IEEE EMC SOCIETY
BOSTON CHAPTER MEETING

EMI TESTING ON SPACE SYSTEMS

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ROHDE&SCHWARZ

Make ideas real

OVERVIEW

- ► **Use of FFT-based Measuring Receivers for more reliable and faster EMI testing on space systems**
- ► **Joined work INTA and Rohde & Schwarz**

GOBIERNO DE ESPAÑA | MINISTERIO DE DEFENSA | INTA INSTITUTO NACIONAL DE TÉCNICA AEROESPACIAL

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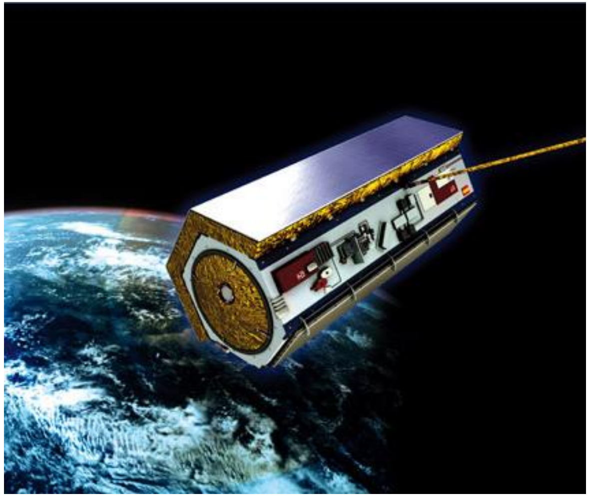
OVERVIEW

- ► Complexity of EMC testing on space systems
- ► CISPR 16 – FFT-based measuring receiver
- ► Consideration of measurement time
- ► ANSER EMC test campaign by INTA
  - ► Comparison measurements on a nanosatellite
  - ► Measurements with small RBW in frequency notches
- ► Conclusions

COMPLEXITY OF EMC TESTING ON SPACE SYSTEMS

The complexity of space systems in terms of

- ► **High integration level, high electronics density**
- ► **Load limitations**
- ► **High reliability**
- ► **Diverse electromagnetic ambient: pre-launch, launch, orbit**
- ► **Qualification tests to demonstrate the design requirements have been achieved with the specified margins: climatic, mechanical, RF tests, EMC…**

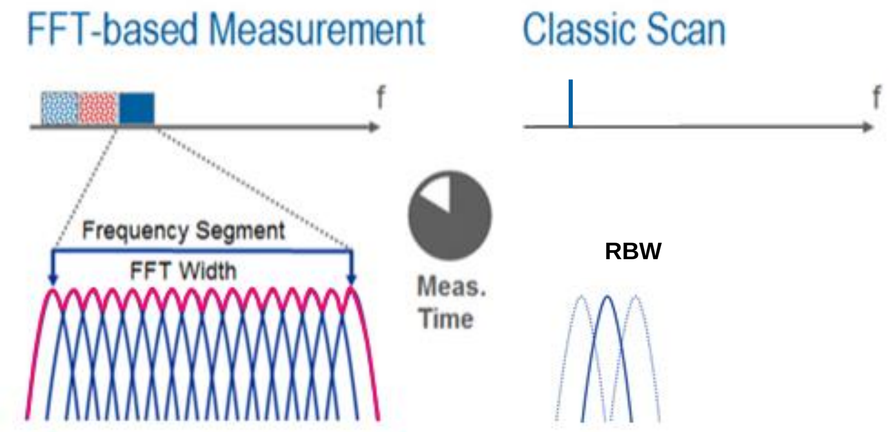


Spanish Satellite Earth Observation "Paz"

MOTIVATION FOR FFT-BASED MEASURING RECEIVERS

- **More Speed – FFT-based receivers are measuring spectral segments much wider than the resolution bandwidth during the measurement time by parallel calculation at several frequencies**

- **More Reliable – FFT allows application of longer measurement times, e.g. for measuring intermittent signals**

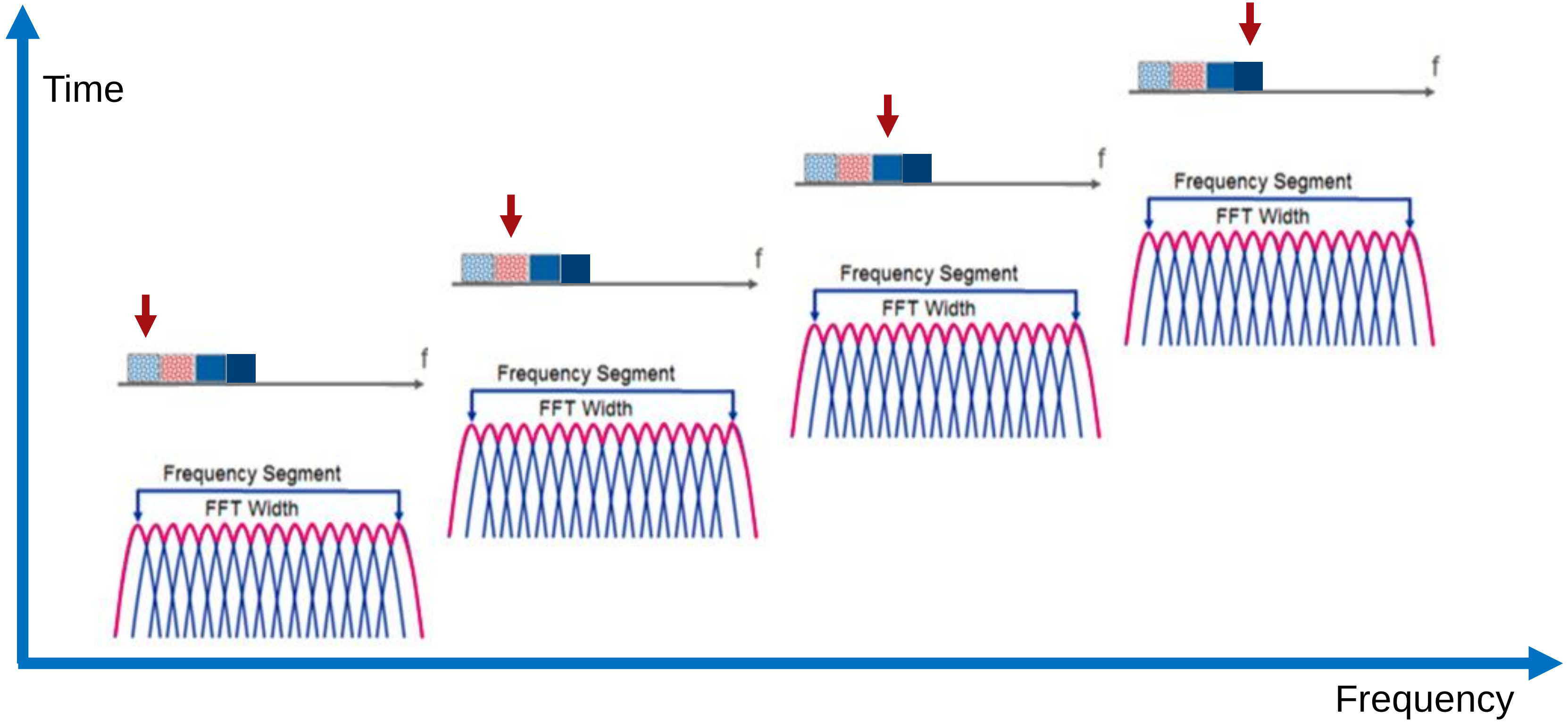


Ultra-fast scan time for entire frequency range

Long scan time for entire frequency range

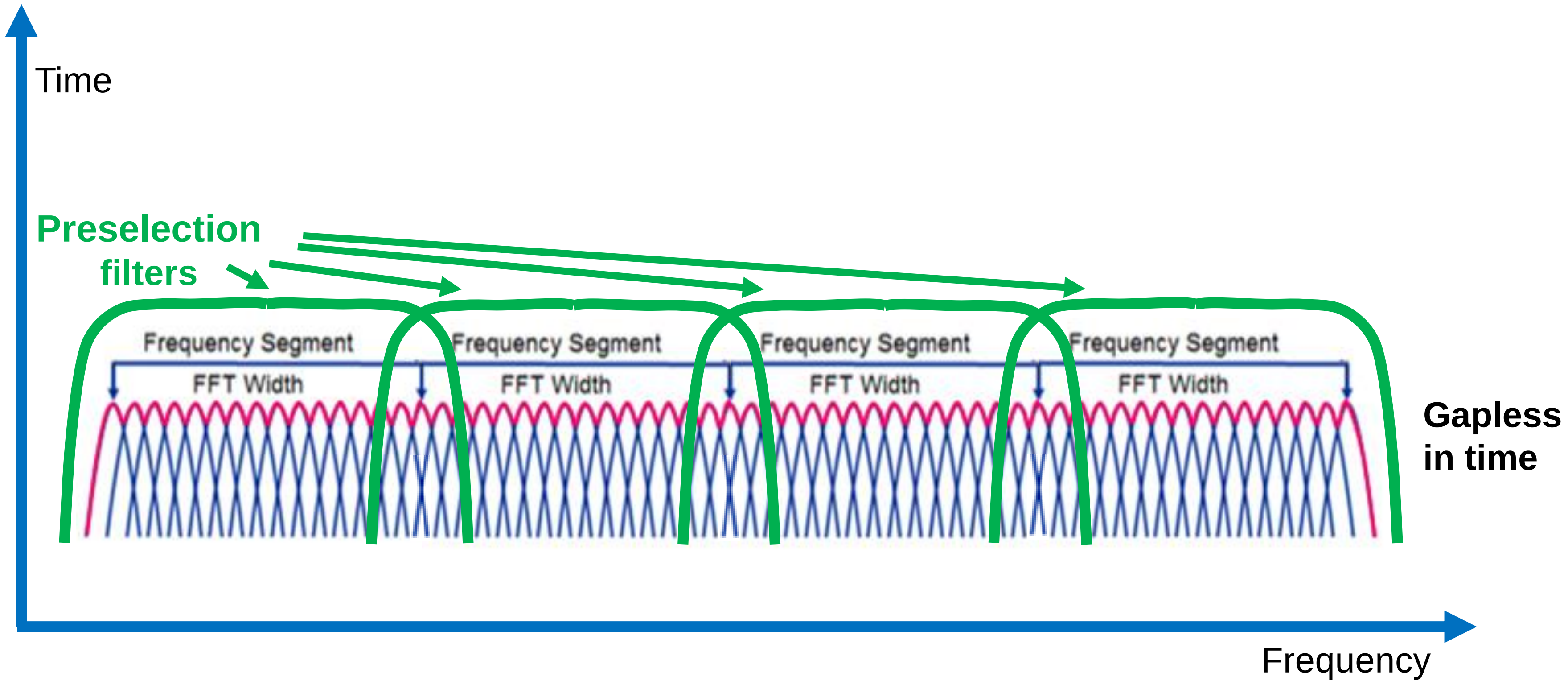
MOTIVATION FOR FFT-BASED MEASURING RECEIVERS

Consecutive measured FFT-Segments if Span > FFF Width



MOTIVATION FOR FFT-BASED MEASURING RECEIVERS

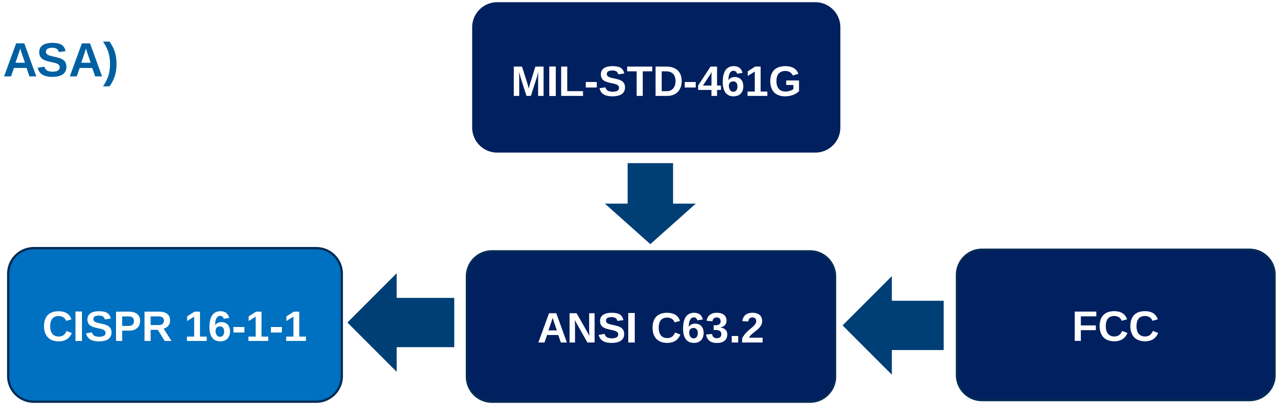
Parallel measured FFT-Segments



CISPR 16 – FFT-BASED MEASURING RECEIVERS

Applicability

- Military & Aerospace Standards
  - MIL-STD 461G
  - AIAA
  - GSFC (NASA)



Additional requirements
18 GHz to 40 GHz

CISPR 16 – FFT-BASED MEASURING RECEIVERS

Applicability

- Commercial Product Standards
  - CISPR 11:2015 (Industrial Scientific Medical)
  - CISPR 14-1:2016 (Household)
  - CISPR 15:2013 (Lighting)
  - CISPR 25:2016 (Automotive)
  - CISPR 32:2012 (Multimedia)
  - CISPR 36:2020 (Automotive)
  - FCC Part 15, ANSI C63.4 (referencing ANSI C63.2:2016)
- Commercial Generic Standards
  - IEC 61000-6-3 (Residential), -6-4 (Industrial), -6-8 (Light-industrial)

CISPR 16 – FFT-BASED MEASURING RECEIVERS

Amendment 1:2010-06 to CISPR 16-1-1 (3rd Ed.)

► **Blackbox approach**

► **FFT-based measurement receiver for compliance testing**

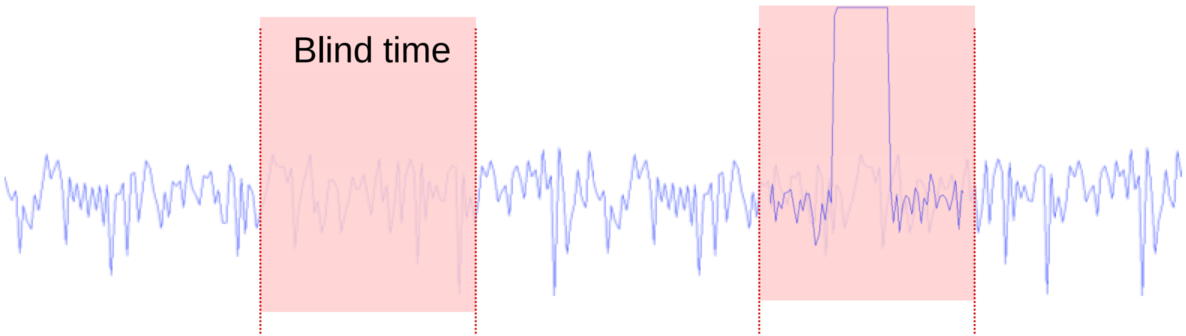
"instrument such as a tunable voltmeter, an EMI receiver, a spectrum analyzer or an FFT-based measuring instrument, with or without preselection, that meets the relevant parts of this standard"

CISPR 16 – FFT-BASED MEASURING RECEIVERS

Amendment 1:2010-06 to CISPR 16-1-1 (3rd Ed.)

► **With traditional instruments there is a blind time between capturing the signal**

► **Information might be and will be overlooked**

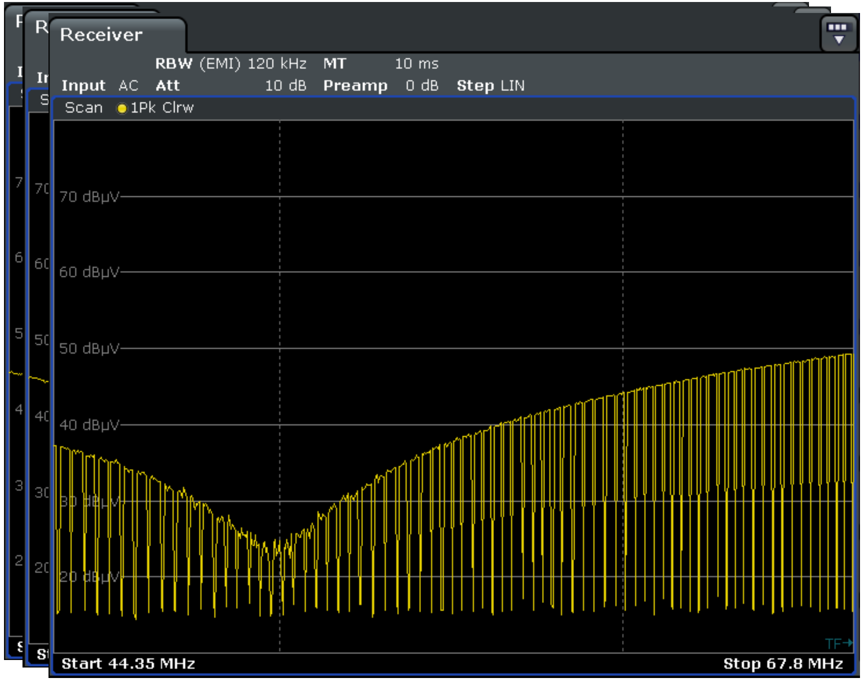


"for EMI measurements, FFT-based measuring instruments shall sample and evaluate the signal continuously during the measurement time"

CONSIDERATION OF MEASUREMENT TIME

Wrong measurement time can result in enormous errors!

- ► Pulse modulated carrier with 12 ms pulse period, Time Domain Scan shows closed trace with 12 ms measurement time
- ► Gaps in TD Scan trace with 10 ms measurement time
- ► Even when 10 ms yields a closed trace in Stepped Scan, zooming in reveals gaps in the trace
- ► Important minimum measurement (dwell) time ≥ signal period!



CONSIDERATION OF MEASUREMENT TIME

More reliable when applying longer measurement times

- ► **Example: MIL-STD-461G (2015)**
- ► **A pulse signal that occurs once per second with a short duration of 10 microseconds will typically be captured at a number of measurement points with a stepped-tuned receiver**
- ► **But would have only about a 1.5 % probability of being captured by the FFT-based measuring receiver (0.015 s measurement time for 1 s period)**
- ► **The solution is to increase the measurement time to at least 1 second to detect the pulse as required in MIL-STD-461G**

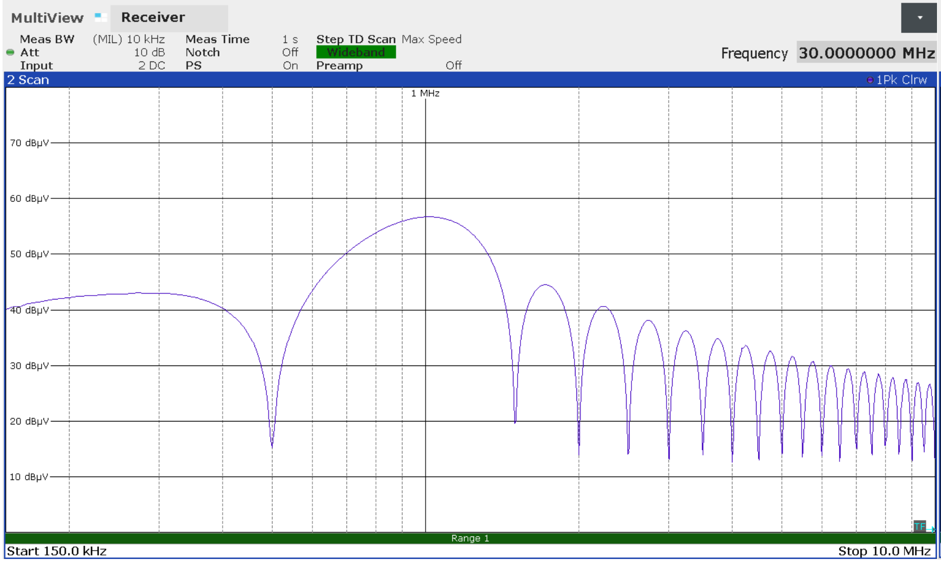
Minimum Dwell Time	
Stepped-Tuned Receiver [1/] (Seconds)	FFT Receiver [2/] (Seconds/ Measurement Bandwidth)
0.15	1
0.015	1
0.015	1
0.015	1
0.015	0.15
0.015	0.15
0.015	0.015

Source: MIL-STD-461:2015 (Rev,G)

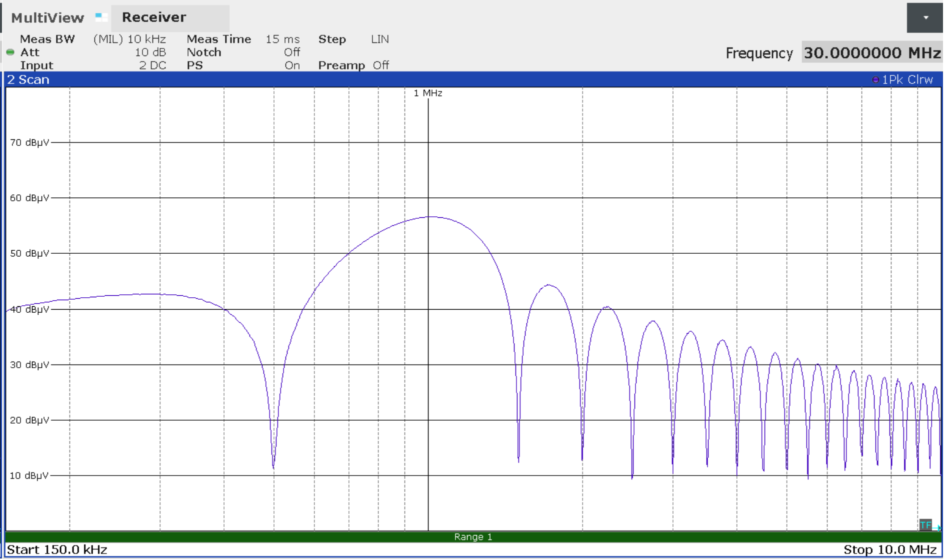
CONSIDERATION OF MEASUREMENT TIME

Reliable pulsed signal measurements independent of scanning method

FFT-based Receiver in TD Scan Mode (RBW = 10 kHz, Minimum DT = 1 s)



Traditional instrument in Stepped Scan Mode (RBW = 10 kHz, Minimum DT = 15 ms)



INTA TESTING CAPABILITIES

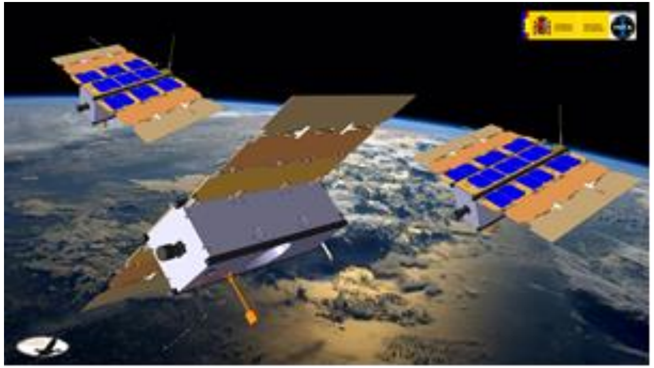
► **EMC Tests according to civilian, military (MIL-STD-461, AECTPs NATO), aeronautical (RTCA DO-160) and space (ECSS-E-ST-20-07c) standards**

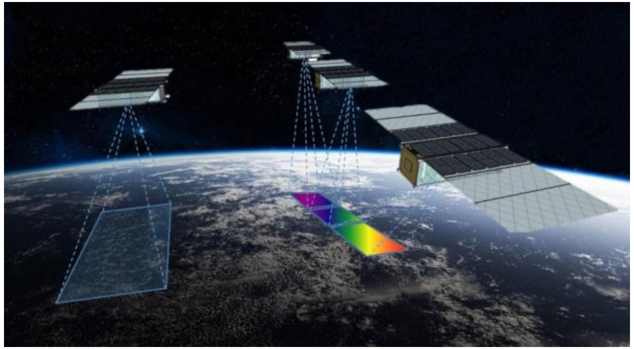
DEYMOS satellite test campaign
INTA semi-anechoic chamber ISO8
(Source: www.inta.es)

ESA VEGA test campaign
INTA anechoic chamber
(Source: www.inta.es)

ANSER EMC TEST CAMPAIGN

- **ANSER (*Advanced Nanosatellites Systems for Earth Observation Research*) designed by INTA**
- **Main concepts**
  - **Constellation of nanosatellites**
  - **Formation flying**
  - **Fractionated instruments**
  - **Miniaturized optical technologies**
- **Main goal**
  - **Earth Observation Missions for monitoring the quality of water reservoirs overthe Iberian Peninsula**

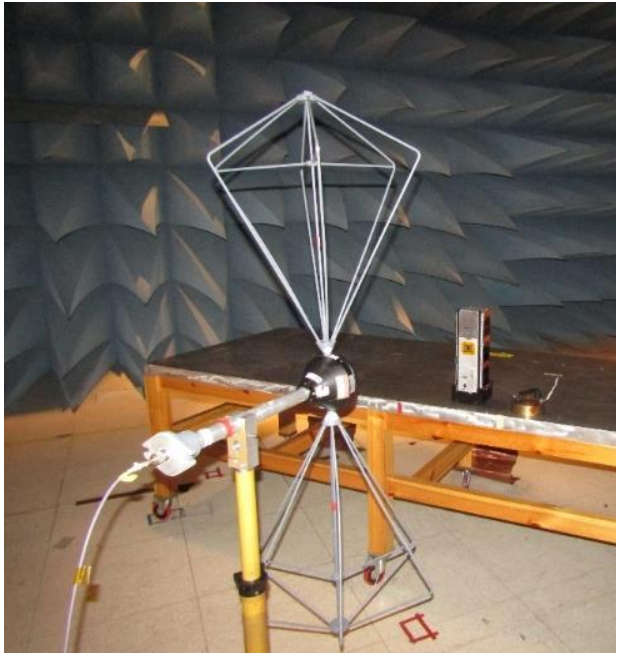

Source: ANSER flyer - INTA


Source: ANSER formation flight - INTA

ANSER EMC TEST CAMPAIGN

Measurement Ranges and Test Setup

- **Facility: INTA semi-anechoic chamber (24 m x 14 m x 10 m) ISO 8 cleanliness conditions**
- **Electric field radiated emissions measurements on the leader Flight Model (FM) from 14 kHz up to 18 GHz**
  - **14 kHz – 30 MHz: Rod Antenna, vertical polarization**
  - **30 MHz – 200 MHz: Biconical Antenna, vertical and horizontal polarization**
  - **200 MHz – 1 GHz: Double Ridge Horn, vertical and horizontal polarization**
  - **1 GHz – 18 GHz: Double Ridge Horn, vertical and horizontal polarization**
- **Test setup:**
  - **RE102 MIL-STD-461G → FFT mode**
  - **RE ECSS-E-ST-20-07c Rev.2 → Stepped tuned mod**

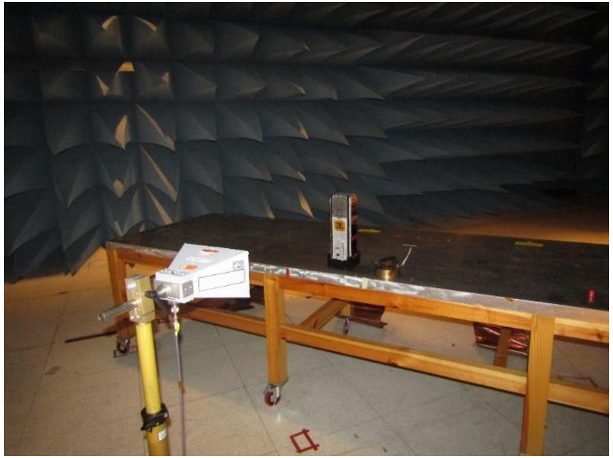


RE – Biconical Antenna
(30 MHz – 200 MHz)
Source: INTA

ANSER EMC TEST CAMPAIGN

Why using a FFT-based measuring receiver?

- ► **More reliable measurements**
  - ► **Capture transient events, e.g. intermittent radio signals, upfolding solar panels…**
- ► **Time saving**
  - ► **EUTs can be operated during short periods of time without damage**
  - ► **Several operating modes tested**
  - ► **Measurement in frequency notches**



RE – Horn Antenna
(1 GHz – 18 GHz)
Source: INTA

COMPARISON MEASUREMENTS

- Electric field radiated emission tests have been performed in the frequency range from 14 kHz to 18 GHz
- According to ECSS-E-ST-20-07c Rev.2 with the measuring receiver in stepped-tuned mode
- And to MIL-STD-461G with the measuring receiver in FFT mode
- Bandwidths (BW) and measurement times

Frequency Range	6 dB bandwidth	Dwell time
30 Hz – 1 kHz	10 Hz	0.15 s
1 kHz – 10 kHz	100 Hz	0.015 s
10 kHz – 150 kHz	1 kHz	0.015 s
150 kHz – 30 MHz	10 kHz	0.015 s
30 MHz – 1 GHz	100 kHz	0.015 s
Above 1 GHz	1 MHz	0.015 s

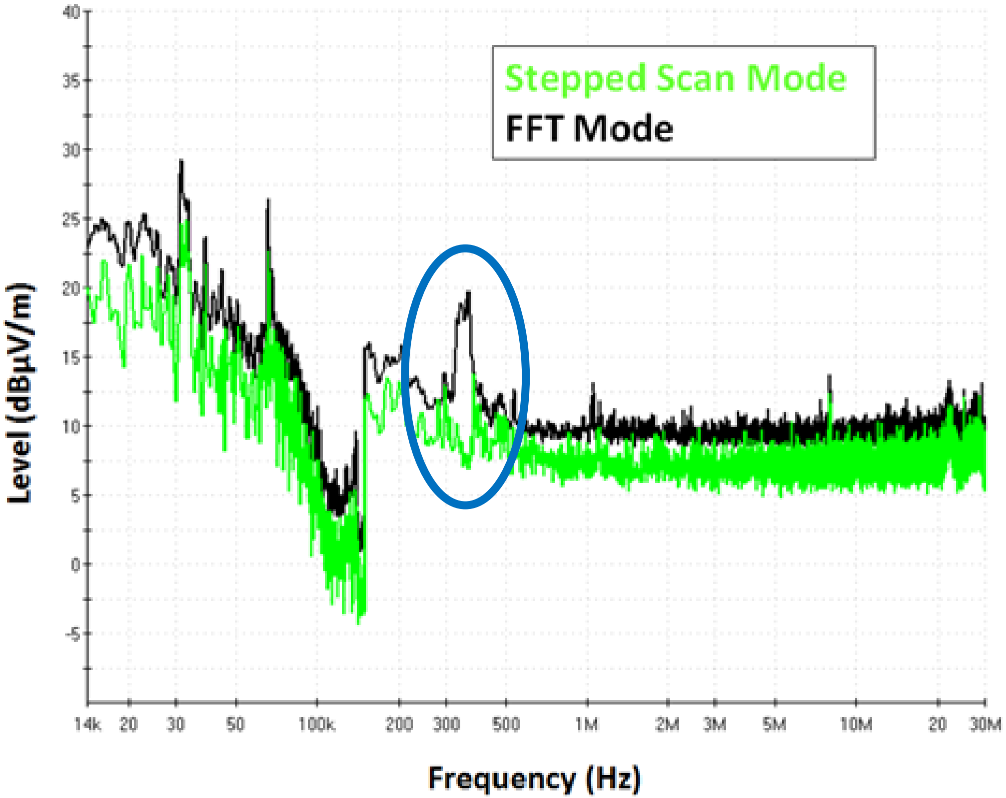
Source: ECSS-E-ST-20-07c Rev.2

Frequency Range	6 dB Resolution Bandwidth	Minimum Dwell Time	
		Stepped-Tuned Receiver 1/ (Seconds)	FFT Receiver 2/ (Seconds/ Measurement Bandwidth)
30 Hz - 1 kHz	10 Hz	0.15	1
1 kHz - 10 kHz	100 Hz	0.015	1
10 kHz - 150 kHz	1 kHz	0.015	1
150 kHz - 10 MHz	10 kHz	0.015	1
10 MHz - 30 MHz	10 kHz	0.015	0.15
30 MHz - 1 GHz	100 kHz	0.015	0.15
Above 1 GHz	1 MHz	0.015	0.015

Source: MIL-STD-461:2015 (Rev,G)

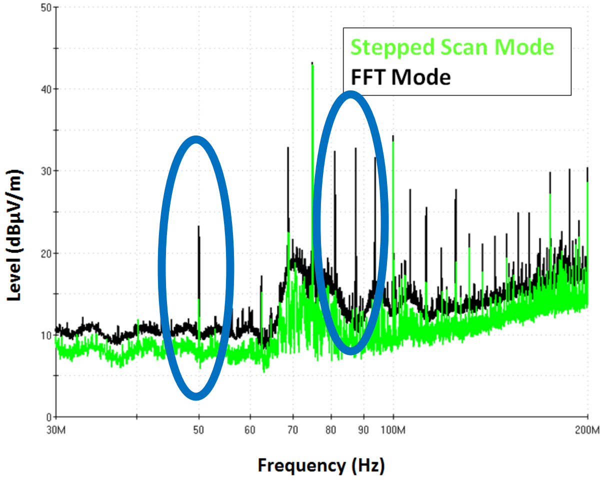
COMPARISON MEASUREMENTS

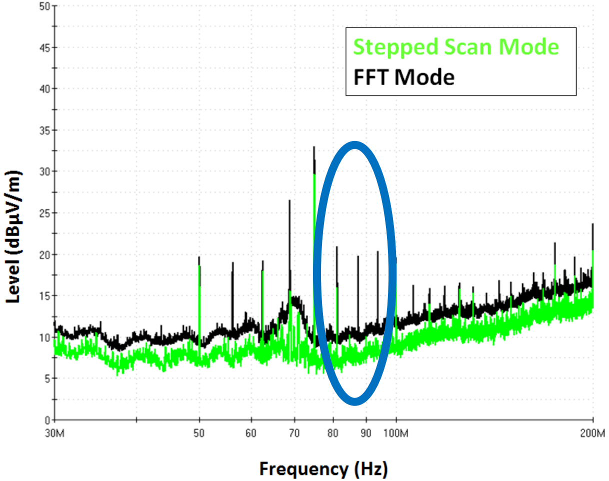
- Measurement results in the range of 14 kHz to 30 MHz, vertical polarization
- Differences can be found around 300 kHz due to a not steady signal



COMPARISON MEASUREMENTS

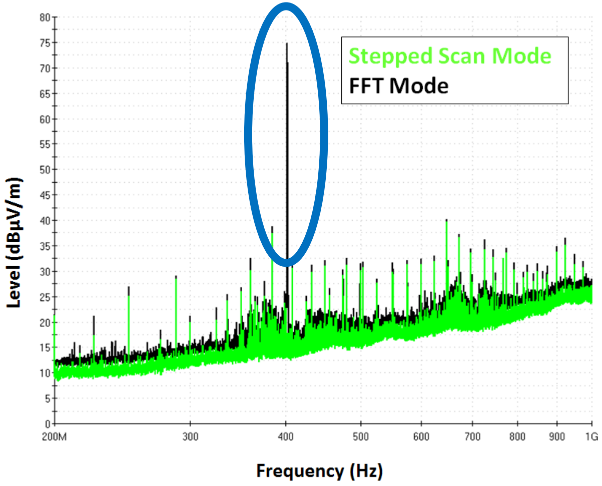
- Measurement results in the range from 30 MHz to 200 MHz, vertical polarization (left) and horizontal polarization (right)
- Significant differences can be found in both polarizations related to an internal clock, some of the harmonics are steady and others are intermittent
- In FFT mode all harmonics are recorded while with the stepped scan mode some of them are missing or the measured level is lower

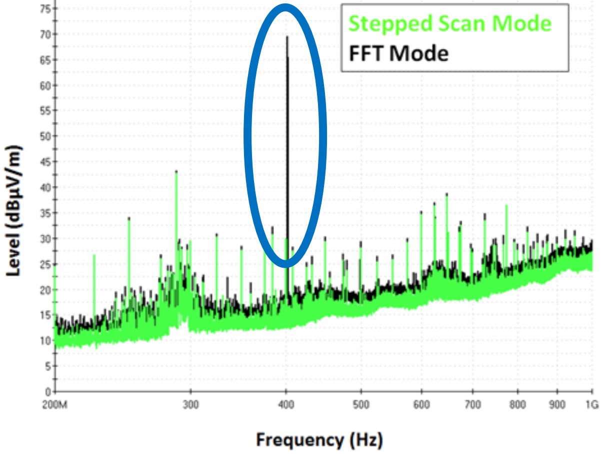




COMPARISON MEASUREMENTS

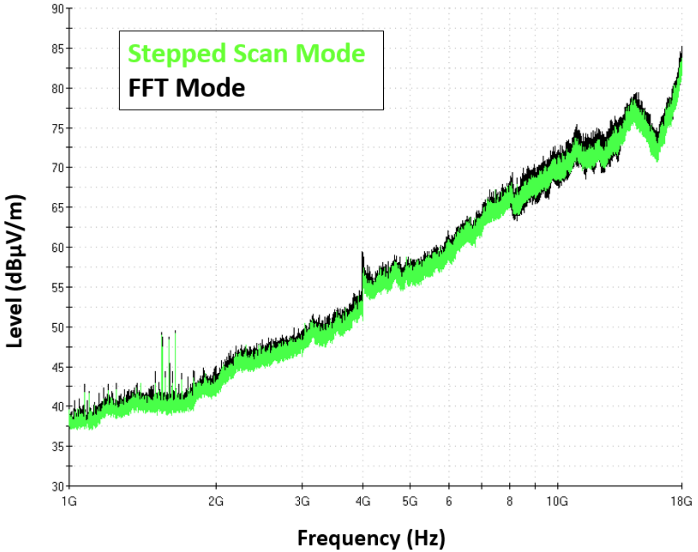
- Measurement results in the range from 200 MHz to 1 GHz, vertical polarization (left) and horizontal polarization (right)
- Significant differences can be found in both polarizations related to an intermittent signal at 401.85 MHz with a duration of 200 ms and a period of 10 seconds
- In FFT mode the signal was captured while with the stepped scan mode not

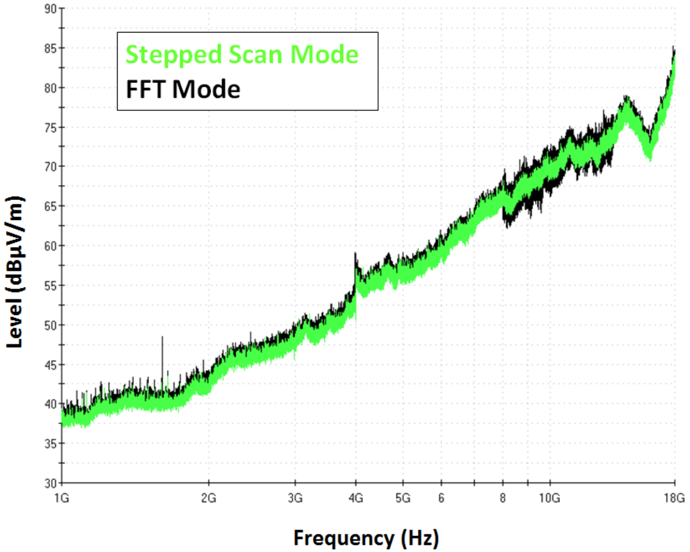




COMPARISON MEASUREMENTS

- **Measurement results in the range from 1 GHz to 18 GHz, vertical polarization (left) and horizontal polarization (right)**
- **In this frequency range no huge differences are found between both measurement modes**





TIME SAVING IN ANSER EMC TEST CAMPAIGN

MIL-STD-461G: EMI receiver in FFT mode

1 minute

Frequency Range	6 dB BW	Step Size	Dwell time	Total duration
14 kHz – 150 kHz PV	1 kHz	250 Hz	1 s	**7''**
150 kHz – 10 MHz PV	10 kHz	2,5 kHz	1 s	**4''**
10 MHz – 30 MHz PV	10 kHz	2,5 kHz	0.15 s	**2''**
30 MHz – 200 MHz PV	100 kHz	25 kHz	0.15 s	**3''**
30 MHz – 200 MHz PH	100 kHz	25 kHz	0.15 s	**3''**
200 MHz – 1 GHz PV	100 kHz	25 kHz	0.15 s	**5''**
200 MHz – 1 GHz PH	100 kHz	25 kHz	0.15 s	**5''**
1 GHz – 18 GHz PV	1 MHz	250 kHz	0.015 s	**16''**
1 GHz – 18 GHz PH	1 MHz	250 kHz	0.015 s	**16''**

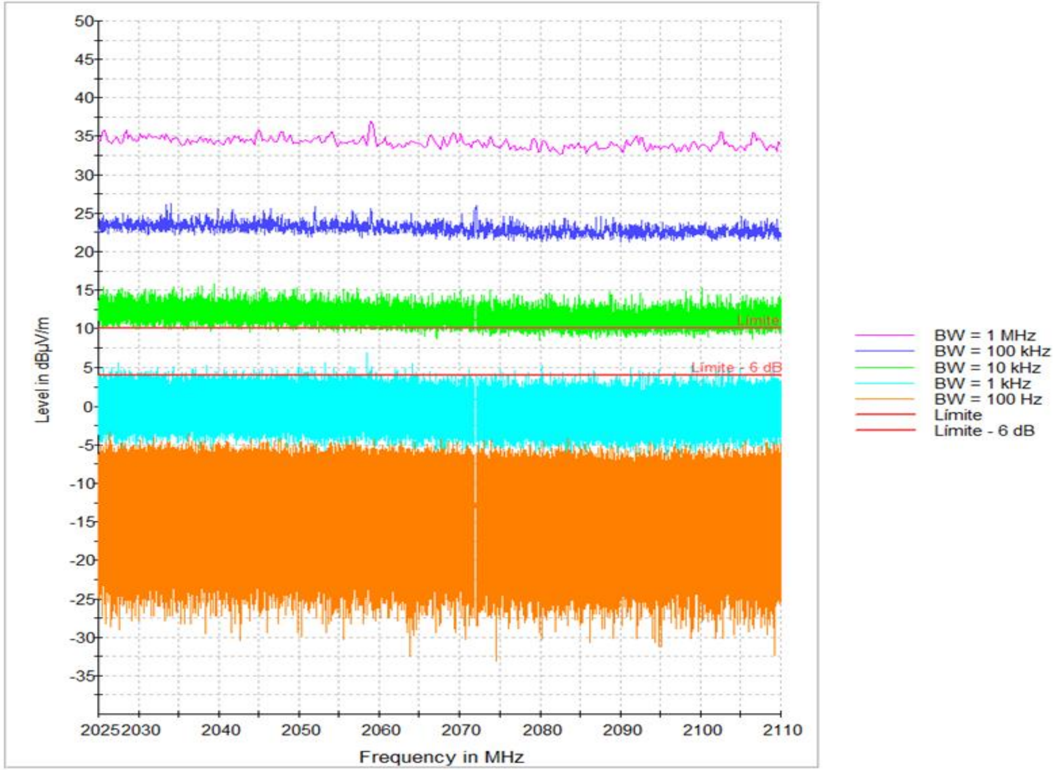
ECSS-E-ST-20-07c Rev.2: EMI receiver in stepped-tuned mode

Frequency Range	6 dB BW	Step Size	Dwell time	Total duration
			0.015 s	**40''**
			0.015 s	**2' 38''**
			0.015 s	**1' 25''**
			0.015 s	**1' 24''**
			0.015 s	**6' 35''**
			0.015 s	**6' 34''**
			0.015 s	**13' 54''**
			0.015 s	**13' 52''**

48 minutes

MEASUREMENTS IN FREQUENCY NOTCHES

- **Frequency notch:**
  2025 MHz – 2110 MHz
- **Ambient noise level requirement:**
  At least 6 dB below applicable limit
- **Adequate bandwidth:**
  100 Hz



MEASUREMENTS IN FREQUENCY NOTCHES

Frequency Range (*Span*)	6 dB BW	Step Size (Δf) (BW * 0,4)	Number of freq. points (n) (*Span*/Δf)	Total duration (n * 0,015 s)
2025 MHz – 2110 MHz → 85 MHz	1 MHz	400 kHz	213	3”
	100 kHz	40 kHz	2125	32”
	10 kHz	4 kHz	21250	5’ 9”
	1 kHz	400 Hz	212500	53’ 8”
	100 Hz	40 Hz	2125000	8h 51’ 15”

- **Stepped Scan Mode with BW = 100 Hz:** **≈ 9 hours**

- **FFT Mode with BW = 100 Hz** **≈ 1,5 minutes**

Frequency Range (*Span*)	6 dB BW	Step Size (Δf) (BW * 0,25)	Total duration (dwell time 0,015 s)
2025 MHz – 2110 MHz → 85 MHz	1 MHz	250 kHz	< 2”
	100 kHz	25 kHz	< 2”
	10 kHz	2.5 kHz	< 2”
	1 kHz	250 Hz	10”
	100 Hz	25 Hz	1’ 33”

CONCLUSIONS

- **FFT-based measuring receivers can be used for EMI compliance measurements in accordance with MIL-STD-461G if the receiver is in line with ANSI C63.2 and CISPR 16-1-1**
- **The use of FFT-based measuring receivers is motivated by reducing the scan time by several orders of magnitude without degradation of accuracy – This is particular useful when measuring with small receiver bandwidth in a frequency notch**
- **Measurement results become more reliable when applying longer measurement times and with multiple scans in combination with the receiver's max hold function – This is particular useful when measuring intermittent disturbance signal and transients**

EMI TESTING ON SPACE SYSTEMS

Thank you for your interest!

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