DYLEMA-Madrid

Madrid Airport and TMA GNSS RFI Monitoring System

ENAIRE

José Luis Madrid Cobos
GNSS RFI Monitoring Technical Manager
ENAIRE - Air Navigation Service Provider
Ministry of Transport, Mobility and Urban Agenda - Spain

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The Origin of DYLEMA-Madrid.

• ENAIRE has a GNSS performance assessment and Radio Frequency interference (RFI) monitoring network in operation since early 2000, with GNSS receivers and RFI detectors (without geolocation capabilities) at Spanish airports with published PBN (Performance Based Navigation) procedures. It is in continuous evolution (retrofits and new installations).

Green color: GPS/Galileo L1/E1/L5/E5a monitoring stations. Purple color: GPS L1 monitoring stations.

The Origin of DYLEMA-Madrid.

• Apart form the fixed GNSS RFI monitoring ground stations, ENAIRE has several portable monitoring stations such as a customized GNSS/GBAS portable monitoring station or spectrum analyzers with directive antennas.

ENAIRE's GNSS/GBAS portable monitoring station.

Example of a spectrum analyzer (Rohde & Schwarz FSH8).

The Origin of DYLEMA-Madrid.

• On 17 February 2016, several pilots started to report GNSS outages just a few minutes after take-off at Madrid airport.

The Origin of DYLEMA-Madrid.

Madrid, 17 – 22 February 2016 GNSS RFI event description:

• Pilots continued to report GPS L1 C/A signal reception outages in departures from Madrid airport between altitudes 5000 to 16000 ft (1500 to 5000 m).

• A NOTAM (Notice to Airmen) was published: “GNSS unreliable or unavailable. RNAV-1 operations restricted to DME-DME”. Pilots discarded GNSS on-board and reverted to conventional navaids procedures around Madrid airport (SID/STAR).

• In case any pilot were still trying to use GNSS, the ATCOs (Air Traffic Controllers) monitored the operations in real time based on radar surveillance, ready to provide radar vectoring to the pilots to ensure that minimum vertical and horizontal separations between aircraft were kept. The increase in ATCOs workload forced to close two of four runways, therefore reducing the airport capacity.

The Origin of DYLEMA-Madrid.

Madrid, 17 – 22 February 2016 GNSS RFI event description:

• Event reported to the Spanish Radio Frequency Spectrum Regulator (SETID).

• Failure of GPS constellation or a Space Weather event: checked & discarded.

• RF signals coming from nearby RF open-field test facilities: checked & discarded.

• ADS-B data analysis could not geolocate the RFI source with enough accuracy to successfully facilitate the localization to the on-ground inspectors, equipped with portable RFI direction finding detectors.

• On Saturday 20 February 2016, an inspection flight arranged by ENAIRE localized the source of the interference with an accuracy of 0.6 NM (1 km). On Monday 22 February 2016, an on-ground inspection was performed and the RFI transmitter was located and switched off.

The Origin of DYLEMA-Madrid.

Madrid, 17 – 22 February 2016 GNSS RFI event. Conclusions:

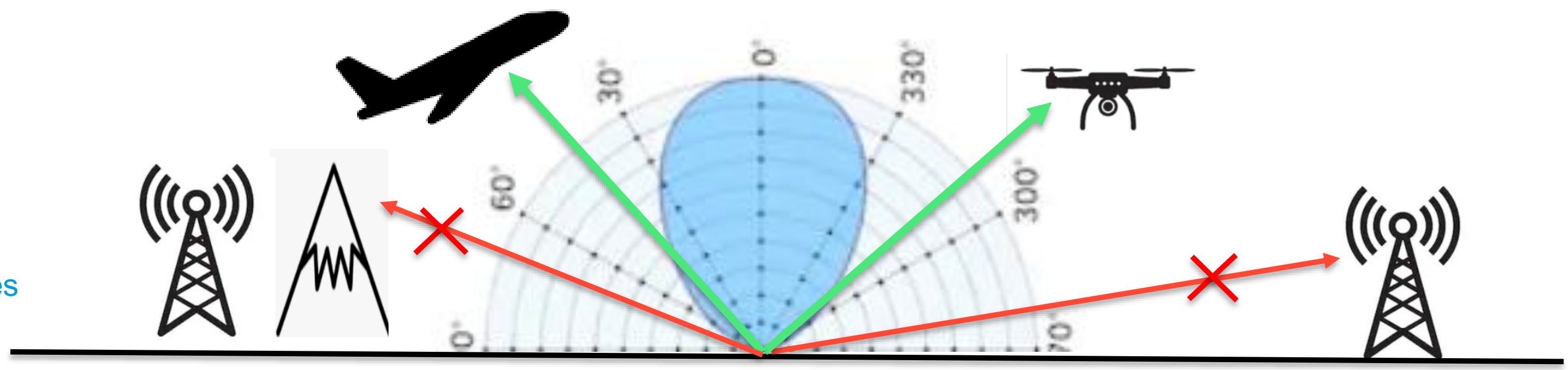
- With the GNSS interference detectors installed near the airport no interference was detected. There were available only two detectors, one at Madrid airport and one at Madrid ACC (Area Control Center).

- Even applying safety contingency procedures in presence of noticeable GNSS RFI there could still be impacts, such as capacity reductions, delays in operations (departures and landings) and associated costs. There is a need for prompt detection and localization capabilities to stop any noticeable GNSS RFI <u>as quickly as possible</u>.

- Arrangement of an inspection flight (with a specialized manned aircraft) for GNSS RFI localization is not suitable in the very short term (tactical level) and is expensive.

The Origin of DYLEMA-Madrid.

- **Correction action #1:** improve the inter-organizational process devoted to the management of planned and unplanned GNSS RFI (Radio Frequency Spectrum Regulator, Ministry of Transport and its agencies, Ministry of Defence, law enforcement agencies, etc.).
- **Correction action #2:** deployment of a <u>wide area</u> GNSS RFI detection and localization system around Madrid airport to <u>detect and geolocate</u> interferences in Madrid CTR (Controlled Traffic Region) and part of Madrid TMA (Terminal Maneuvering Area) to support and protect PBN procedures based on GNSS (SID, STAR and approach procedures). After a validation period continue with the deployment in the rest of the Spanish main airports.
- **Correction action #3:** GNSS RFI monitoring sensor aboard a UAV to detect and localize GNSS RFI in areas or scenarios where the fixed monitoring ground stations are not able to receive the RFI above the sensitivity threshold. Not only in RFI BVLOS (Beyond Visual Line of Sight) scenarios!



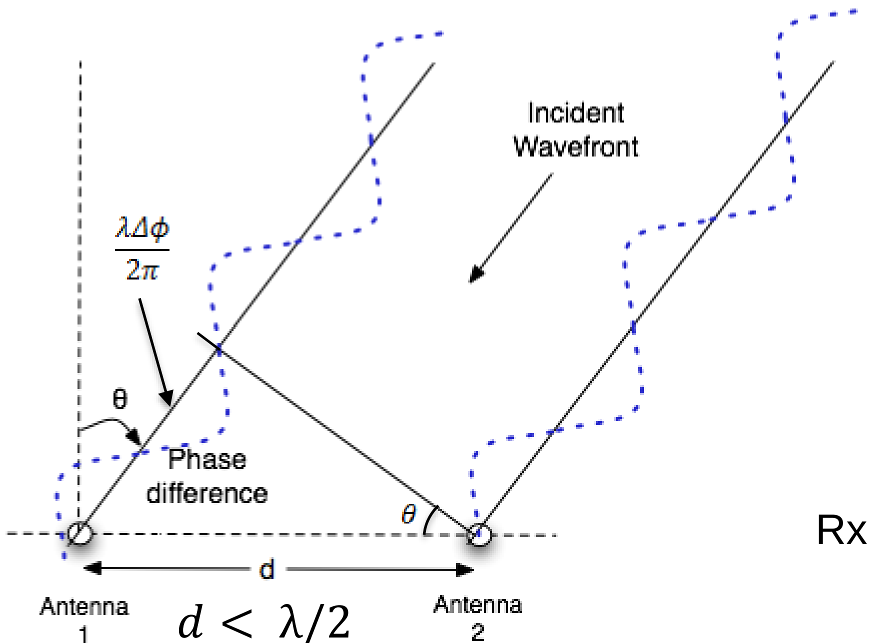
DYLEMA-Madrid Brief Technical Description

- RFI detection and localization system based on the AOA (Angle Of Arrival) technique.
- Target coverage: approximately 20 Km radius from the center of the airport.
- Jamming monitoring: GNSS L1/E1 and L5/E5a frequency bands.
- Spoofing monitoring: GPS L1 C/A.
- RFI source geolocation accuracy: ≤ 1 Km (68%).
- Jamming alert threshold: ICAO SARPS Annex 10 Vol 1 in-band CW interference thresholds for GPS L1 C/A: "-126.5 dBm during code acquisition, -120.5 dBm during code tracking, at the antenna port with -5.5 dBi at 5º EL". Calibration required at the RFI monitoring station depending on the real scenario: typical RFI source vs aircraft relative position in the elevation plane, the monitoring station antenna gain, the distance difference between the RFI source to the aircraft and to the RFI monitoring station, etc. (a very complex scenario). In most cases, a check shall be done with ATCOs and pilots to confirm if an unplanned RFI event detected on-ground is really affecting the on-board GNSS reception before publishing a "GNSS unreliable/unavailable due to interference" NOTAM.
- Spoofing / Space Weather Event alert thresholds:
  - ✓ Horizontal & Vertical Positioning Errors (HPE, VPE), GPS Time & Speed Errors (TE, SE) based on the GPS SPS Performance Standard (95%).
  - ✓ Carrier-to-noise-density ratio (C/N0): based on an ad-hoc 24-hour calibration.

Main RFI geolocation techniques

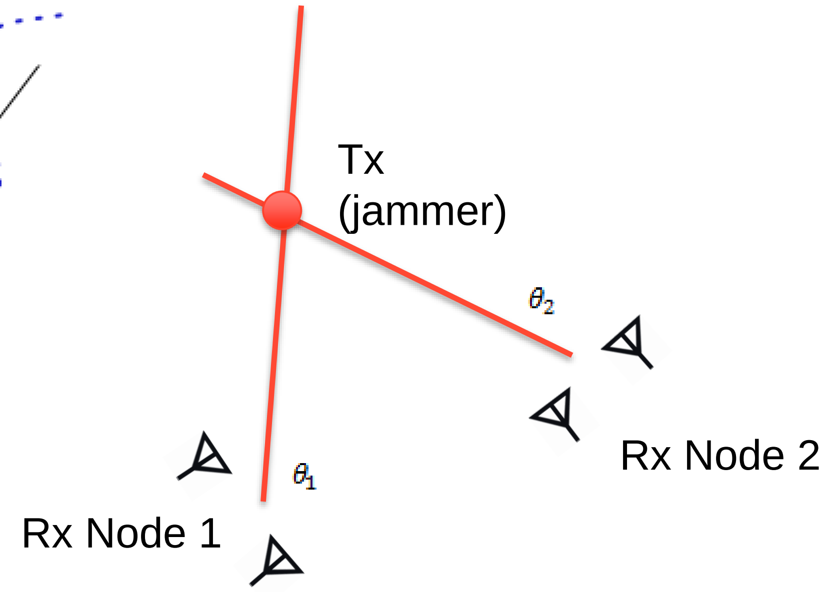
- **AOA (Angle Of Arrival, based on phase difference or correlative interferometry):**
  - ✓ Locates an interference source by measuring its phase difference of arrival between two or more antennae in an array. Only bearing (AOA) is obtained with one monitoring station.
  - ✓ Location of the interference source is based on the intersection of two (or more) straight lines (bearings) from two (or more) monitoring stations (Rx nodes).
  - ✓ At least two Rx nodes are needed.
  - ✓ Outperforms in rural areas, with any RF bandwidth (CW, narrowband, wideband).
  - ✓ Drawbacks: low performance in urban areas (NLOS scenarios & multipath).
- **TDOA (Time Difference Of Arrival):**
  - ✓ Locates an interference source by measuring its signal time difference of arrival between pairs of nodes in the network.
  - ✓ Location of the interference source is based on the intersection of two hyperbolas.
  - ✓ At least 3 Rx nodes are needed (i.e., two pairs of Rx nodes).
  - ✓ Drawbacks: synchronization of the Rx network (1 us of clock drift means 300 m of error in position), GPS time could be jammed or spoofed, group delay calibration per Rx.
- **PDOA (Power Difference Of Arrival):**
  - ✓ Locates an interference source by measuring its received power difference between pairs of nodes in the network. Similar characteristics of TDOA but working with RF power instead of time. It is usually the least accurate method, but useful in combination.
- **Hybrids:** AOA+TDOA, AOA+PDOA, TDOA+PDOA, AOA+TDOA+PDOA …
- Watson-Watt / Adcock (amplitude), pseudo-doppler direction finding (phase based),...

AOA - Angle Of Arrival Technique



$$Phase\ Difference = \Delta\phi = \frac{2\pi d}{\lambda} \sin\theta$$

$$Angle\ Of\ Arrival = \theta = \sin^{-1}\frac{\lambda \Delta\phi}{2\pi d}$$



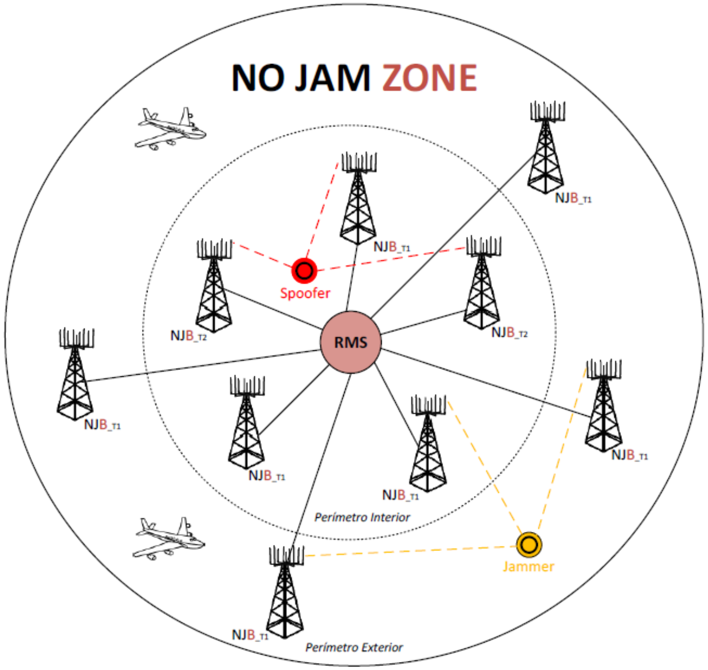
DYLEMA-Madrid:

< ± 3º AOA accuracy (1σ).

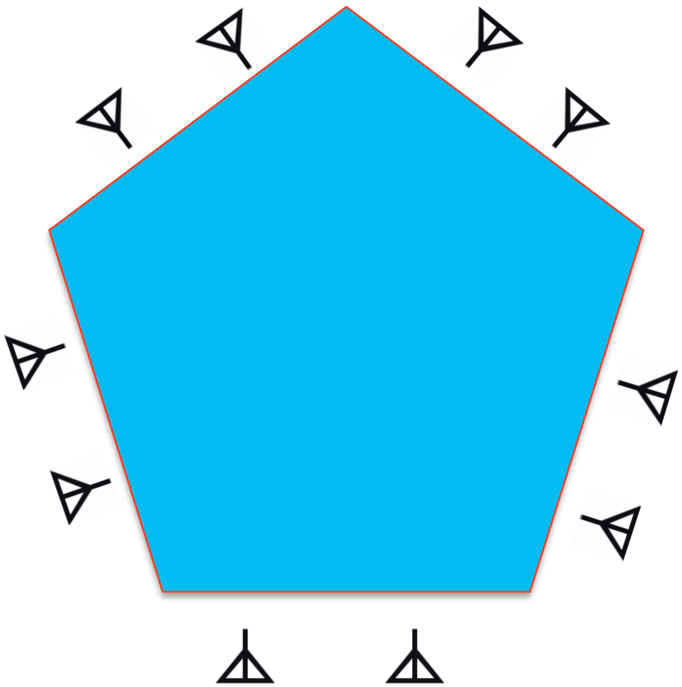
< 1 Km geolocation accuracy with distance between detectors < 10 Km

DYLEMA-Madrid System Architecture

- 9 AOA RFI & Spoofing monitoring stations (Type 1), 2 Spoofing-only monitoring stations (Type 2), an IP communications network and a Monitoring and Control Center.
- NOJAMZONE© Type 1 Monitoring Station: jamming and spoofing detection with AOA.
- NOJAMZONE© Type 2 Monitoring Station: only spoofing detection, without AOA (reinforce spoofing detection in sensitive areas such as airport runways).
- Site Acceptance Test: 17 December 2019.
- Start of monitoring operations at ENAIRE GNSS 24/7 Operations Center: 29 April 2020.

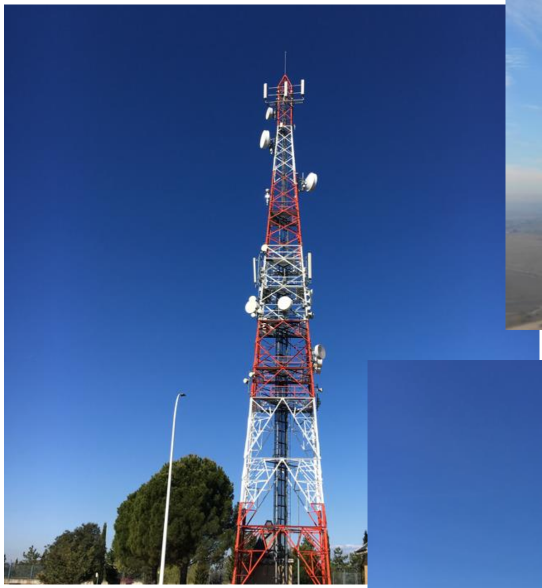


DYLEMA-Madrid Type 1 Monitoring Station



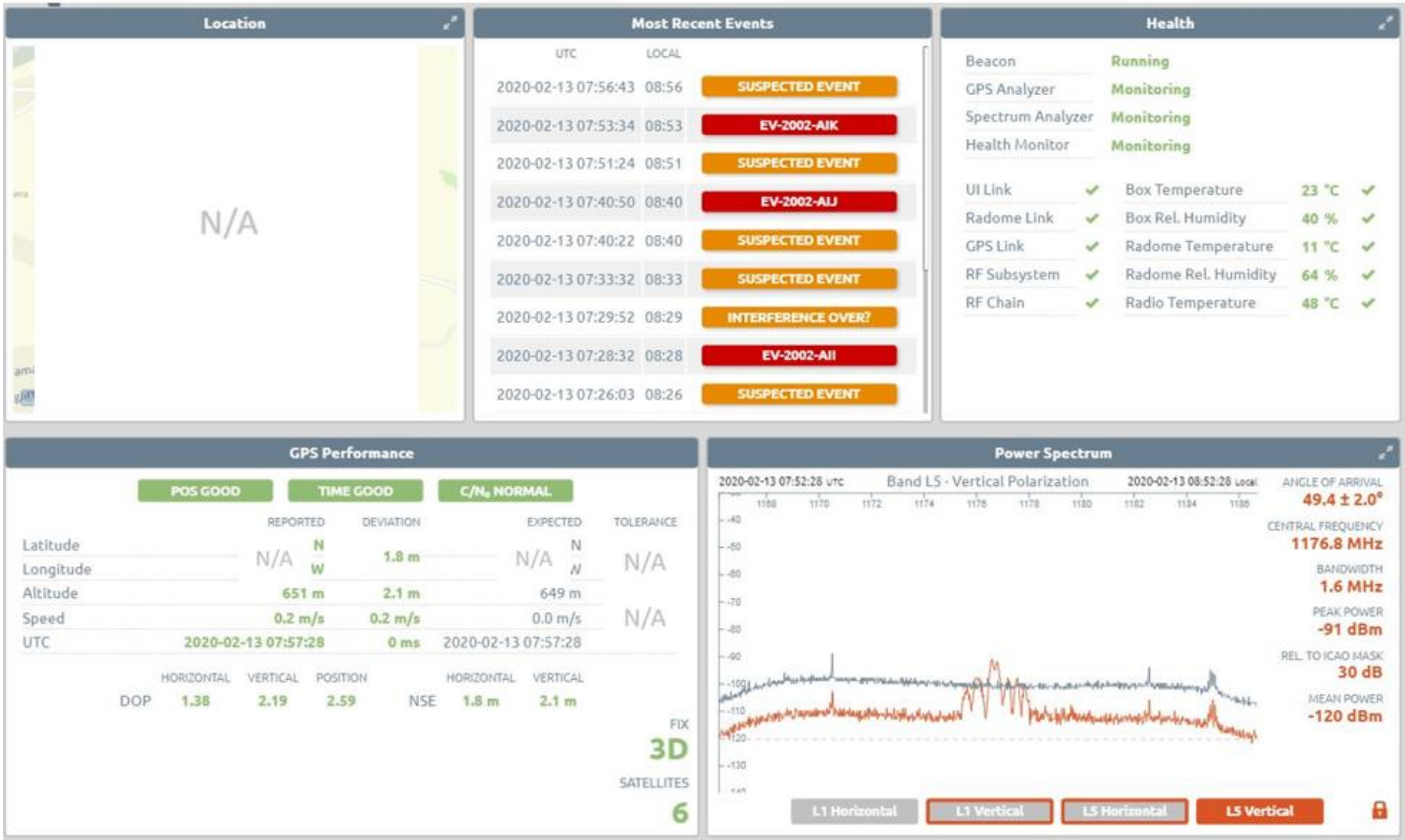
AOA Antenna module
(top view)

≈7 dBi gain

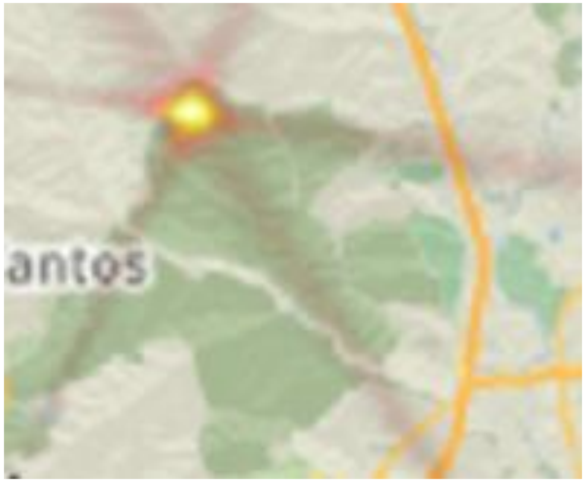


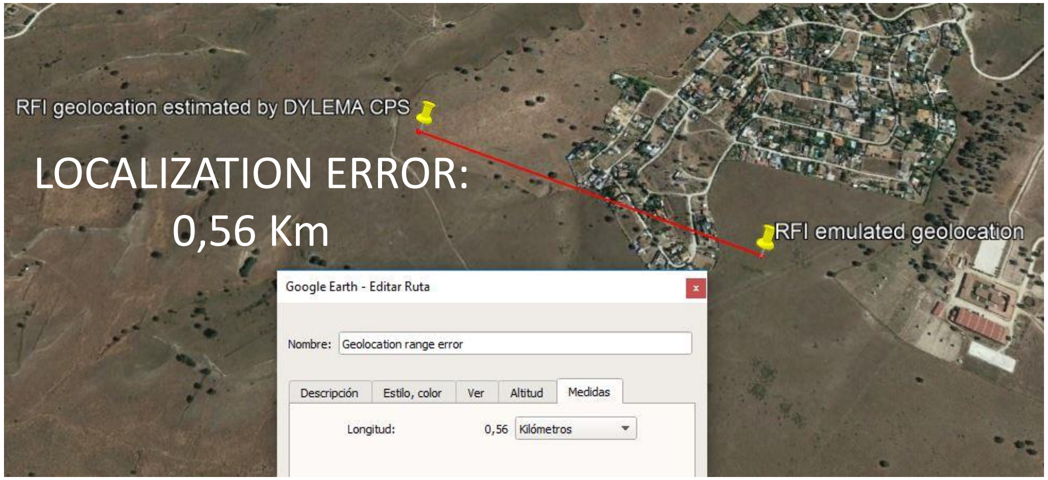
Note: Type 2 monitoring station consists only of the NOJAMBOX module and not the AOA antenna module.

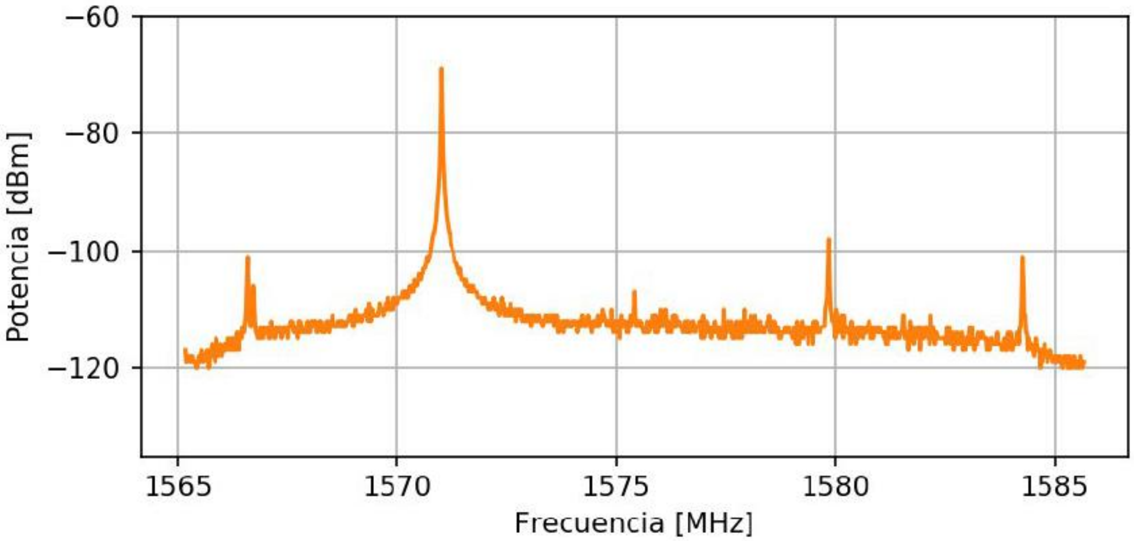
DYLEMA-Madrid Human Machine Interface



DYLEMA-Madrid Site Acceptance Test (17 Dec 2019)

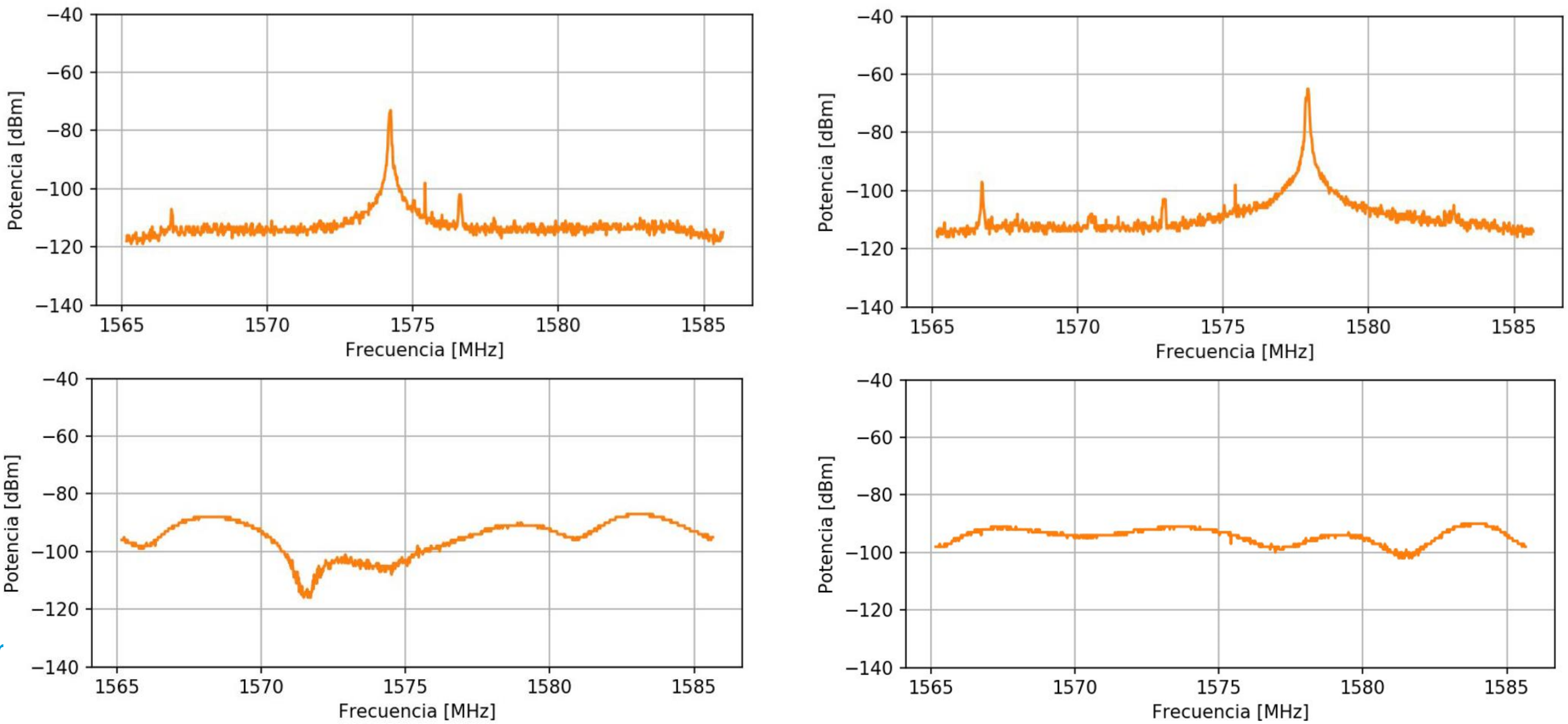






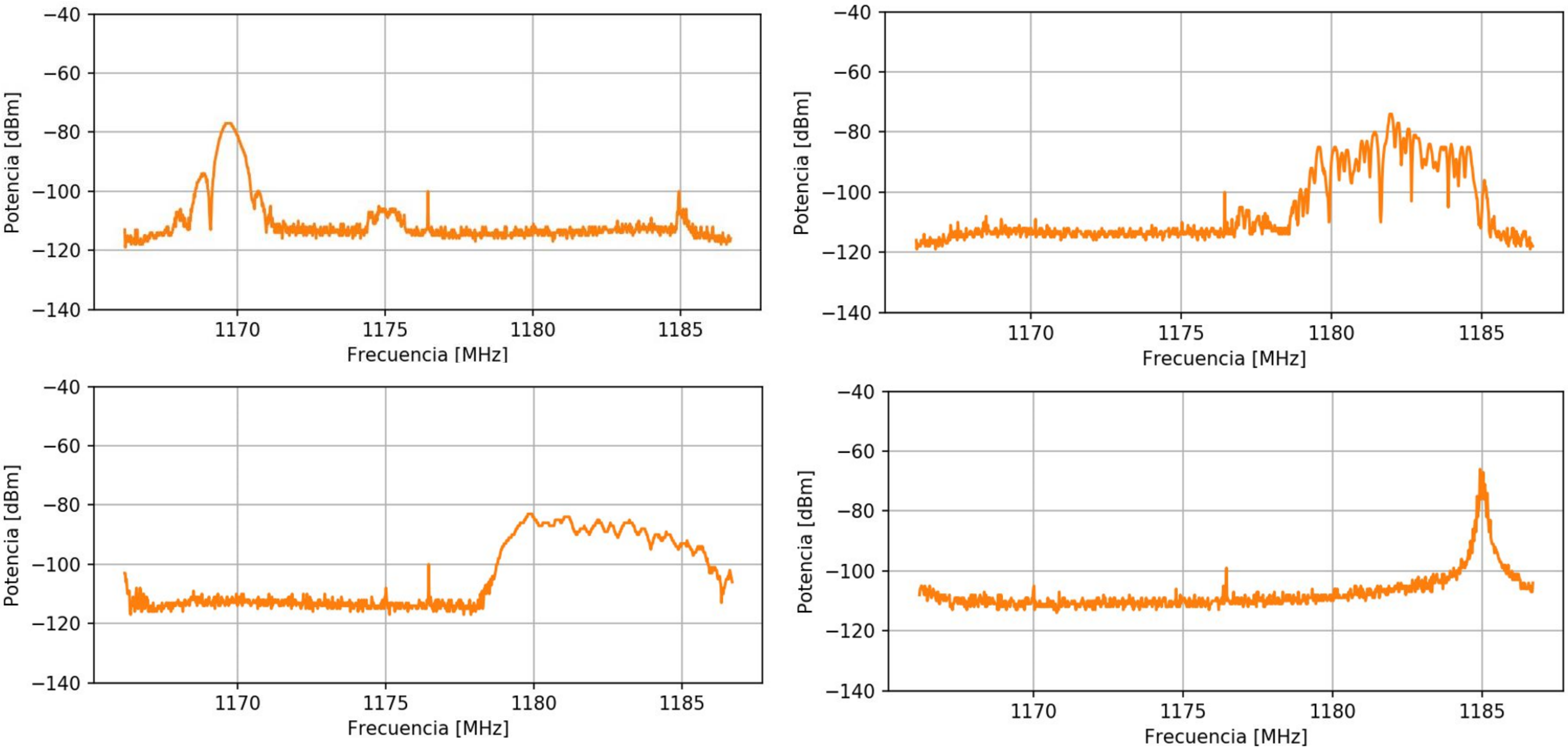
DYLEMA-Madrid L1 GNSS RFI detected events

- L1 spoofing events from April 2020 to August 2021:
    - ✓ No events detected (GPS L1 C/A).
- L1 jamming/interference events from April 2020 to August 2021 (16 months):
    - ✓ > 300 events with duration < 2 minutes. Most likely low power jammers.
    - ✓ 27 events with 20 > d ≥ 2 minutes. Most likely low power jammers.
    - ✓ 3 events with duration ≥ 20 minutes. Most likely low power jammers.



DYLEMA-Madrid L5 GNSS RFI detected events

- L5 jamming/interference events from April 2020 to August 2021 (16 months):
  - ✓ > 300 events with duration < 2 minutes.
  - ✓ 23 events with 20 > d ≥ 2 minutes. JTIDS (Joint Tactical Information Distribution System).
  - ✓ 1 event with duration ≥ 20 minutes (permanent). DME (DVOR/DME VTZ, 10 Km away).
  - ✓ Not really interference events. Pulsed transmissions compatible with GNSS L5.



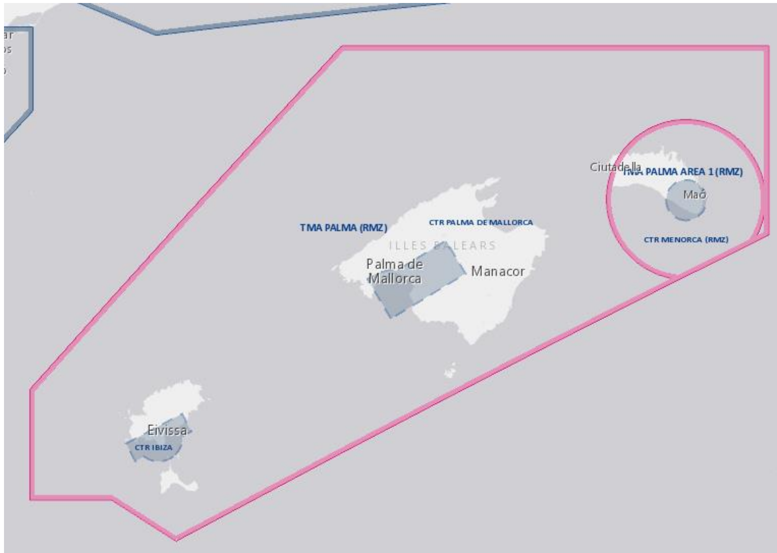
DYLEMA-Madrid L5 GNSS RFI detected events

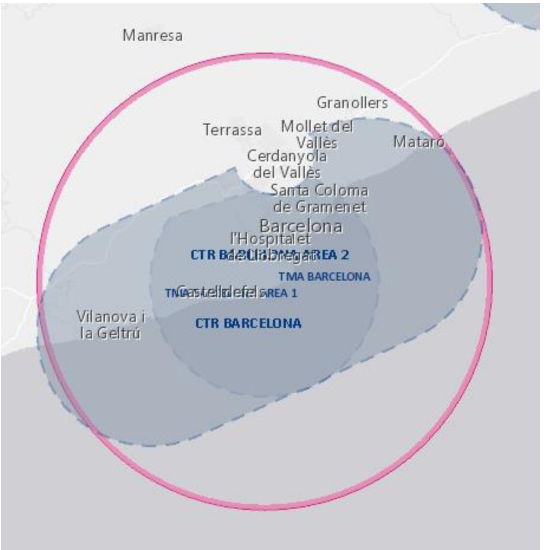
- DME VTZ (Torrejón Air Force Base):

TORREJÓN DVOR (1° W 2015)	VTZ	115.10 MHz	H24	402832.2N 0032819.3W	HR MAINT: MON: 1530-1830 LT
TORREJÓN DME	VTZ	CH 98X	H24	402832.2N 0032819.3W (660 m)	HR MAINT: MON: 1530-1830 LT

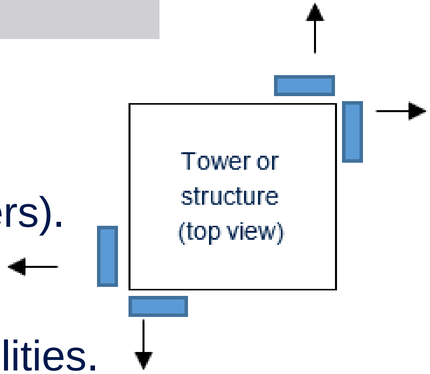
Channel pairing				DME parameters					
				Interrogation				Reply	
					Pulse codes				
						DME/P mode			
DME channel number	VHF frequency MHz	MLS angle frequency MHz	MLS channel number	Frequency MHz	DME/N µs	Initial approach µs	Final approach µs	Frequency MHz	Pulse codes µs
98X	115.10	–	–	1 122	12	–	–	1 185	12
98Y	115.15	5 077.8	656	1 122	36	36	42	1 059	30
98Z	–	5 078.1	657	1 122	–	21	27	1 059	15

DYLEMA-Palma de Mallorca / Barcelona





- Main new features:
  - ✓ Separated antenna modules: optimal solution (mounted in towers).
  - ✓ Increased monitored bandwidth per GNSS band (> 60 MHz).
  - ✓ Improved jamming and spoofing detection & localization capabilities.
  - ✓ GNSS observables storage and download in RINEX 3.05 or greater.
  - ✓ Real time transmission of GNSS observables in RTCM 3.0 or greater to a NTRIP-Caster (Networked Transport of RTCM via Internet Protocol).
  - ✓ Generation of pre-established reports in XML apart from DOC and PDF formats.



Thanks for your attention.

José Luis Madrid-Cobos – jlmadrid@enaire.es