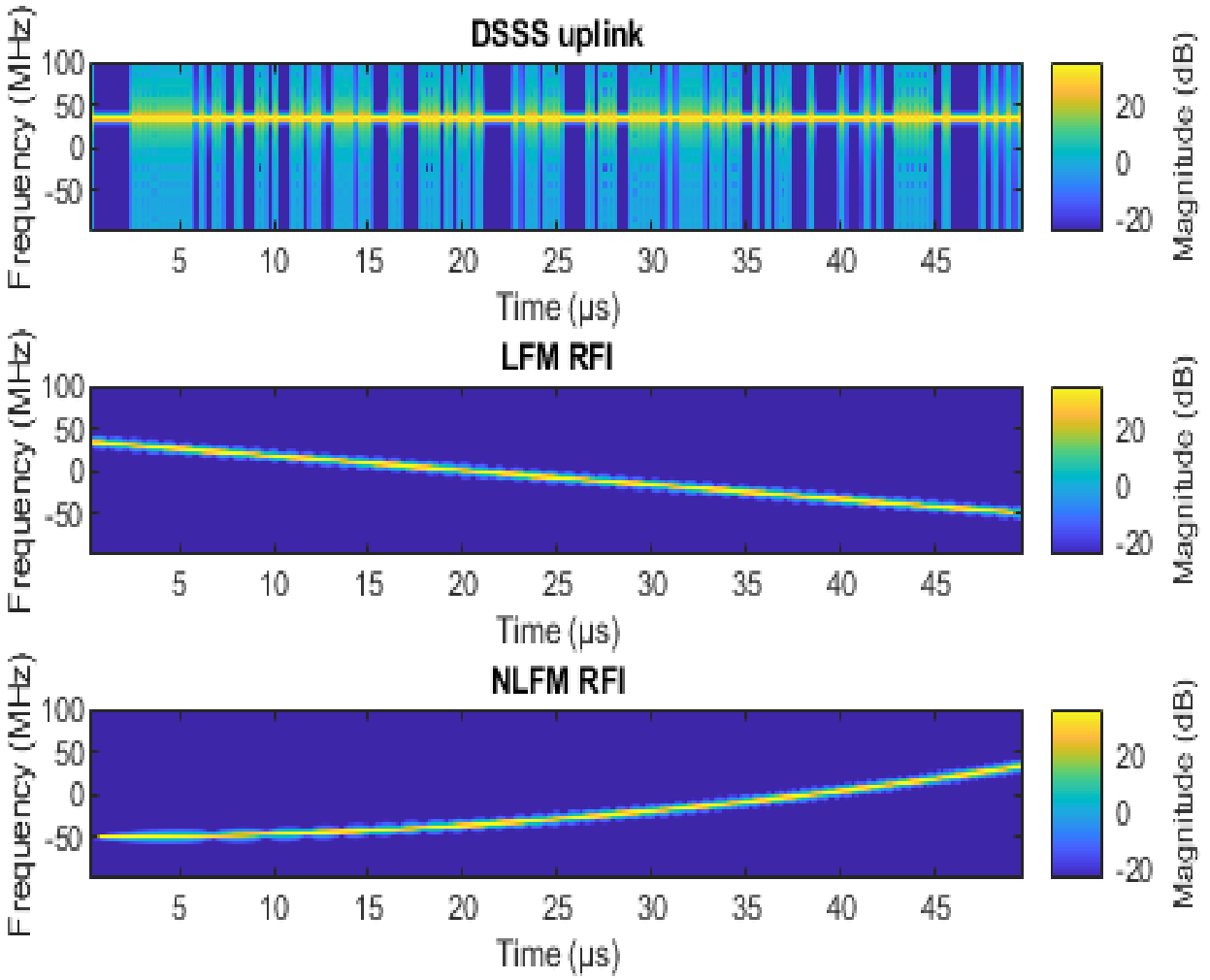
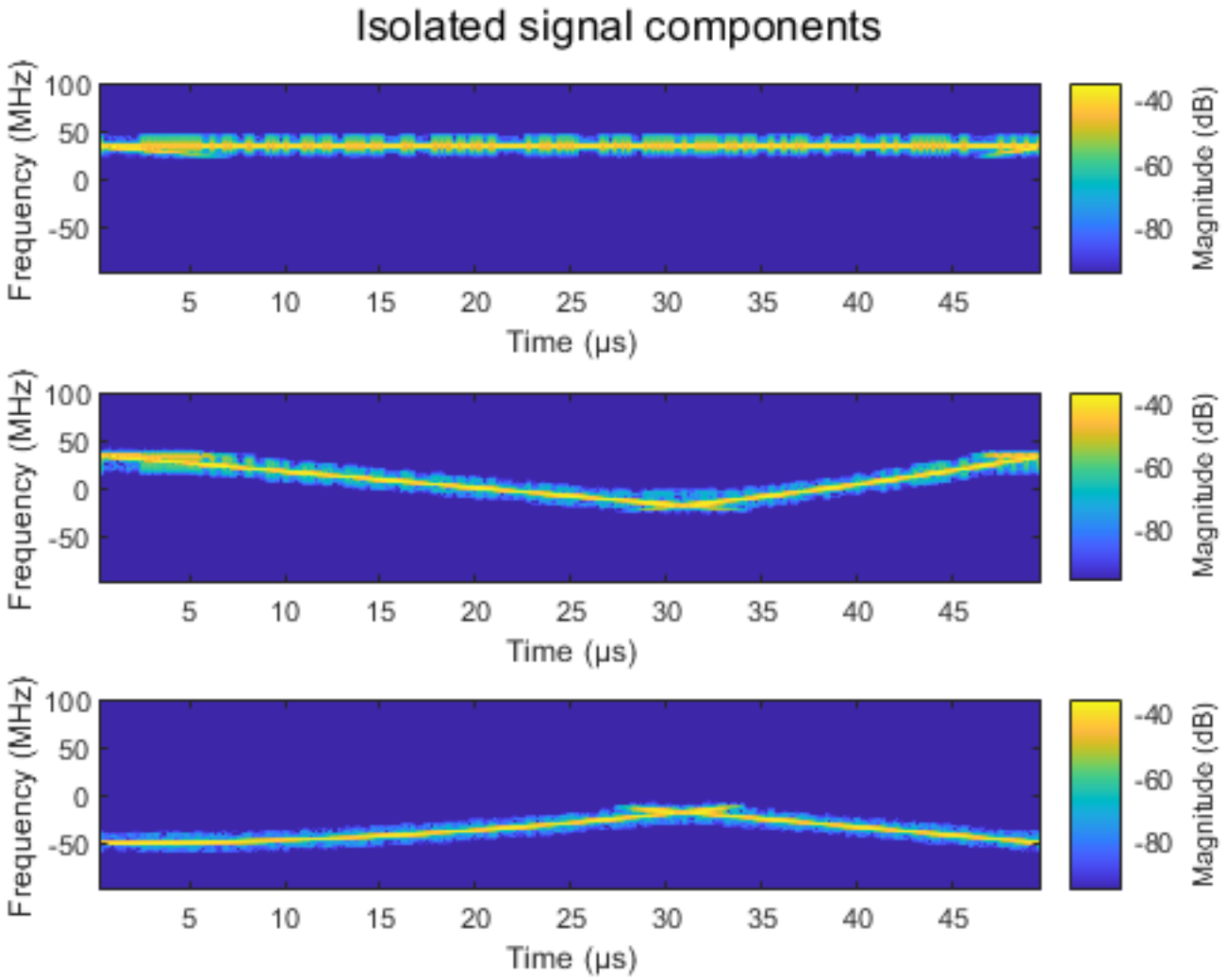
Isolation Example, 1

- We show the performance of all isolation algorithms
- Three signals are mixed and isolation applied.
- FOM for normalized error between signal input component and isolated component (0 – 1).
- Here: **input signals**



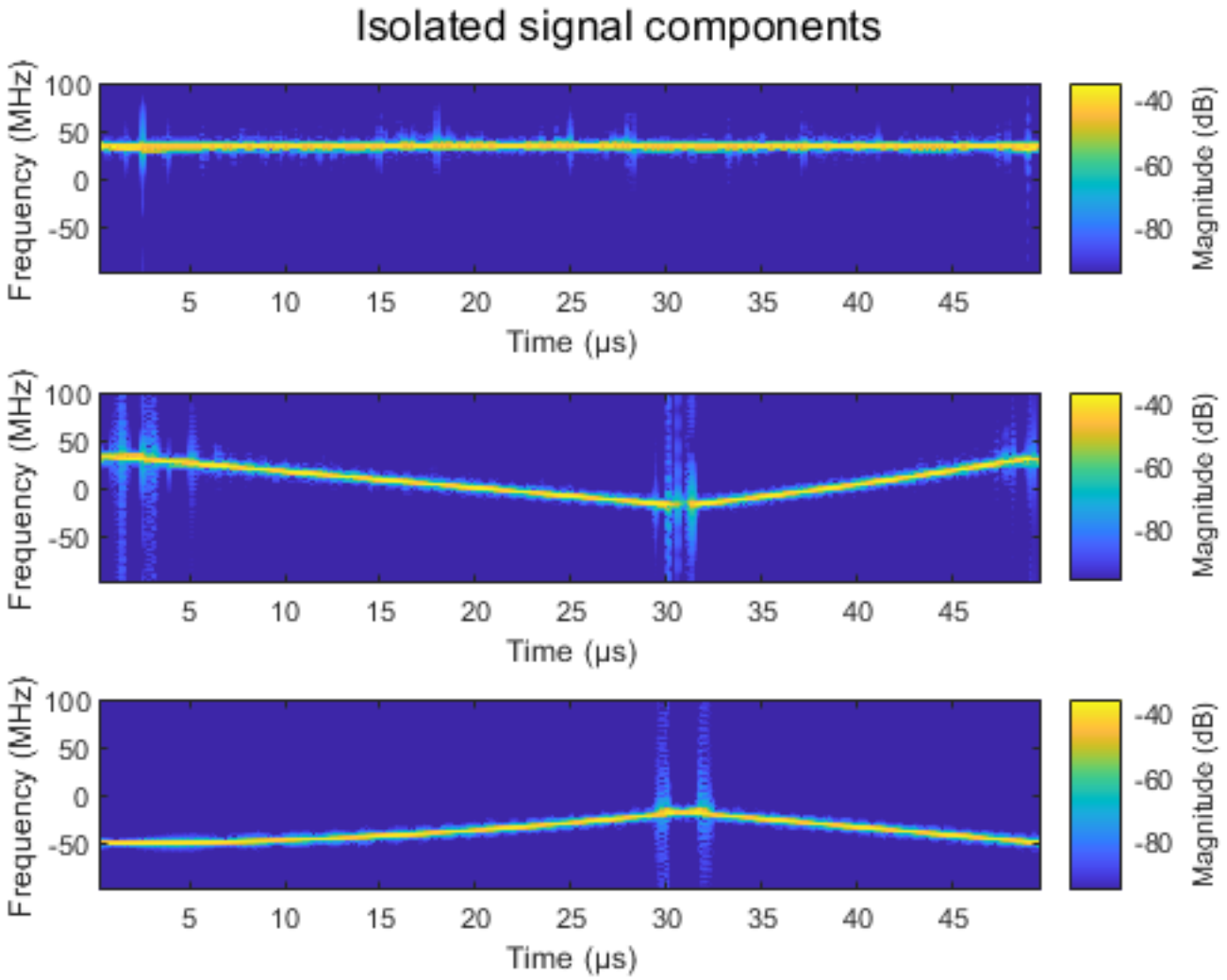
Isolation Example, 1

- Algorithm: **STFT**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.08
  - LFM: 0.41
  - NLFM: 0.37



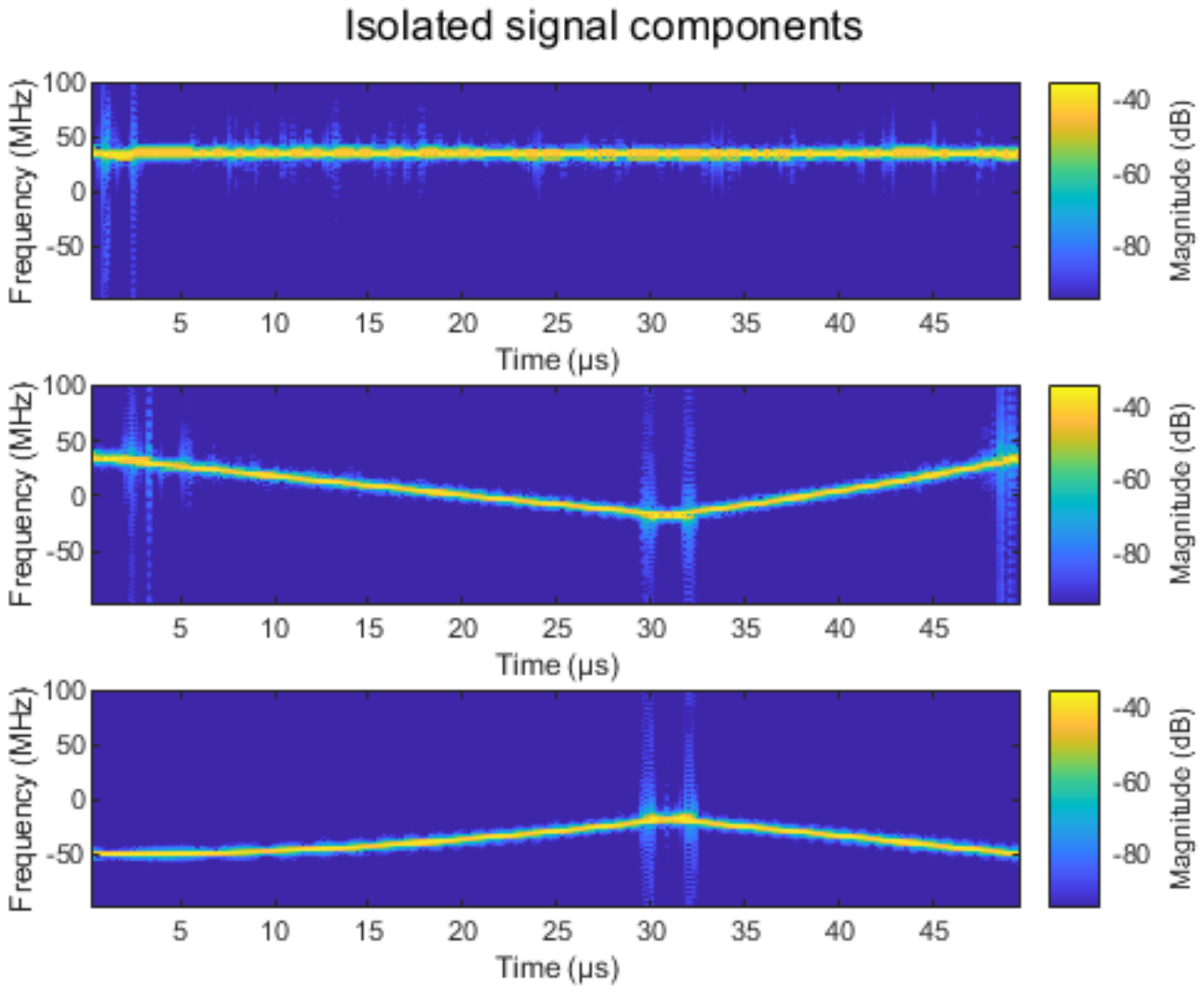
Isolation Example, 1

- Algorithm: **FSST**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.08
  - LFM: 0.39
  - NLFM: 0.37



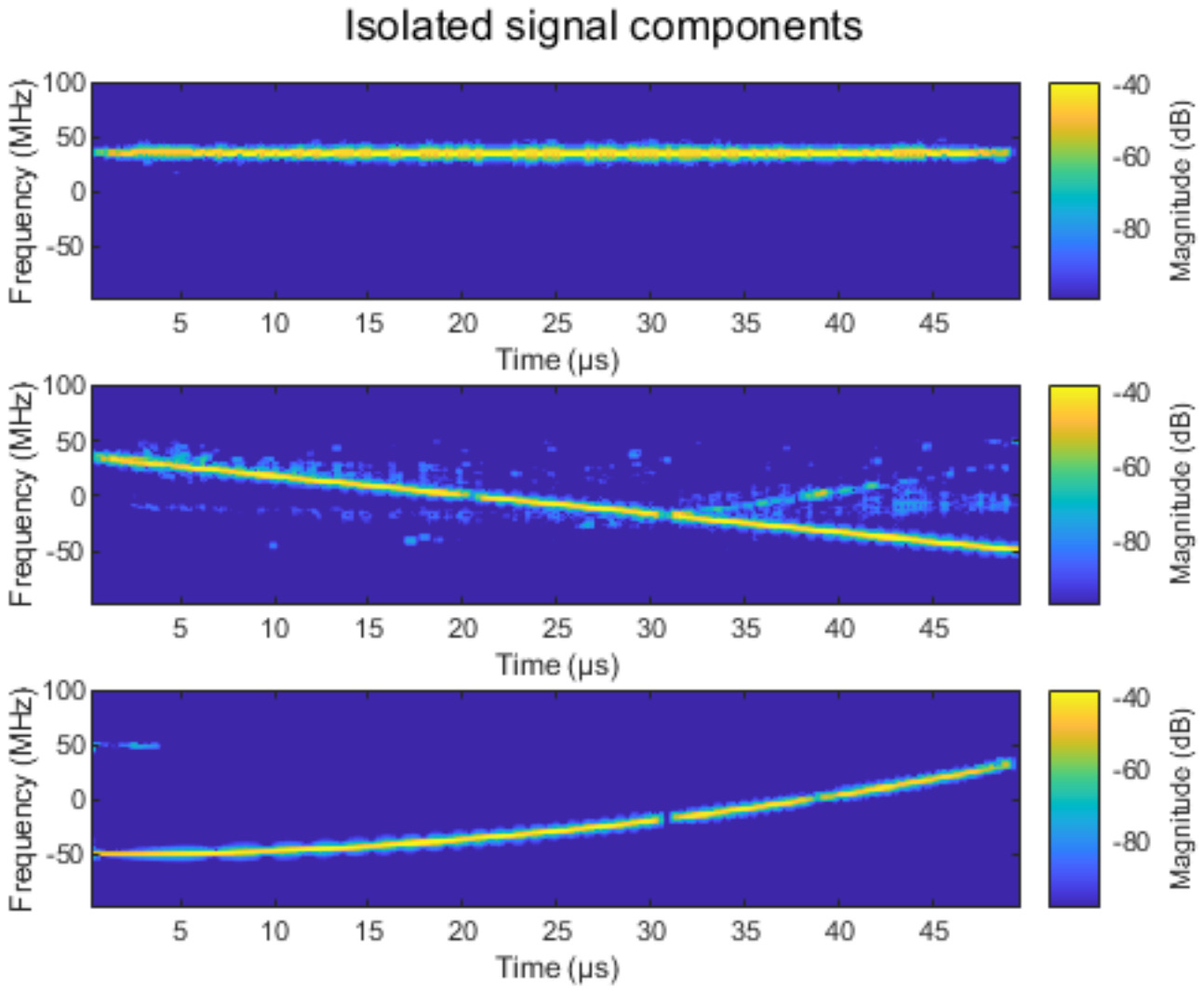
Isolation Example, 1

- Algorithm: **SQTFD**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.07
  - LFM: 0.40
  - NLFM: 0.37



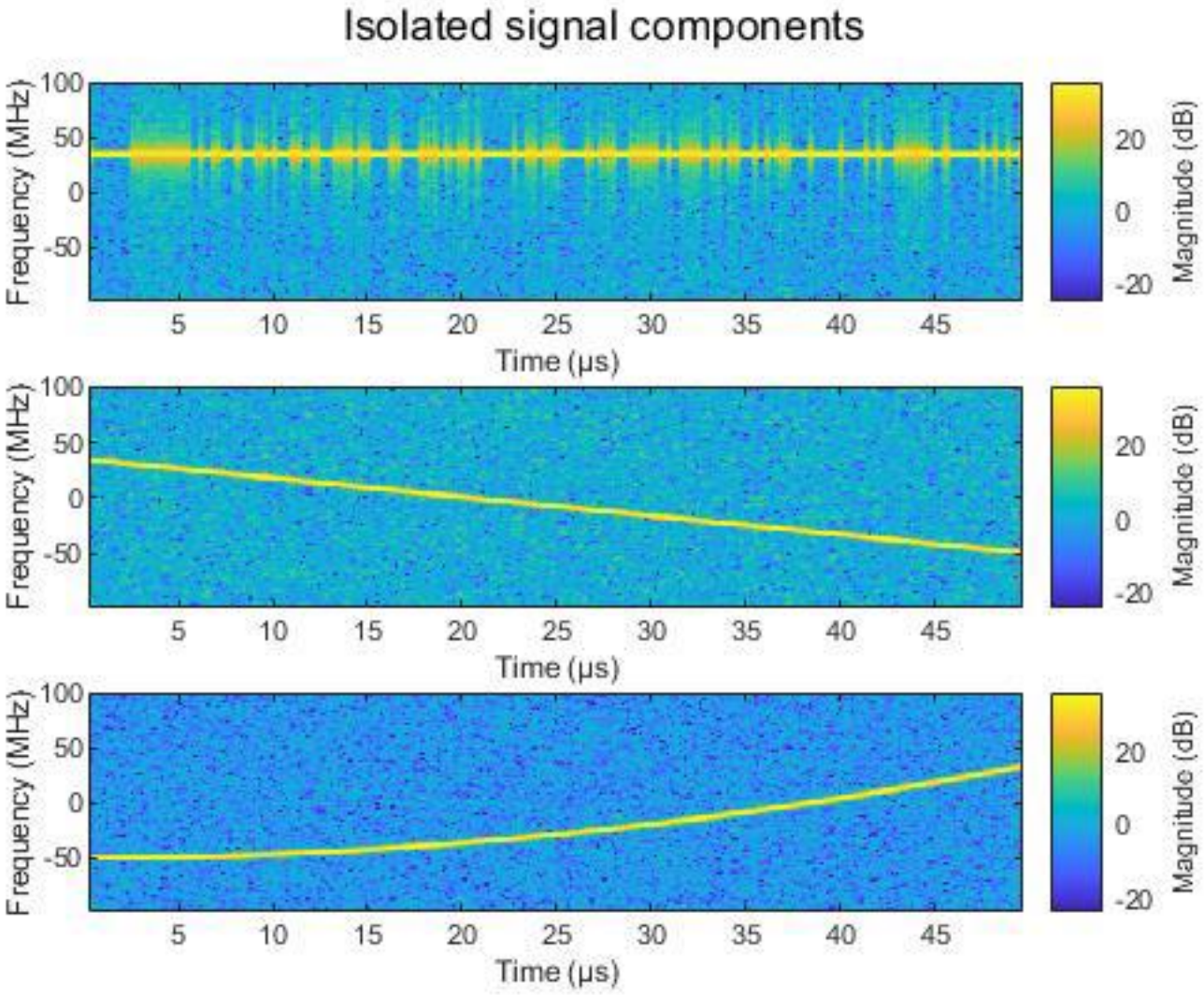
Isolation Example, 1

- Algorithm: **MQTFD**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.10
  - LFM: 0.06
  - NLFM: 0.19



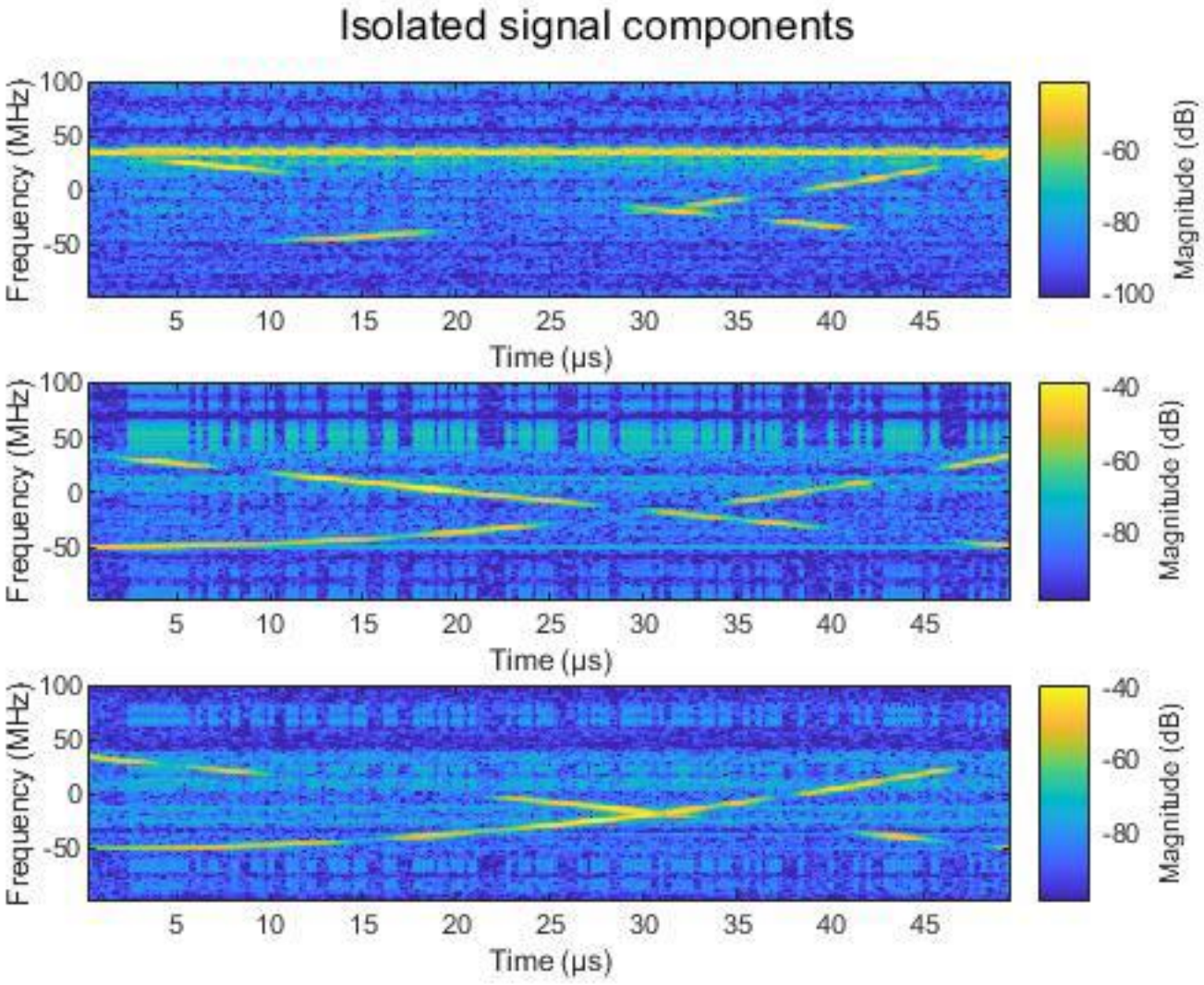
Isolation Example, 1

- Algorithm: **ICA**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.01
  - LFM: 0.02
  - NLFM: 0.01



Isolation Example, 1

- Algorithm: **CICA**
- Signals are mixed and isolation applied.
- FOM calculated:
  - DSSS: 0.57
  - LFM: 0.82
  - NLFM: 0.75



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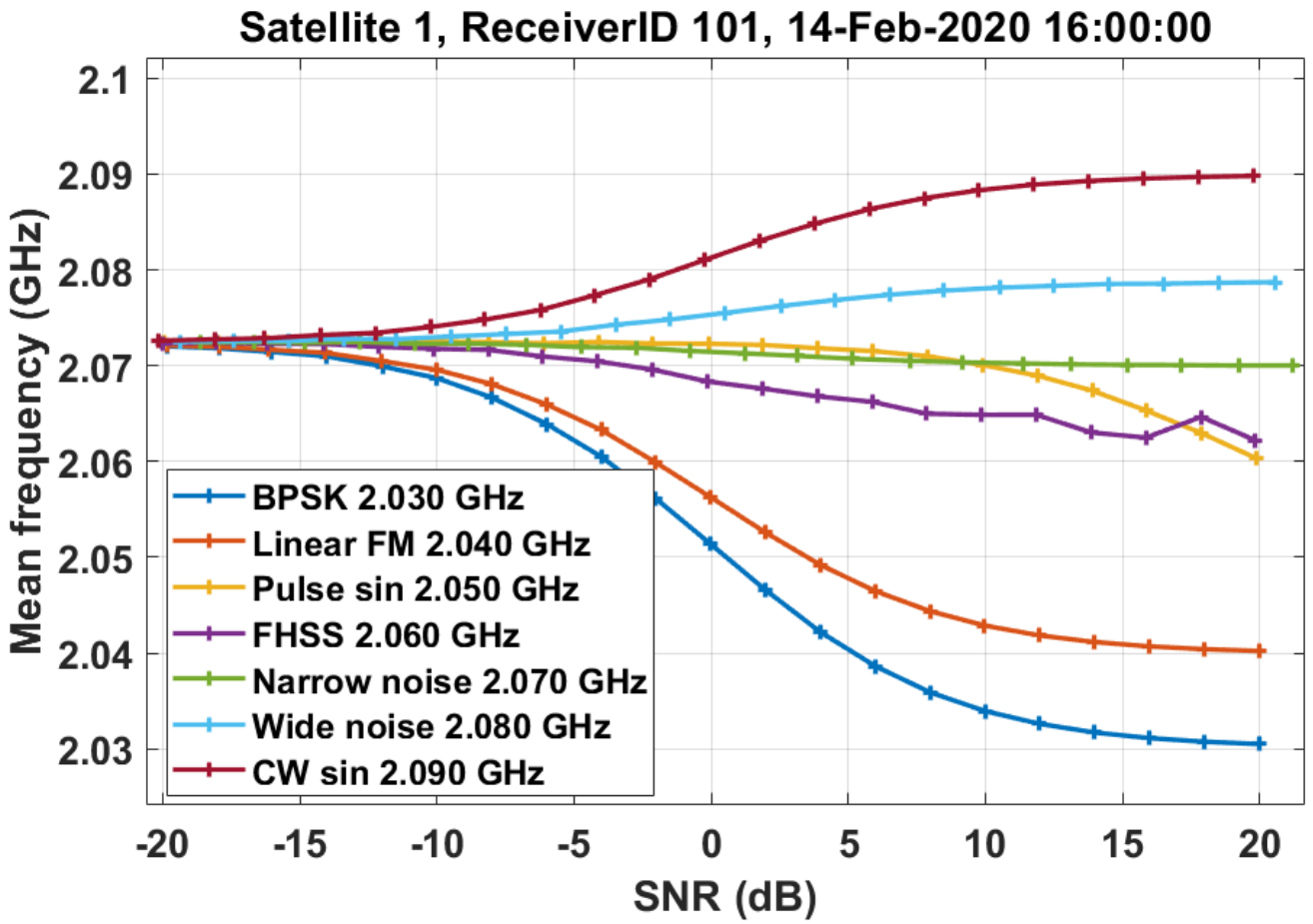
Characterization, Example 1

- Accuracy of the **signal mean frequency** estimation for Galileo S-band receiver
- 5-10 dB INR is needed for <10% error in mean frequency
- At low SNR the algorithm converges to the receiver band centre frequency



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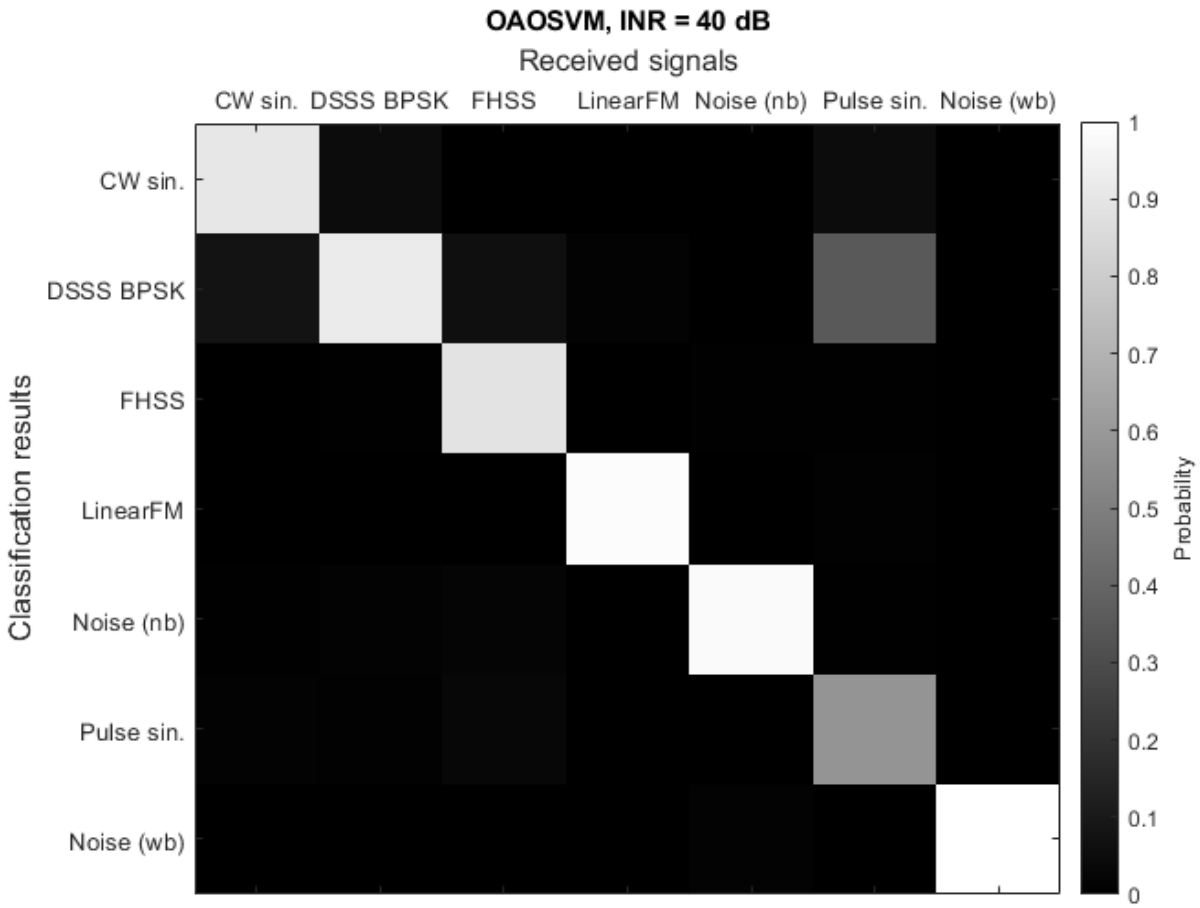
Classification

- Support Vector Machines were studied for
  - SVM architectures: One-Against-One, One-Against-All, Multi-Class
  - Features: Time domain features, Spectral Correlation Function, PSD
  - Kernel (mapping) functions, teaching set size, intensity of the RFI
- Neural Networks were studied for
  - Network architecture, e.g., number of layers/blocks, fully connected layers
  - Training parameters:training algorithm and its parametrization, training set size
  - Intensity of the RFI

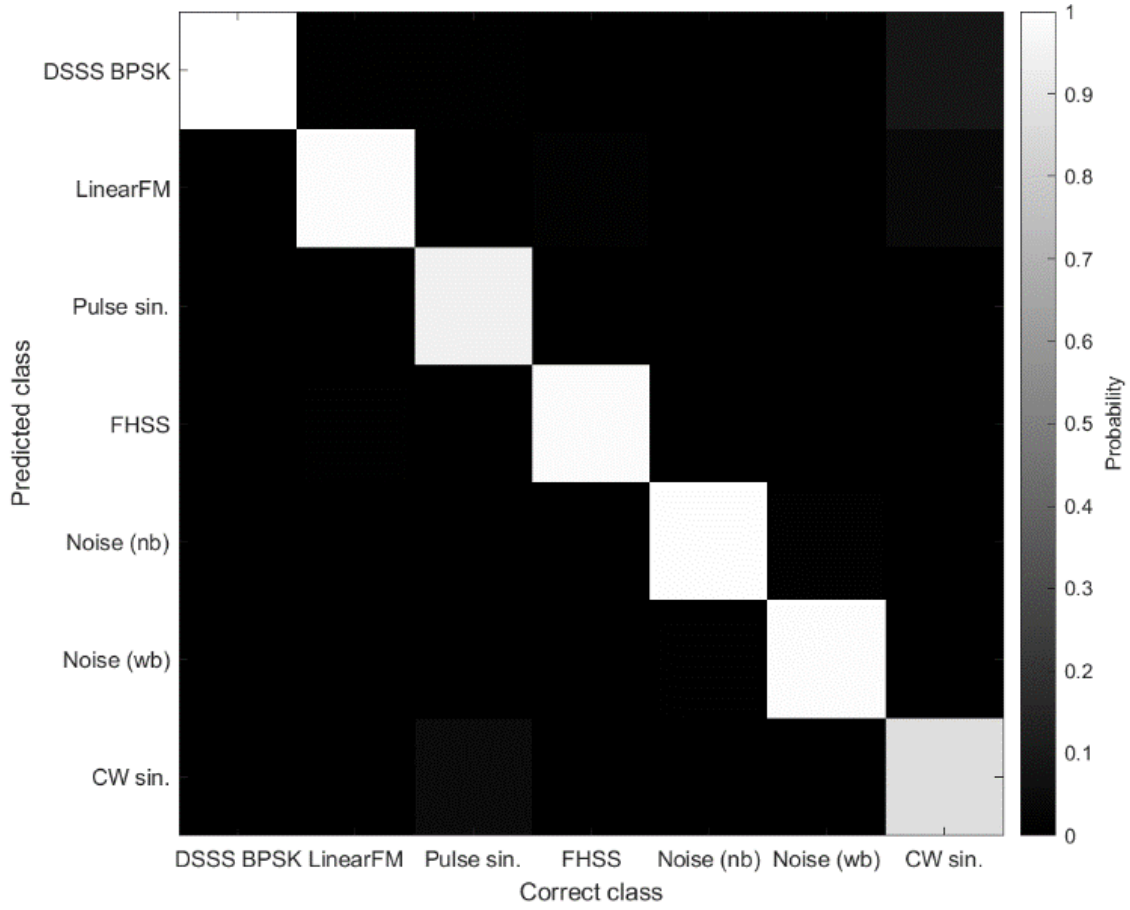
Support Vector Machines

- Best performance was achieved with SVM with
  - One-Agains-One architecture
  - Spectral correlation function
  - Exponential mapping
  - Frequency normalisation pre-processing
- 89 % probability of correct classification

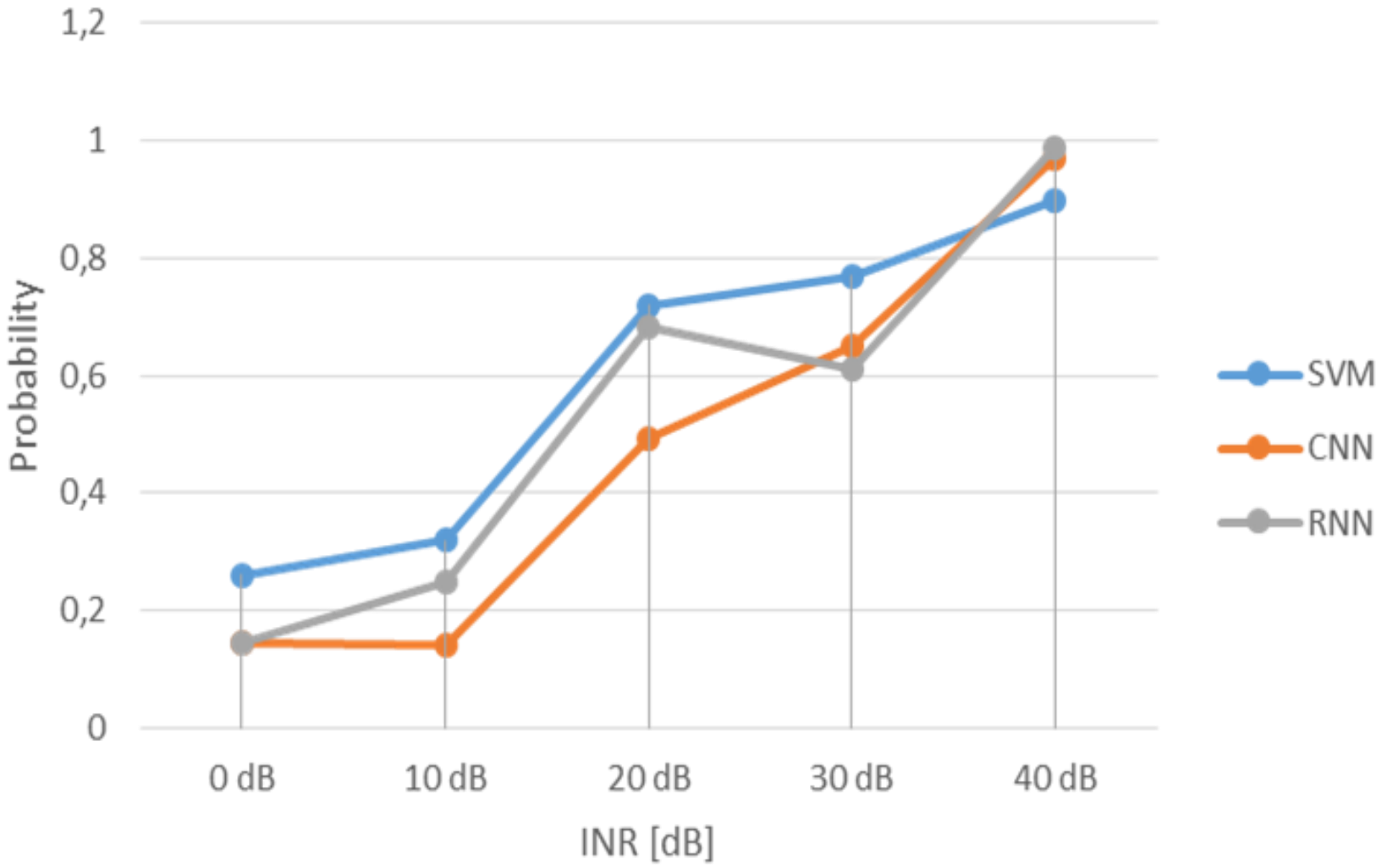


Neural Networks

- Examples of Recurrent and Convolutional Neural Networks (RNN and CNN) were tested
- Various networks established with Matlab's Deep Learning Toolbox and imported to IDS Simulator
- In strong signal conditions near perfect (~99%) classification performance



Comparison of Classification Methods



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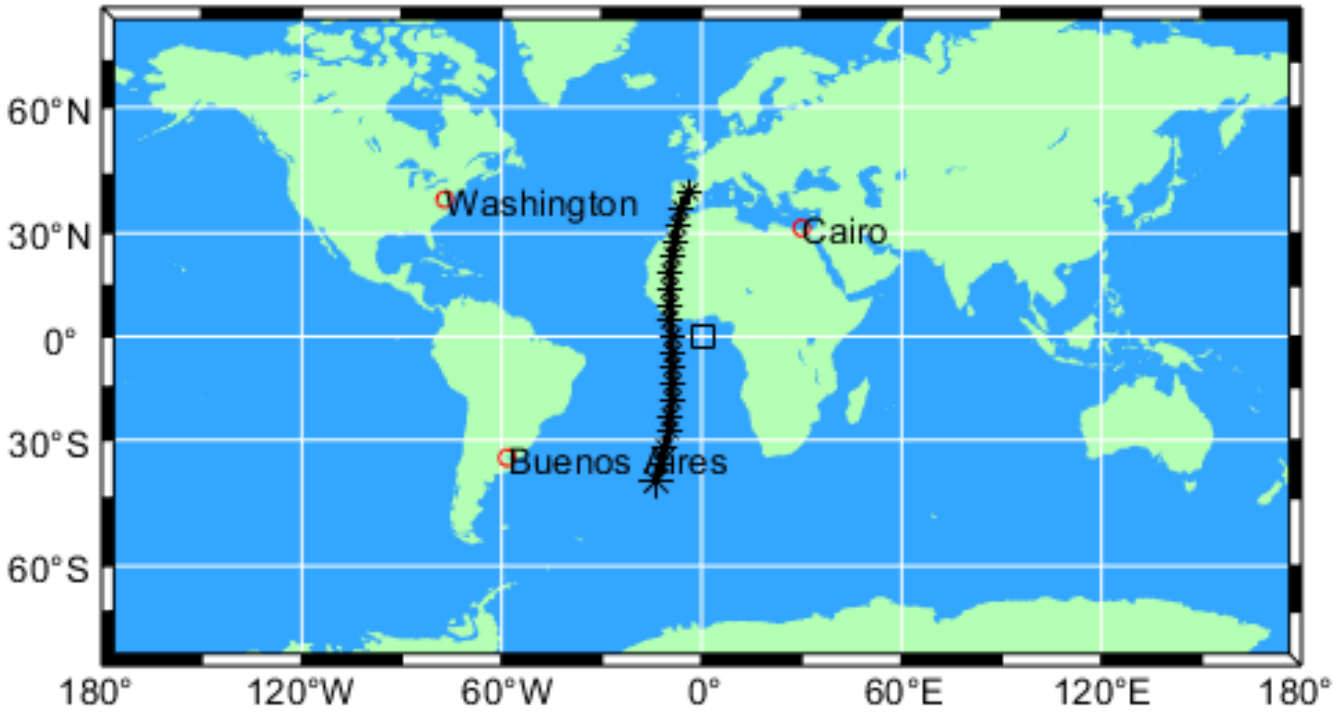
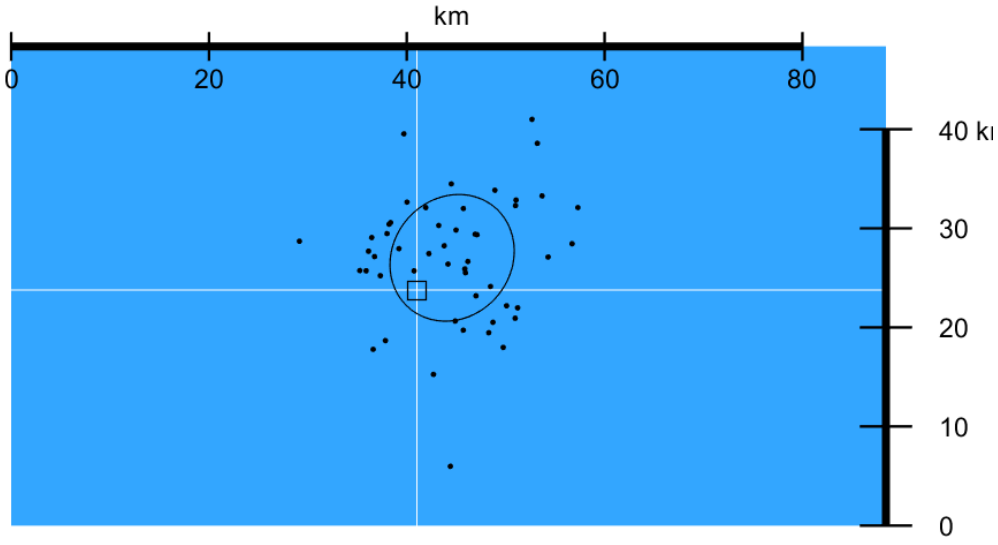
MUSIC, Example 1

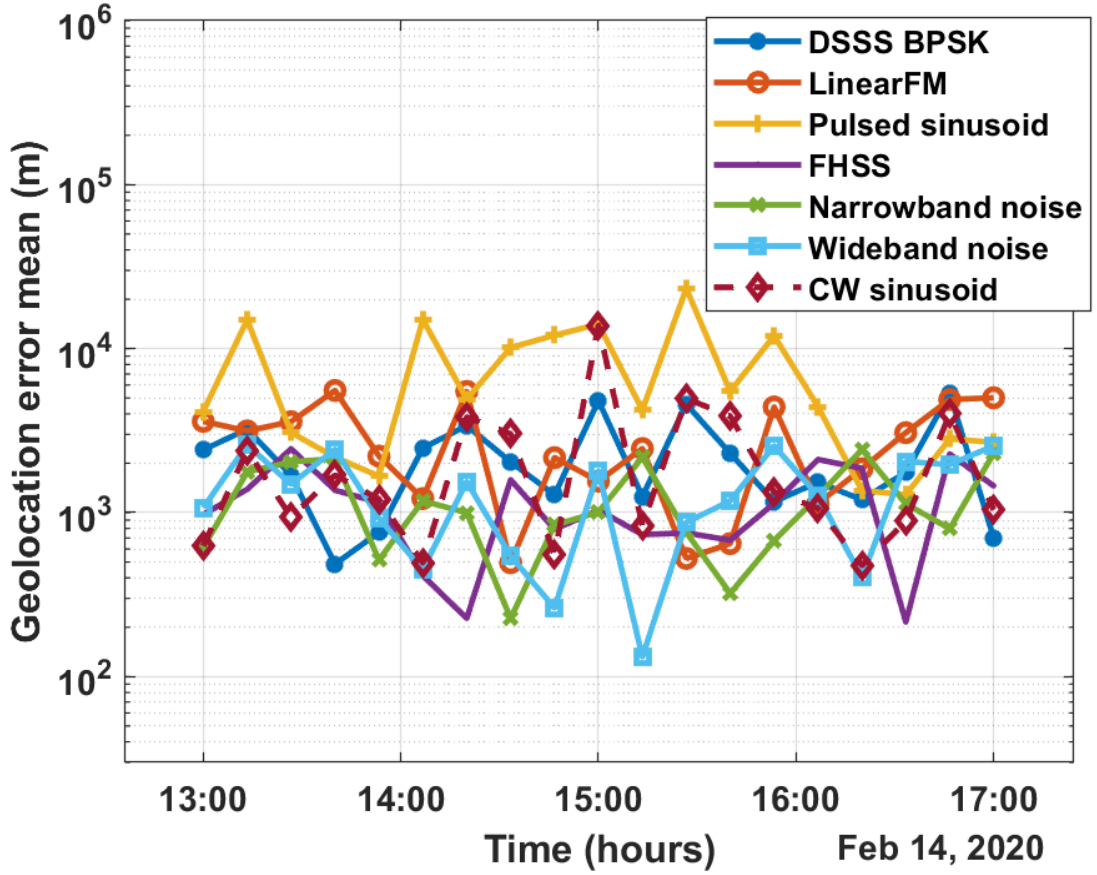
- Hexagonal SAR antenna array with 6 receivers (scaled to S-band)
- Galileo orbit height
- Galileo S-band receiver characteristics
- 7 reference RFI types, ~2(dB INR
- 19 time moments (50 samples at each moment)



MUSIC, Example 1

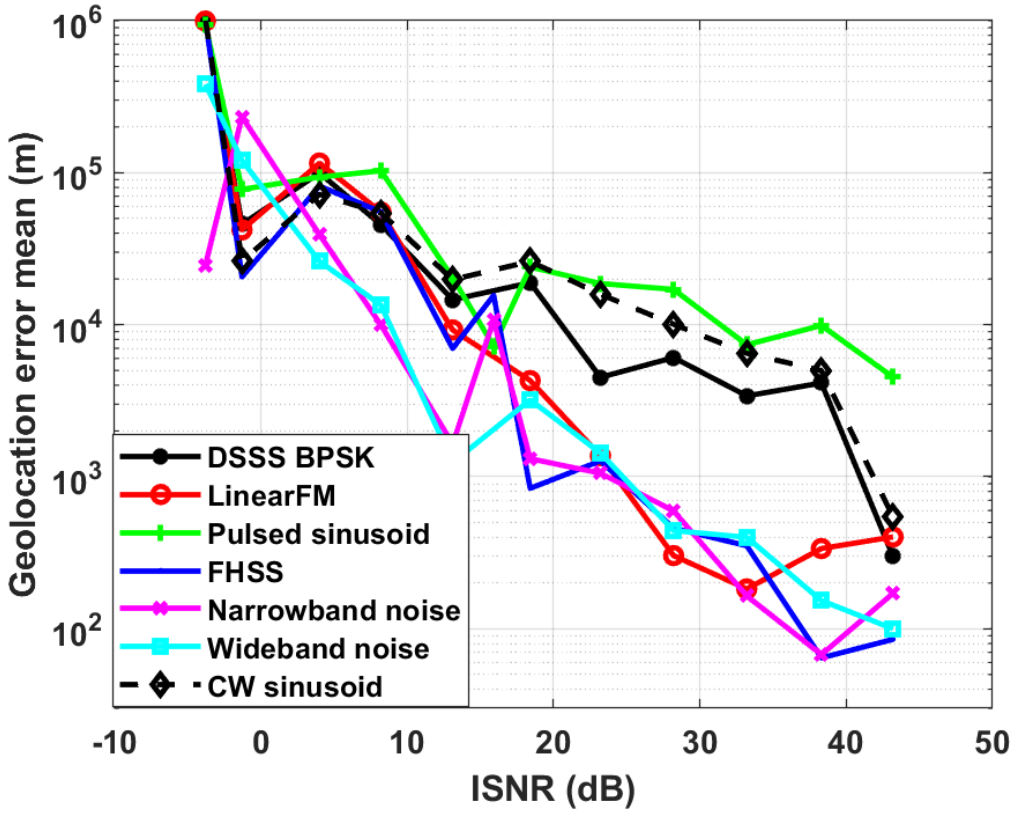
- Right: Localization mean error vs. Time
- Below: 50 localizations at time moment 15:00 for BPSK





MUSIC, Example 2

- Mean localization error in the same scenario for time moment 15:00 for various RFI types as a function of ISNR
- Best accuracy for noise signals
- Localization accuracy worsens for narrow band signals



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Conclusions, 1/2

- IDS Simulator is a Matlab-based RFI scenario simulation tool with wide space of tunable parameters for scenario, satellites, receivers, RFIs, their properties, etc.
- A set of RFI counteraction algorithms was implmented and tested with the simulator.
- There still exists almost endless amount of characteristics that would be useful to include to the simulator. Even though many are included, a lot is not. Expansion easy!

Conclusions, 2/2

- Spectral analysis based algorithms (in many algorithm domains) are getting more common with the fast development of DSP chips and relevant IP-cores.
- Neural Networks is a technology that develops fast due to their applicability and adjustability to many domains. Neural Networks has also many commercial applications e.g., in computer vision, thus it's development is fast due to strong market pull.
- Performance of localization methods from small satellite constellations (tandem/tiplet) was found to be (surprisingly?) good. There exists commercial companies doing that atm. Their potential is promising.

Thank You!
Questions/Discussion?

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