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SATMAR: in-orbit demonstration of RF monitoring and maritime signal exploitation capabilities with an SDR payload

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The RF spectrum: a congested and contested domain

CONGESTED

Ever-growing civil and commercial RF activity, with unintentional interference affecting essential services.

CONTESTED

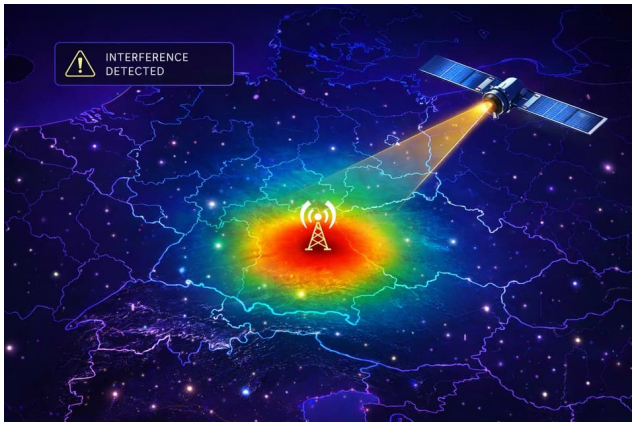
Deliberate interference, jamming and spoofing increasingly affect maritime communications and navigation.

COMPETITIVE

Multiple actors operating in the same spectral space, with limited situational awareness.

Why from space?

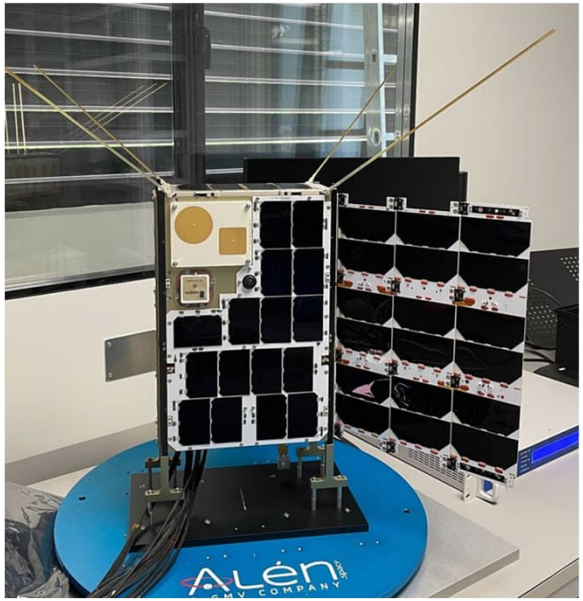
- Persistent, wide-area observation complements terrestrial surveillance networks
- Situational awareness over maritime, remote and hard-to-access regions
- No territorial dependency; recurrent revisits enable long-term pattern analysis
- Traditionally reserved to large, high-cost platforms — miniaturisation and digital processing now bring these capabilities to SmallSat and CubeSat platforms



RF interference detection and geolocation from orbit

Mission overview and objectives

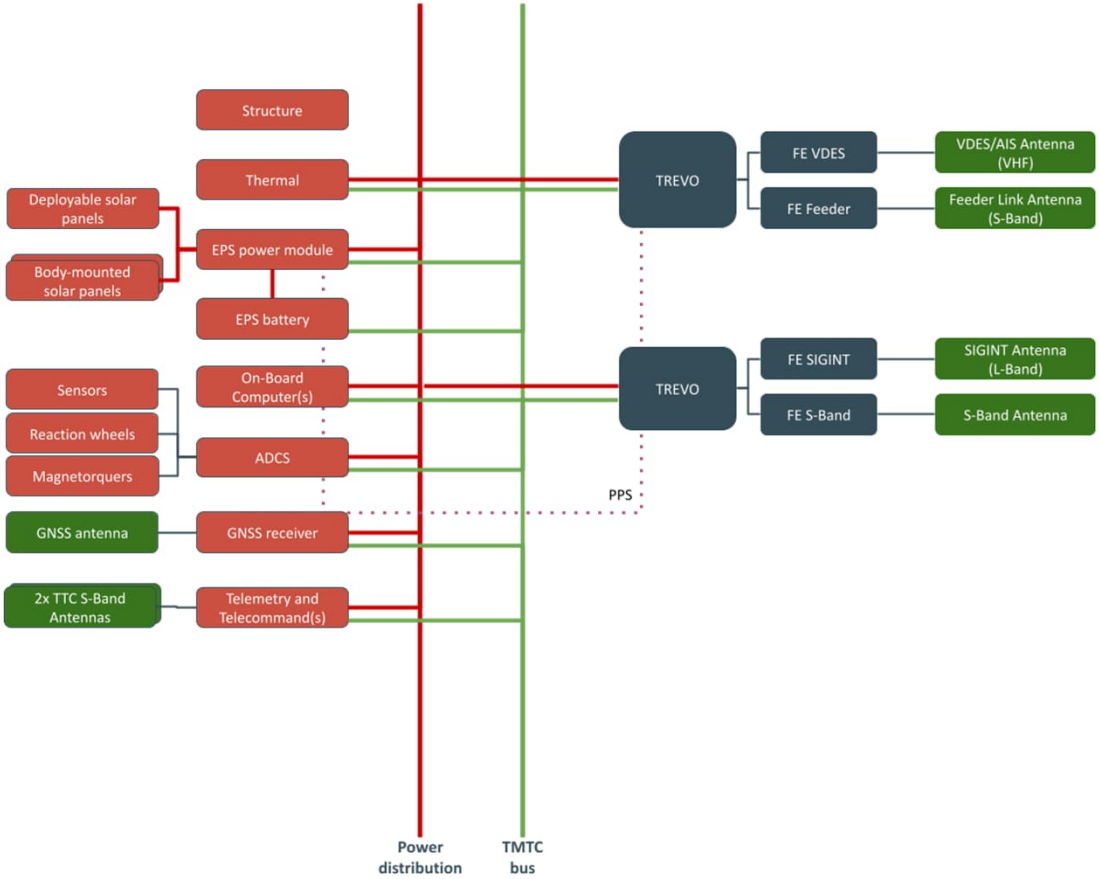
- **Mission:** SATMAR
- **Financed by:** Puertos del Estado (Spanish National Ports Authority)
- **Main objective:**
  - Digitalisation of maritime communications through the VDES standard.
- **Secondary objectives:**
  - In-orbit validation of Alén Space products.
  - Validation of Feeder Link 2.0 and the VDES frontend
  - Testing of new iterations of TREVO SDR and OBSW
  - Development and preliminary testing of the SIGINT and spectrum monitoring application
  - Continuous in-orbit experimentation for products and new developments.
- **Launch:** 23 June 2025 (SpaceX's Transporter 14 mission)

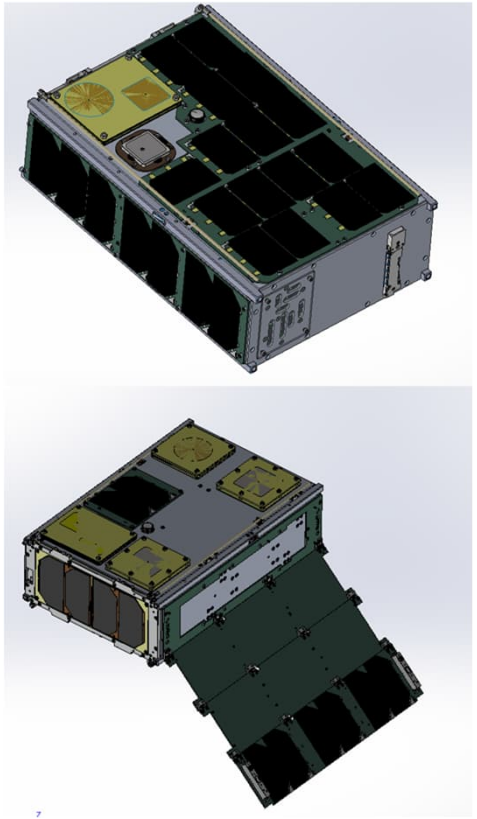


PROYECTO FINANCIADO POR EL FONDO PORTS 4.0
Puertos del Estado
PORTS 4.0

Alén space A GMV COMPANY
Egatel

6U satellite architecture





Payload architecture: TREVO SDR

Payload architecture

As a payload, TREVO has a strong flight heritage (2024): 4 missions, 7 satellites, +7 applications.

- AIS/ADS-B tracking, spectrum monitoring, VDES, 5G NB-IoT, VHF communications.
- All of them 100% successful.

SATMAR payload configuration

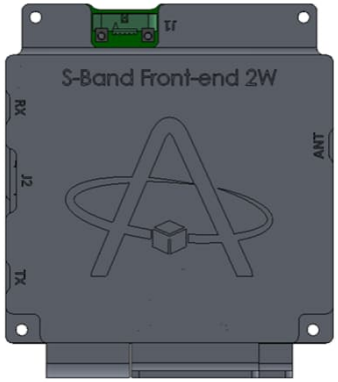
- 2x TREVO SDR in 2x2 configuration (2x SoC & 2x TRX)
  - AIS/VDES & Feeder Link: vessel tracking (main payload) and high-capacity downlink
  - SIGINT payload: L-band and S-band monitoring
- Each SoC + TRX pair is fully independent
- Each TRX can be connected to multiple frontends

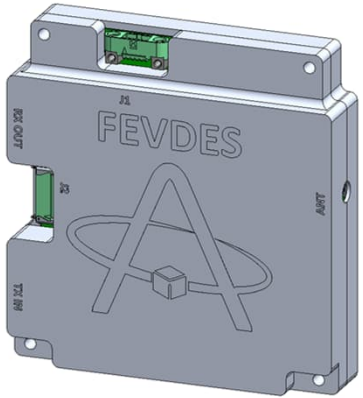
TREVO SDR — SoC and TRX modules

Payload architecture: antennas and frontends

Antennas

Description	Peak gain	Frequency	Polarisation
S-band antenna	6.3±0.3dBic @Rx, 5.4±0.4dBic @Tx, Δ = ±0.3dB	Rx: 2025-2110 MHz Tx: 2200-2290 MHz	RHCP
S-band antenna	6.7±0.2dBic @UL, 7.2±0.5dBic @DL, Δ = ±0.3dB	2025-2110 MHz (UL) 2200-2290 MHz (DL)	RHCP
VHF antenna	0.8 dB at 161 MHz	130-210MHz	RHCP
L-band antenna	5.6±0.1dBic, Δ = ±0.3dB	1610-1675MHz	RHCP





VHF front-end characteristics:

- Frequency band: 156 – 163 MHz.
- Reception gain: 21 dB.
- Noise figure: 2.5 dB

L-band front-end characteristics:

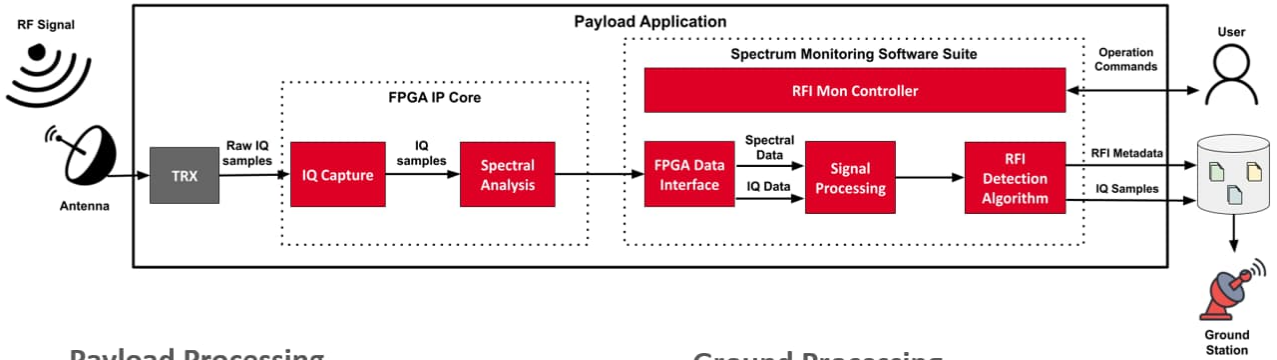
- Frequency band: 1610 – 1675 MHz.
- Reception gain: 22 dB.
- Noise figure: 1.125 dB.

S-band front-end characteristics:

- Frequency band: 2025 – 2110 MHz (Rx)
- Reception gain: 39 dB.
- Noise figure: <5 dB.

On-board processing (SpMon-toolkit)

- Software suite developed by Alén Space, operated via telecommands
- Includes tools for IQ sample capture and transmission
- Turns the captured samples into compact information products:
  - Sub-band extraction
  - Energy metrics generation
  - Parameterisable spectrogram creation
- This way, only the IQ samples of the time fragment where a relevant event is detected are downlinked.

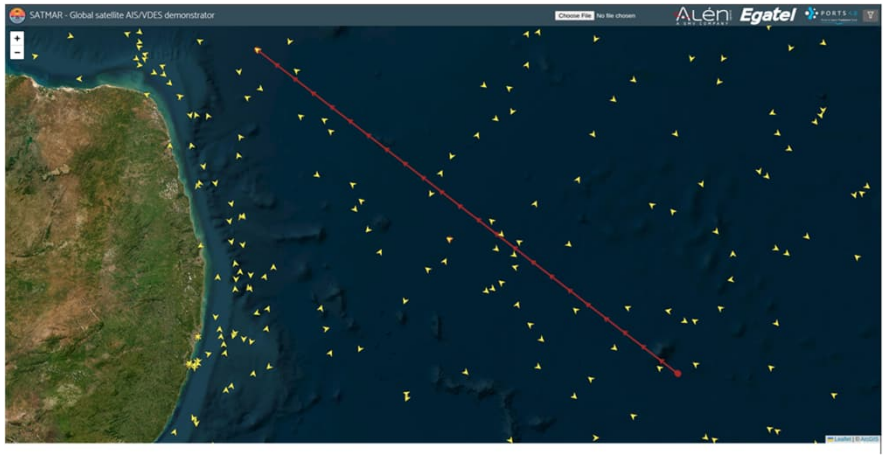


Payload Processing
Performs real-time RF monitoring and initial signal exploitation

Ground Processing
The ground segment performs advanced analysis and intelligence fusion

Payload validation: AIS

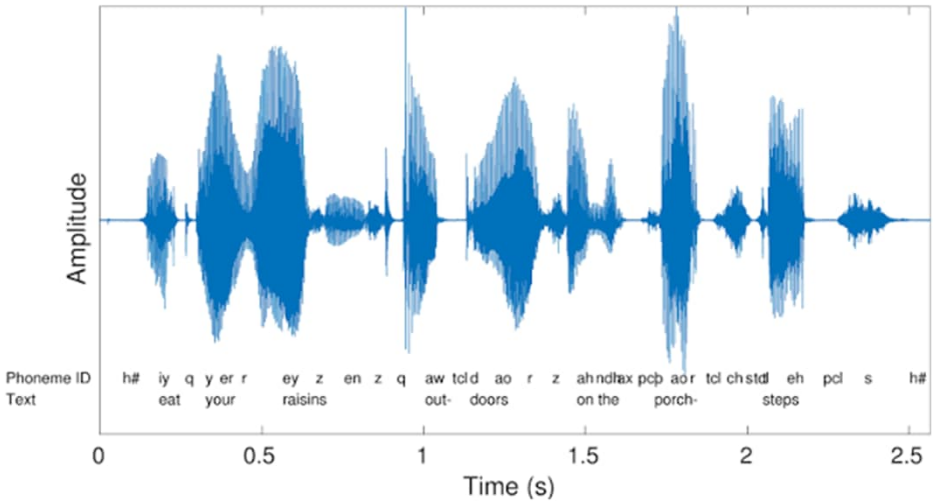
- Downlink of the received packets, including:
  - Statistics
  - Packets detected by AIS
  - Packets received on each channel
- Packet downlink through the Feeder Link
- Packets loaded into the AIS viewer (map display)



AIS viewer. Messages received from SATMAR.

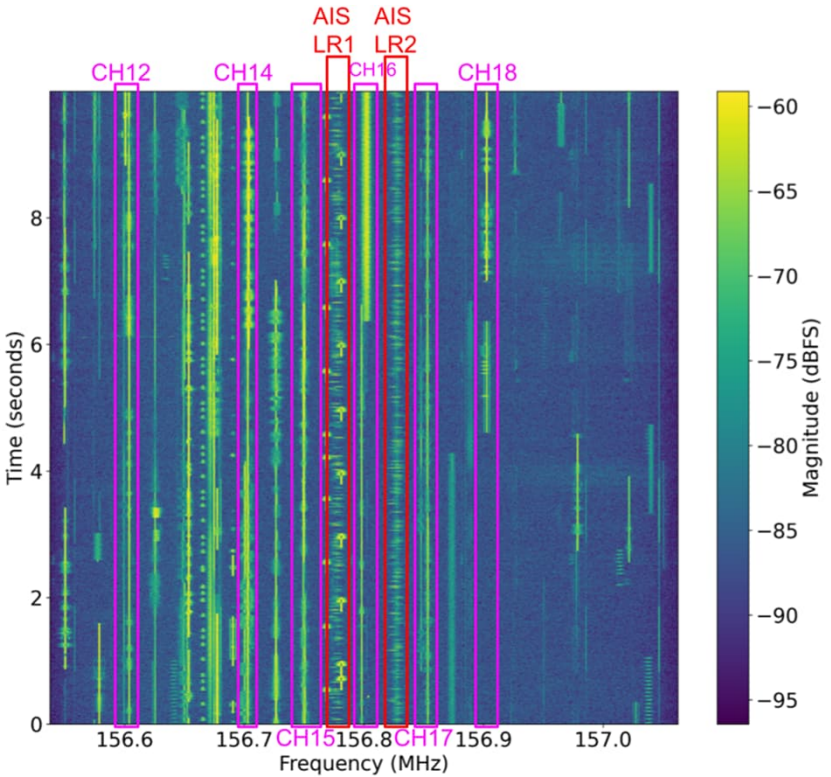
Payload validation: VHF voice channels

- Wideband capture of VHF maritime communications
- Ground-segment recovery and demodulation of maritime voice channels
- Channel 16 (156.8 MHz, international distress channel) and other voice channels successfully isolated



Payload validation: spectrum monitoring (SIGINT)

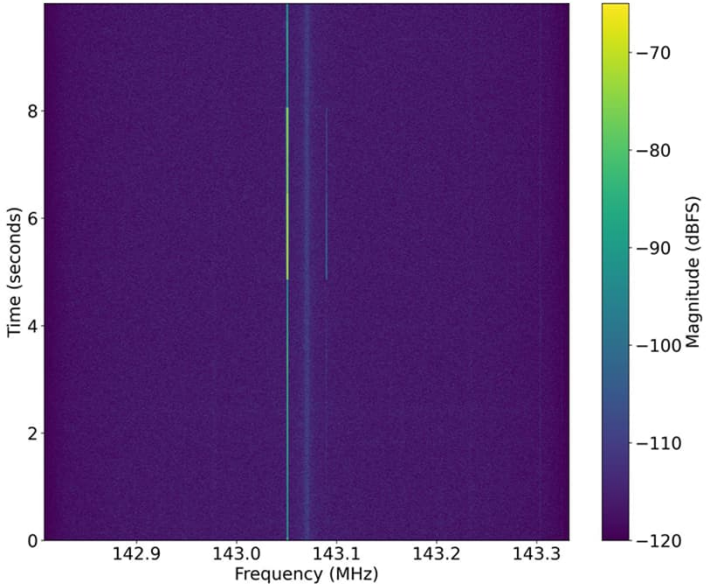
- RF emissions are monitored to:
  - Detect interference
  - Detect unauthorised transmissions
  - Characterise and identify signals of interest.
  - Assess spectrum congestion over a given region
- IQ sample capture in:
  - VHF
  - S band
  - L band.
- Telecommand-based payload operation (SpMon-toolkit)
- Data is downlinked to the ground for further analysis.



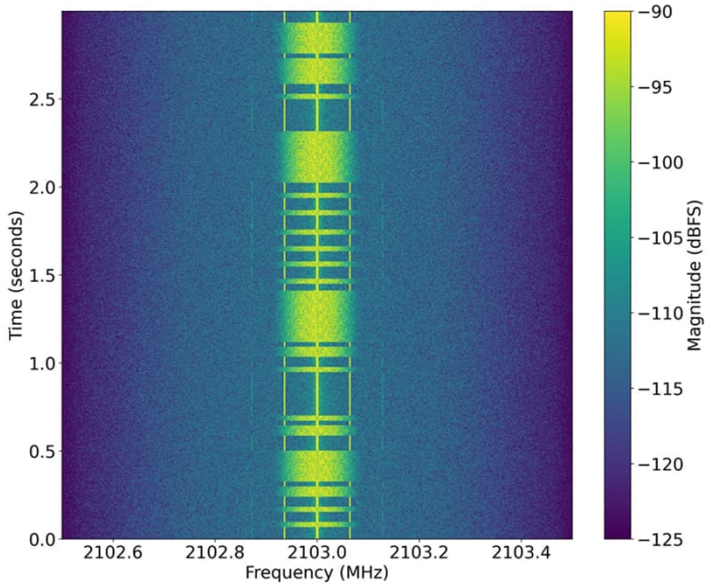
VHF maritime band spectrogram showing the AIS channels and multiple maritime voice channels.

Payload validation: spectrum monitoring (SIGINT)

- Detection of the GRAVES space surveillance radar.
- Detected despite operating outside the nominal band of the VHF front-end
  - Very high-power transmission



- Detection of TT&C uplink commands transmitted from ground stations at 2103 MHz.

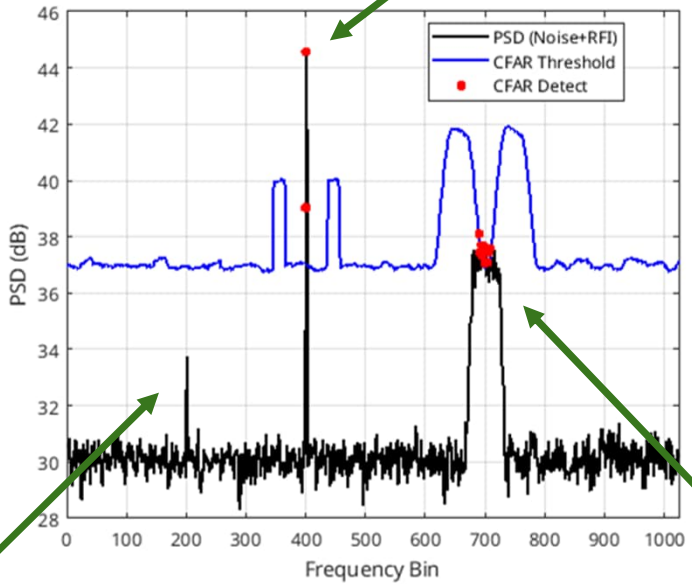


Under development: autonomous RF event detection

- Development of autonomous algorithms based on Power Spectral Density (PSD) and Spectral Kurtosis.
- Implementation of CFAR techniques and noise floor estimation.

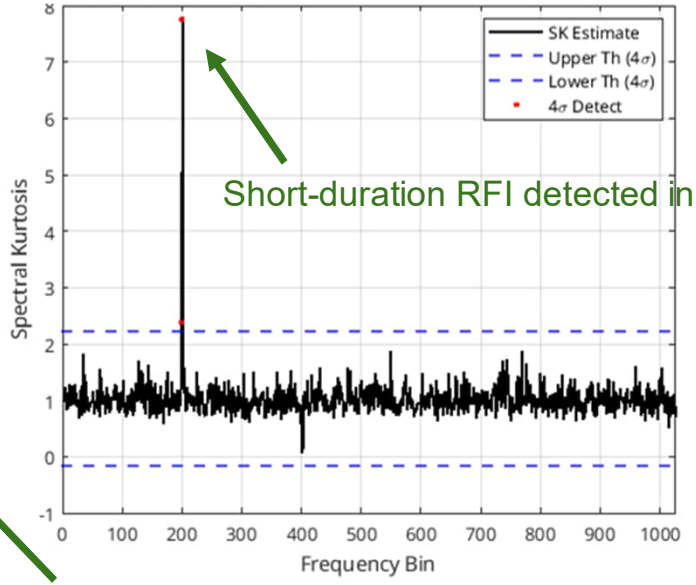
CFAR

CW RFI detected in bin 400



Short-duration RFI remains undetected (bin 200)

Spectral Kurtosis

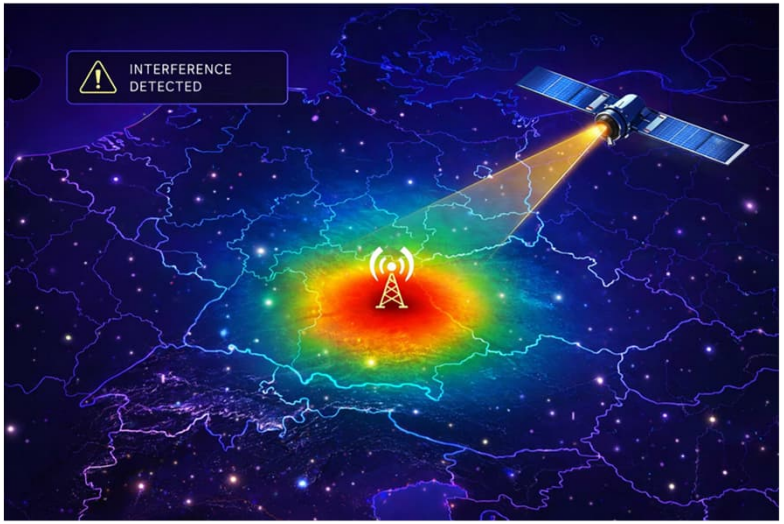


Short-duration RFI detected in bin 200

Narrowband RFI detected in bin 700

Under development: multi-satellite RFI geolocation

- TDOA (Time Difference of Arrival): extraction of time observables offering high accuracy for wideband interference.
- FDOA (Frequency Difference of Arrival): analysis of the Doppler shift derived from orbital motion, offering high accuracy for narrowband interference.
- DOA (Direction of Arrival): power variation depending on the satellite elevation with respect to the RFI.



Conclusions

SATMAR has validated three key milestones:

1. On-board AIS demodulation and representation on the ground.
2. Recovery and processing of analog VHF voice channels.
3. Overall operability of the SDR payload for multi-band SIGINT capture.

Consolidating this technological baseline allows us to scale towards missions focused on precise emitter geolocation, automated signal classification and improved RF situational awareness.

SATMAR 1st Nadir Sensor image

INTERNATIONAL SPACE RADIO MONITORING MEETING

Thank you!

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