MIL-STD-461G & CISPR 16-1-1 Emission Measurements using FFT Receivers

ABSOLUTE EMC

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GAUSS INSTRUMENTS

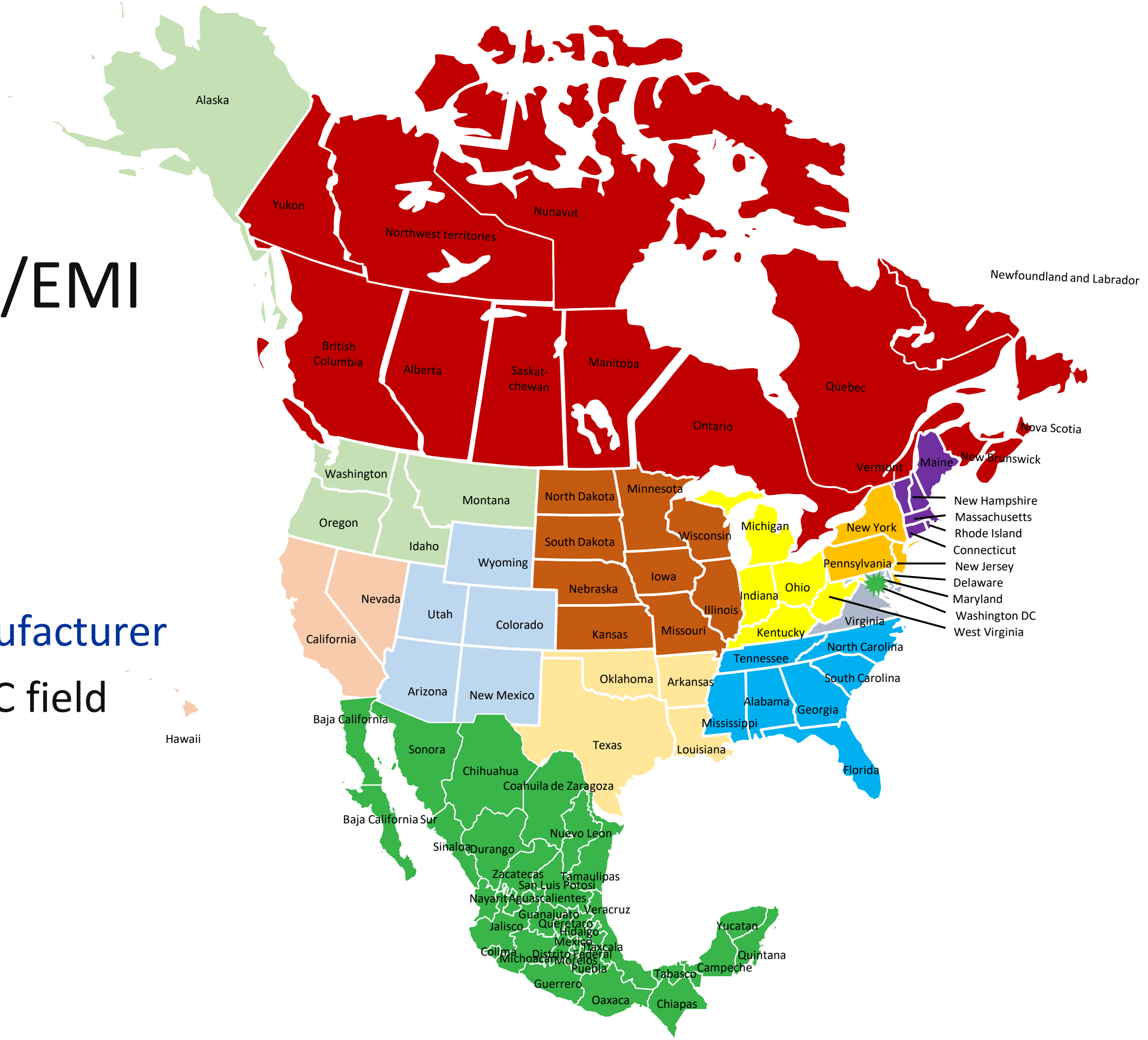


Contents

- Overview
- MIL-STD-461G requirements for CE/RE
- Spectrum analyzer vs. Receiver vs. FFT Technology vs. FFT Receiver
- Dynamic Range
- Define the use of preselection
- Pre-scanning vs. Compliant Results
- Accuracy/Repeatability with a FFT Receiver
- FFT Application examples beyond MIL-STD

Why am I here?

- Jason H. Smith
  - 21+ years total experience in EMC/EMI
    - 7 years EMC Lab Manager Radiation Science+
      - FCC, MIL-STD, DO, CE Mark
    - 8 years Applications Engineering Manager
      - IEC 77B 77C WG10 Member
      - RF Immunity and Emissions equipment manufacturer
    - 6 years Sales/Marketing Manager in the EMI/EMC field
      - AE2 Lightning committee



Emissions Testing is Time Consuming

- All testing is a compromise
  - From real world problems vs. what can be done in a lab
  - For a reasonable cost and time
- Compromises are made to allow for testing in a reasonable time
- Further compromises are made for complex products
- Can this be pushed too far effecting results & reproducibility?

- New FFT technology can reduce compromise

FFT is here!

- Old Standards (MIL 461F) have been written for Superheterodyne (Superhet) / Spectrum analyzer
- New Standards (MIL 461G CISPR 16-1-1) point out requirements for FFT-based testing
- CISPR recommends FFT-based testing
- ETSI and similar Standards use Real-time Spectrum Analyzer and Spectrum Analyzer

- The “perfect EMI Test Box” should have
  - Superhet Mode
  - FFT- Based Mode (full Compliance)
  - Real-time Mode according to MIL 461G and CISPR und ANSI
  - IQ – Data and wide IF Bandwidth
  - Mobile usage

MIL-STD-461G

General Requirements for RE/CE Receiver

RE/CE Receiver

4.3.4 Ambient electromagnetic level.
During testing, the ambient electromagnetic level measured with the EUT de-energized and all auxiliary equipment turned on shall be at least 6 dB below the allowable specified limits when the tests are performed in a shielded enclosure…..

4.3.9 Operation of EUT.
During emission measurements, the EUT shall be placed in an operating mode which produces maximum emissions. During susceptibility testing, the EUT shall be placed in its most susceptible operating mode. For EUTs with several available modes (including software/firmware controlled operational modes), a sufficient number of modes shall be tested for emissions and susceptibility such that all circuitry is evaluated. The rationale for modes selected shall be included in the EMITP.

4.3.10 Use of measurement equipment.
Measurement equipment shall be as specified in the individual test procedures of this standard. Any frequency selective measurement receiver may be used for performing the testing described in this standard provided that the receiver characteristics (that is, sensitivity, selection of bandwidths, detector functions, dynamic range, and frequency of operation) meet the constraints specified in this standard and are sufficient to demonstrate compliance with the applicable limits. Typical instrumentation characteristics may be found in ANSI C63.2. Measurement receivers using Fast Fourier Transform (FFT) time domain measurement techniques are acceptable for use, as long as Table II parameters are directly user accessible and can be verified.

RE/CE Receiver

4.3.10.1 Detector.
A peak detector shall be used for all frequency domain emission and susceptibility measurements….

4.3.10.3 Emission testing.
4.3.10.3.1 Bandwidths.
The measurement receiver bandwidths listed in Table II shall be used for emission testing. These bandwidths are specified at the 6 dB down points for the overall selectivity curve of the receivers. Video filtering shall not be used to bandwidth limit the receiver response. If a controlled video bandwidth is available on the measurement receiver, it shall be set to its greatest value. Larger receiver bandwidths may be used; however, they may result in higher measured emission levels. No bandwidth correction factors shall be applied to test data due to the use of larger bandwidths.

RE/CE Receiver

TABLE II. Bandwidth and measurement time.

Frequency Range	6 dB Resolution Bandwidth	Dwell Time		Minimum Measurement Time Analog-Tuned Measurement Receiver 1/
		Stepped-Tuned Receiver 1/ (Seconds)	FFT Receiver 2/ (Seconds/ Measurement Bandwidth)	
30 Hz - 1 kHz	10 Hz	0.15	1 6.67x	0.015 sec/Hz
1 kHz - 10 kHz	100 Hz	0.015	1 66.7x	0.15 sec/kHz
10 kHz - 150 kHz	1 kHz	0.015	1 66.7x	0.015 sec/kHz
150 kHz - 10 MHz	10 kHz	0.015	1 66.7x	1.5 sec/MHz
10 MHz - 30 MHz	10 kHz	0.015	0.15 10x	1.5 sec/MHz
30 MHz - 1 GHz	100 kHz	0.015	0.15 10x	0.15 sec/MHz
Above 1 GHz	1 MHz	0.015	0.015	15 sec/GHz

FFT is requiring more time sampling

RE/CE Receiver

1/ **Alternative scanning technique**. Multiple faster sweeps with the use of a maximum hold function may be used if the total scanning time is equal to or greater than the Minimum Measurement Time defined above.

2/ **FFT Receivers.** FFT measurement techniques may be used provided that FFT operation is in accordance with ANSI C63.2. The user interface of the measurement receiver must allow for the direct input of the parameters in Table II for both FFT Time Domain and Frequency Stepped modes of measurement in the same manner, without the necessity or opportunity to control FFT functions directly.

"Ideally the acquisition of the FFT receiver and calculation shall be during the dwell time gapless, preferable in real-time"

- **Receiver must be gapless during measurement**
- **Best if readout is real-time for better analysis**

RE/CE Receiver

4.3.10.3.2 Emission identification.
All emissions regardless of characteristics shall be measured with the measurement receiver bandwidths specified in Table II and compared against the applicable limits. Identification of emissions with regard to narrowband or broadband categorization is not applicable.

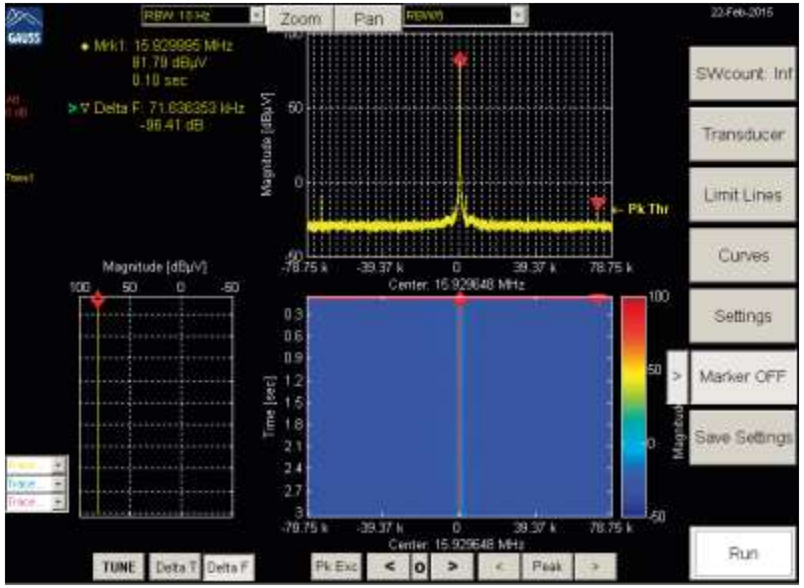
4.3.10.3.3 Frequency scanning.
For emission measurements, the entire frequency range for each applicable test shall be scanned. Minimum measurement time for analog measurement receivers during emission testing shall be as specified in Table II. Synthesized measurement receivers shall step in one-half bandwidth increments or less, and the measurement dwell time shall be as specified in Table II. For equipment that operates such that potential emissions are produced at only infrequent intervals, times for frequency scanning shall be increased as necessary to capture any emissions.

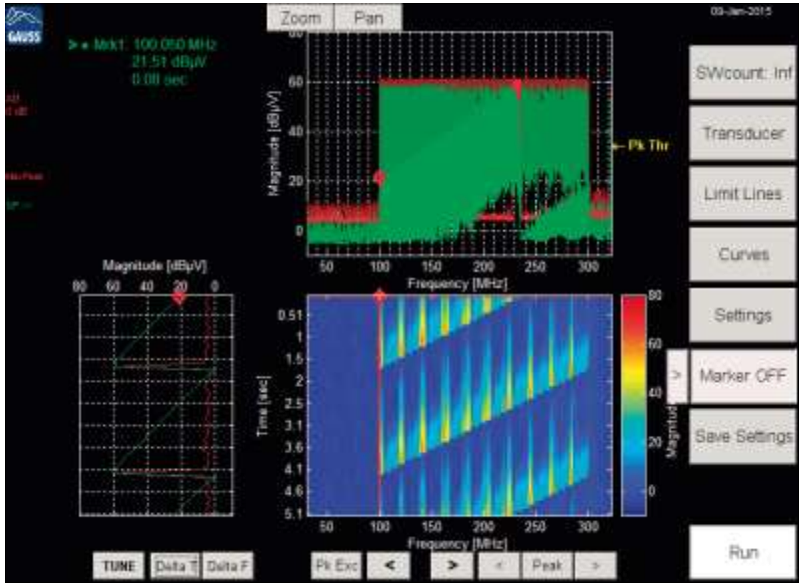
RE/CE Receiver

Specification	Requirement	Notes
Frequency Range	30Hz – 18GHz (antenna port up to 40GHz)	
Bandwidths	6 dB down points	3dB RBW not allowed
6dB Resolution Bandwidths (RBW)	10, 100 Hz, 1, 10, 100 kHz, & 1 MHz	Or greater allowed
Steps	½ RBW	Or smaller allowed
Dwell time	≥0.015 – 1sec	Longer possible to cover whole EUT cycle
Detector	Peak	
Required Interface Input	Input of Frequency, RBW, step size, dwell time, Detector	Required for FFT but assume this is required for all measurements
Low noise floor	>6dB below limit line with Antenna (18dBμV/m 2-100MHz)	Lower limits are required for special programs
Software	Required to automate factors + sweep	
Compliant too	ANSI C63.2	Required for FFT
Calibrated in accordance with	ISO/IEC 17025 or ISO 10012	

MIL-STD-461

FFT based receivers can be used for older versions of standards including *MIL-STD-461 <F & CISPR 16* as long as it meets the basic receiver requirements



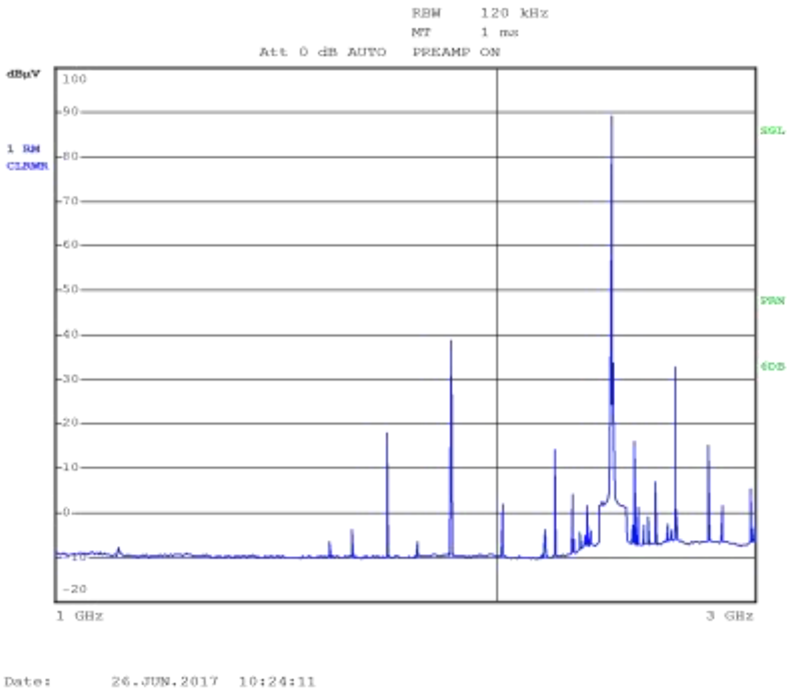


Important Specs for S.A. & Receivers

- Spurious Free Dynamic Range (real-time)
  - This is the input range (dBµV)
  - With no attenuation/preamp switching
  - The ability to measure a large signal next to a small signal
- Noise floor
  - Sensitivity of the system (how low a signal it can measure)
  - Pre-Amp normally required
  - Does the pre-amp effect Dynamic range or other specs
- 3dB vs. 6dB RBW
- Pre-selection
  - This is what sets the receiver apart
  - Improves Dynamic Range + Noise floor
  - Every manufacturer approaches this differently

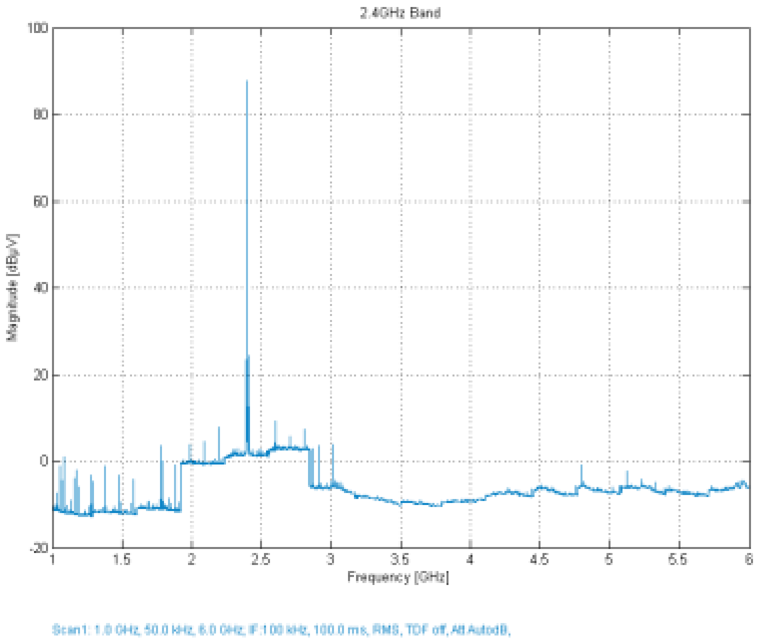
Dynamic Range

- Spurious Free Dynamic range
- Limited where intermodulation may occur IP3
    - Comparison of Spurious Response for 2.4 GHz WLAN Measurement



Conventional Receiver shows only 50 dB Spurious Free Dynamic Range

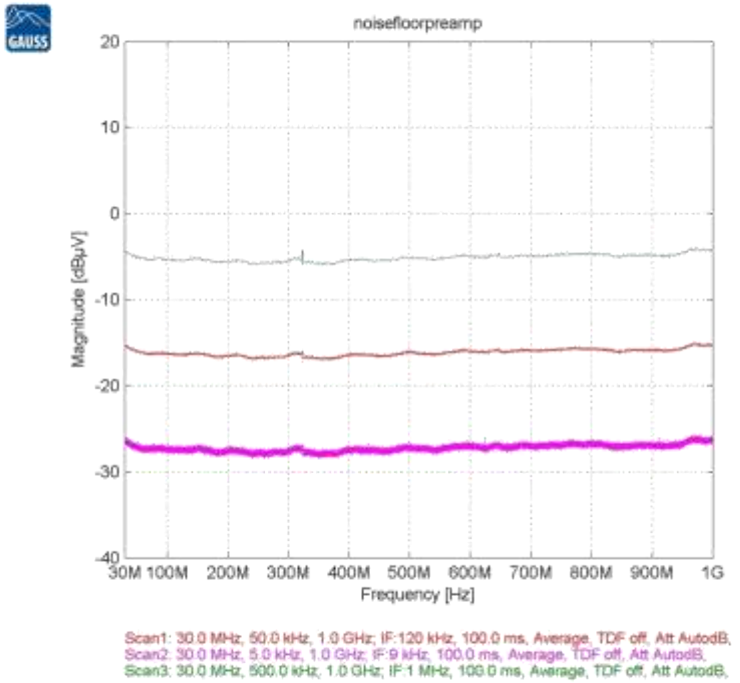
External Notch Filter required



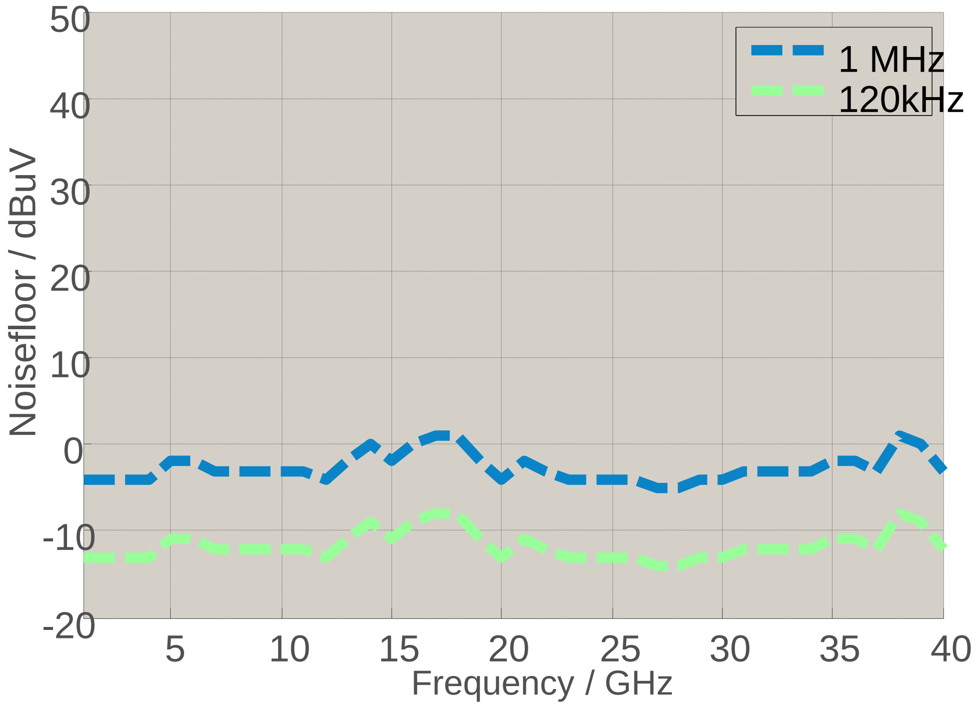
Shows about 90 dB Spurious Free Dynamic Range

Noise Floor (Sensitivity)

- Noise Floor Examples



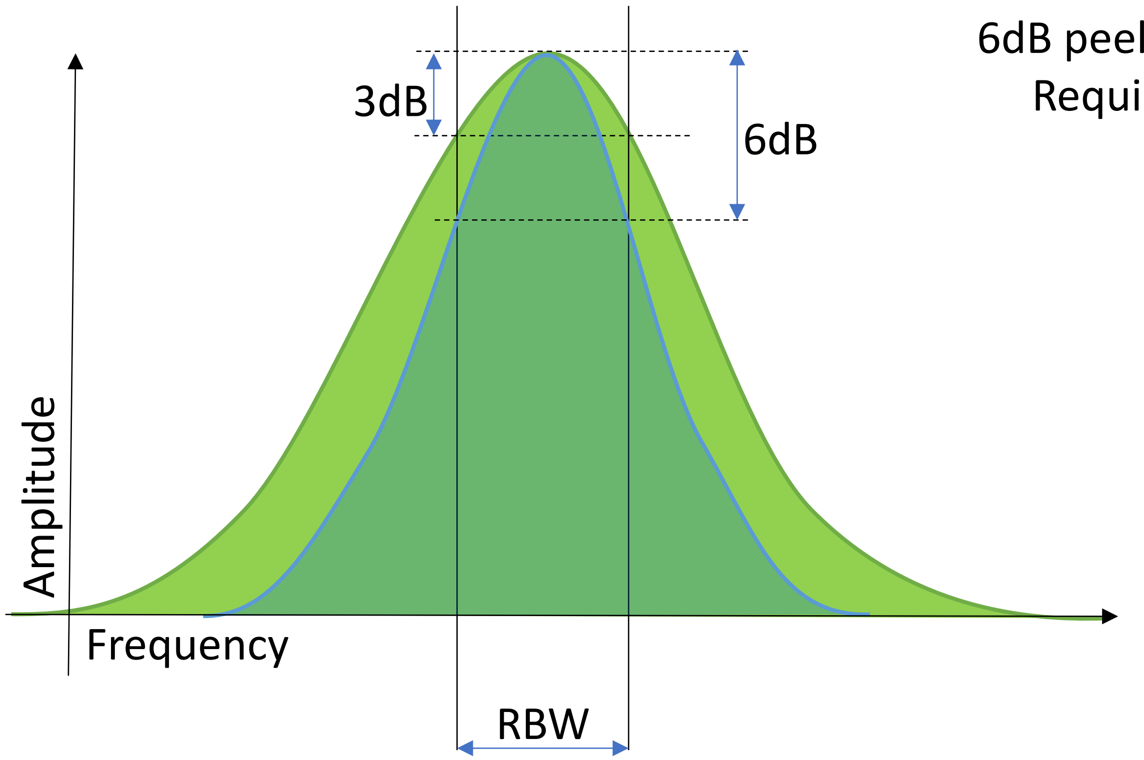
30 MHz – 1 GHz



1 – 40 GHz

Resolution Bandwidth or IF

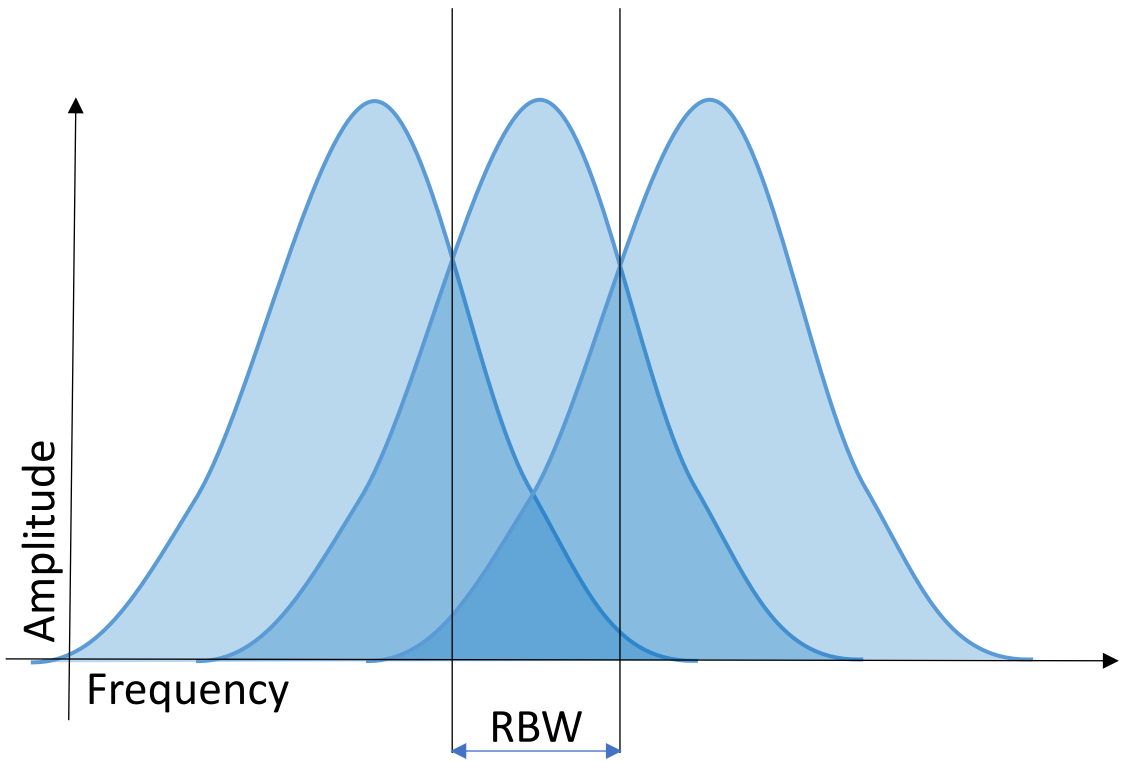
- 3dB vs. 6dB RBW



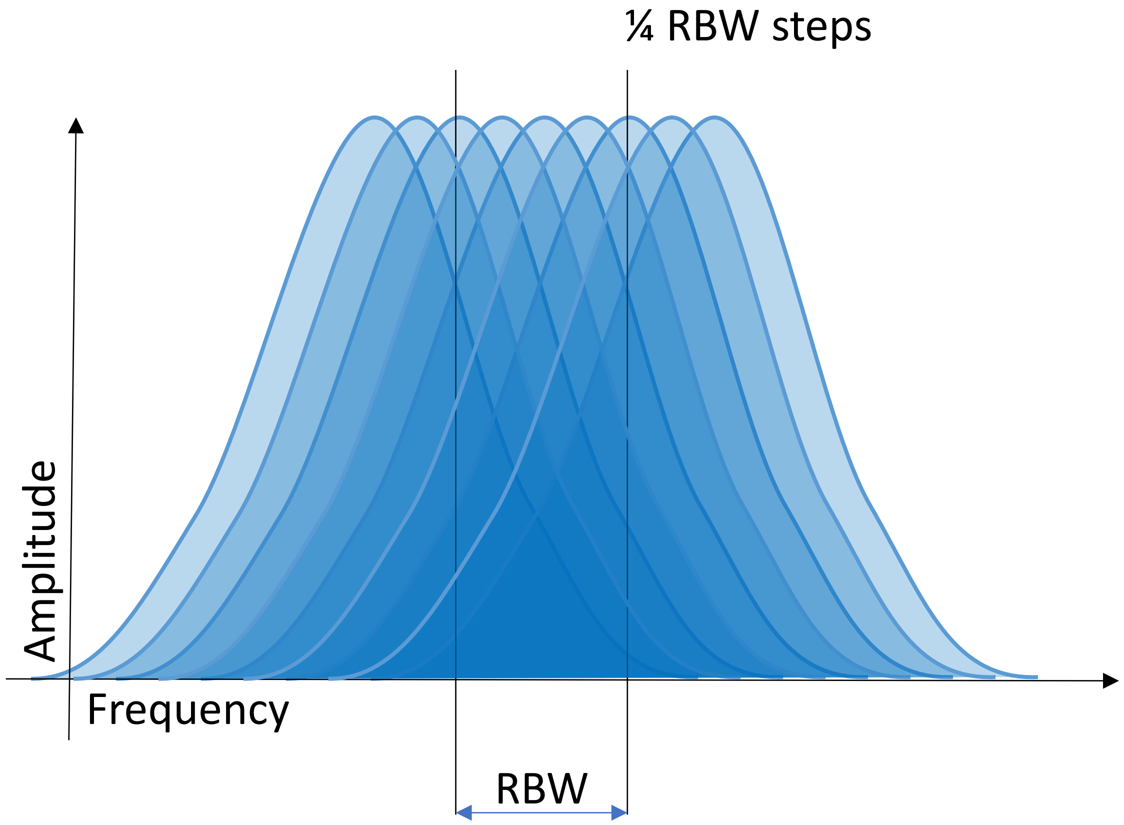
6dB Bandwidth is more accurate
6dB peek envelope is less
Requiring smaller step sizes

Frequency Steps

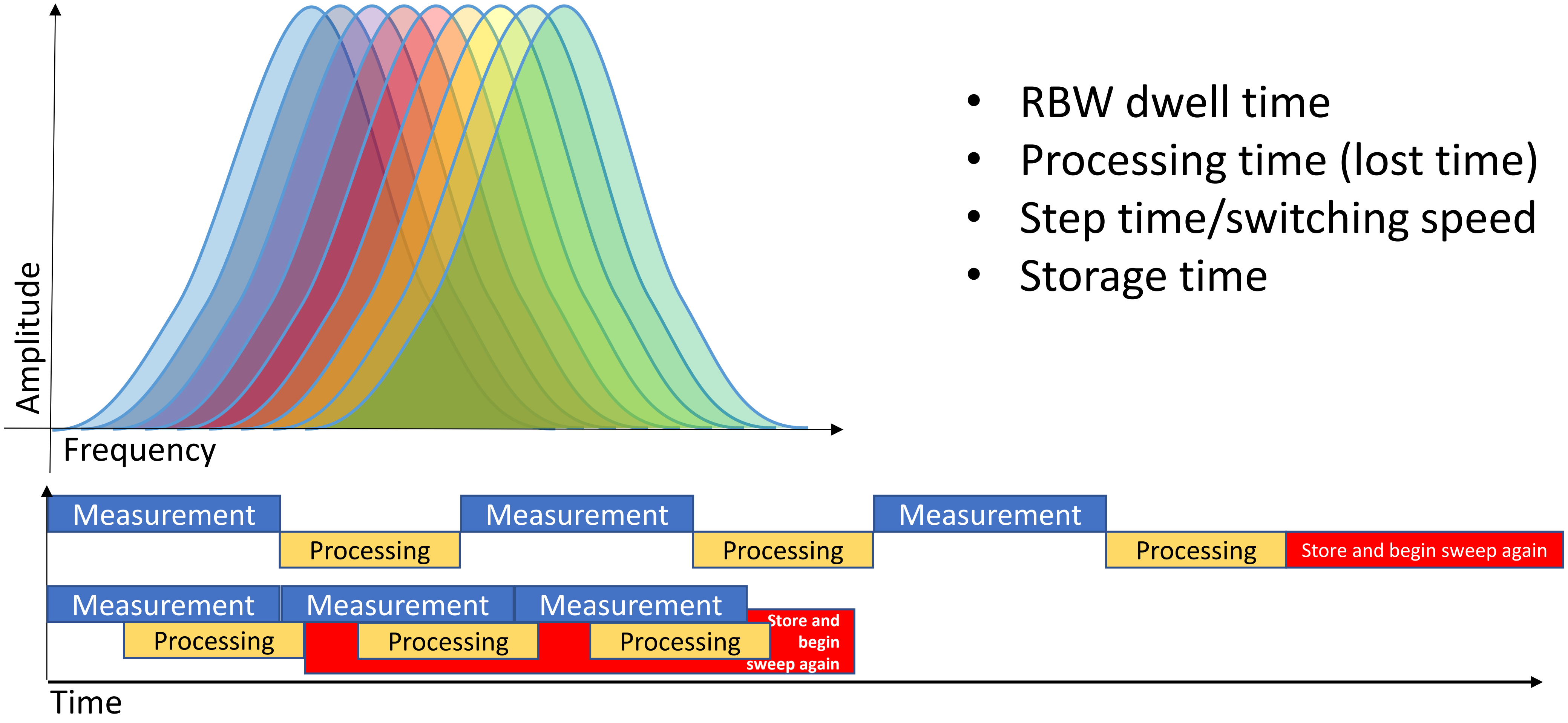
- 1 RBW steps



- ½ RBW steps



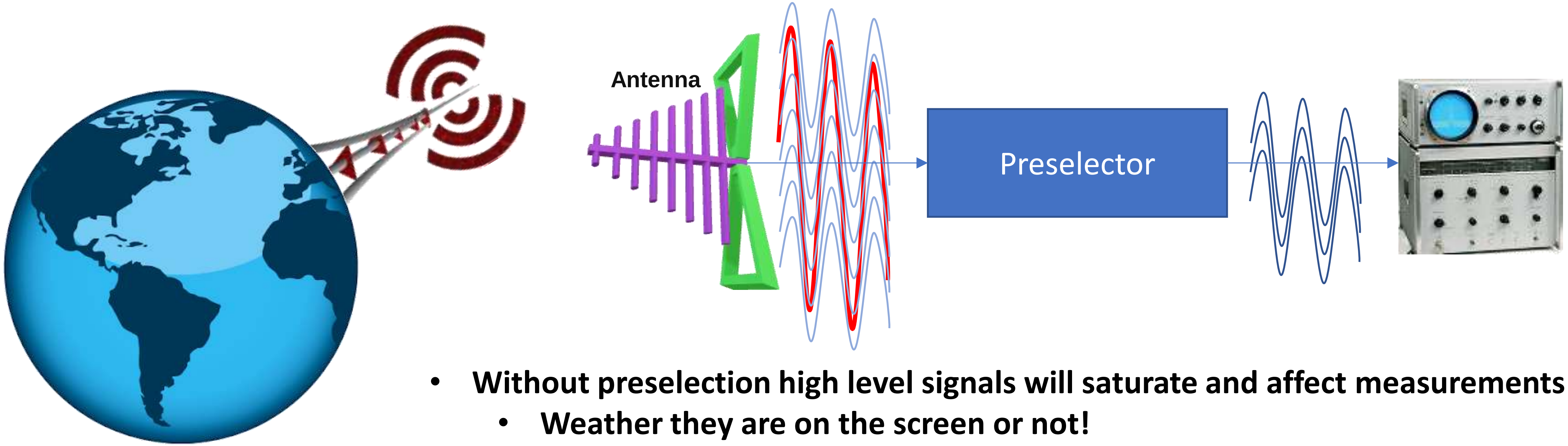
Sweep Time



- RBW dwell time
- Processing time (lost time)
- Step time/switching speed
- Storage time

Pre-selector

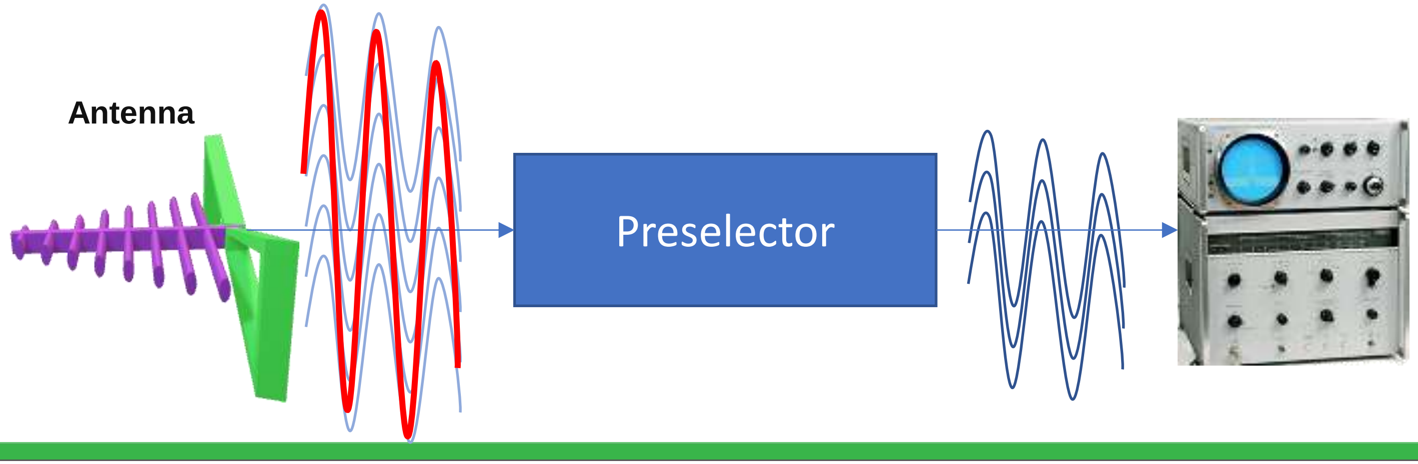
- Pre-selection for receivers
  - Narrows energy “seen” by front end of Receiver
  - Less energy noise going in = lower noise floor



- **Without preselection high level signals will saturate and affect measurements**
  - **Weather they are on the screen or not!**
  - **Intermodulation / Artifacts: cause a hair pulling result**

Pre-selector

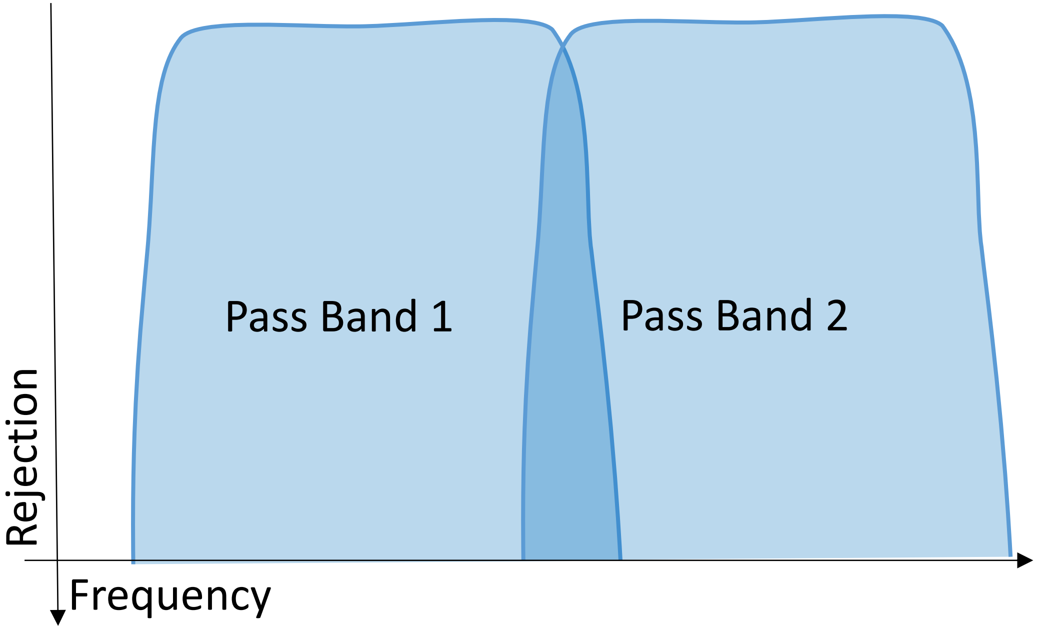
- Pre-selection for receivers
  - Preselection is needed for CISPR/ANSI requirements
    - Needed to measure high voltage ps pulse
  - Preselection is required throughout the frequency range
  - Preselection is unique to each manufacturers design



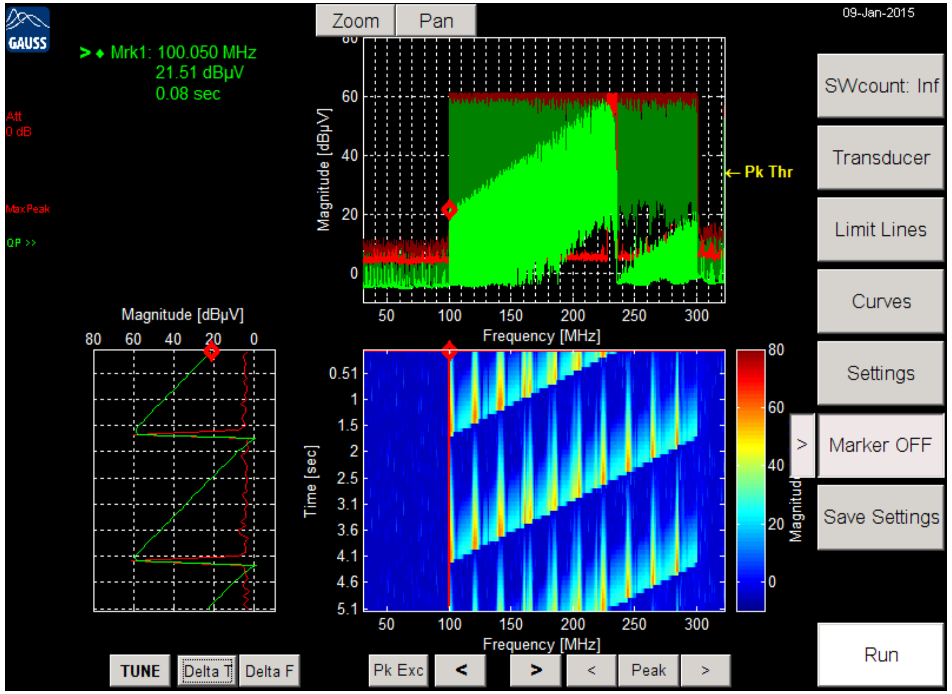
Pre-selector

- What is in a pre-selector
  - High pass and low pass filters
    - Pass Band filters
  - YIG tracking Filter
    - Only a few MHz Bandwidth
  - Lots of switching

- With FFT Technology Pre-selection bandwidth becomes an Issue



Receiver Compliance



The combination of:

- Sensitivity
- Superius free dynamic range
- Preselection

All together allow receivers to be compliant

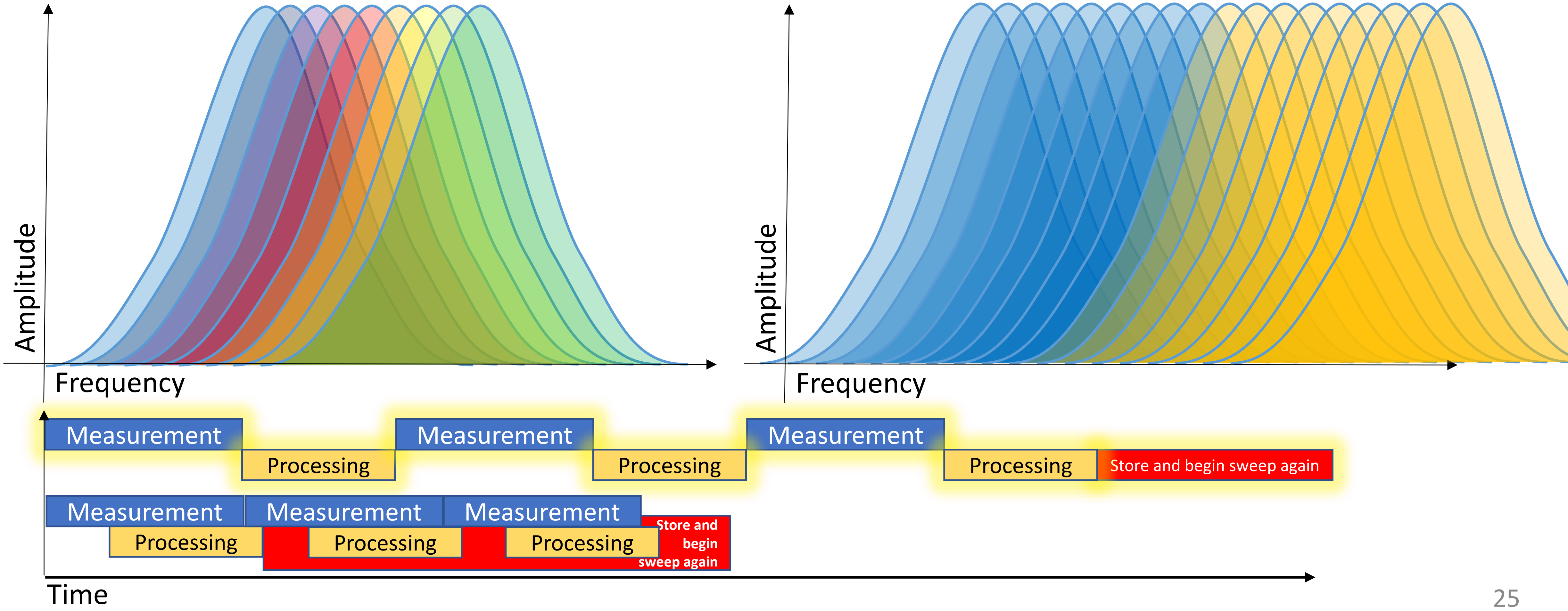
- ANSI and CISPR are written in a way the receiver is a “black box”
  - Make the right measurements you are compliant
- Use of a 300ps pulse with repetitions from 1 - 1000Hz
  - Fast +70V pulse with measurements down to 1Hz

S.A. vs. Receivers

Requirements	Spectrum Analyzer	Receiver	Pre-compliant receiver
6dB RBW (IF)	Maybe options	**Yes**	Yes
Preselection	Possible on high end units to improve noise floor but not compliant	**Yes**	Some
Detectors (Peak, QP, AVG, …)	Maybe options but not compliant	**Yes**	Yes
Internal mixing products	More Possible	**Less Possible**	Possible
Read out comparison	May read high	**Compliant**	Same reading, except for slow pulsed signals in few Hz range
Notes	Will get you a measurement but much more care is needed to verify it is a “good” reading.	**More safeguards are in place more accurate results**	Some high cost Preselection and filtering is removed but results are constant to a full compliant receiver

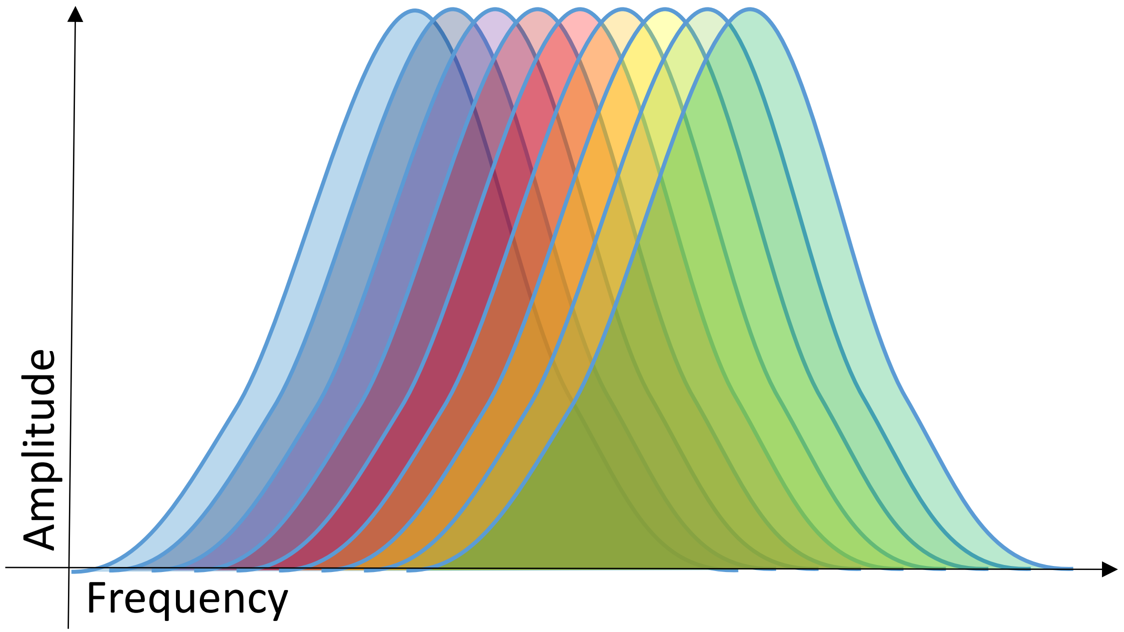
What does FFT give you?

- Traditional
- FFT

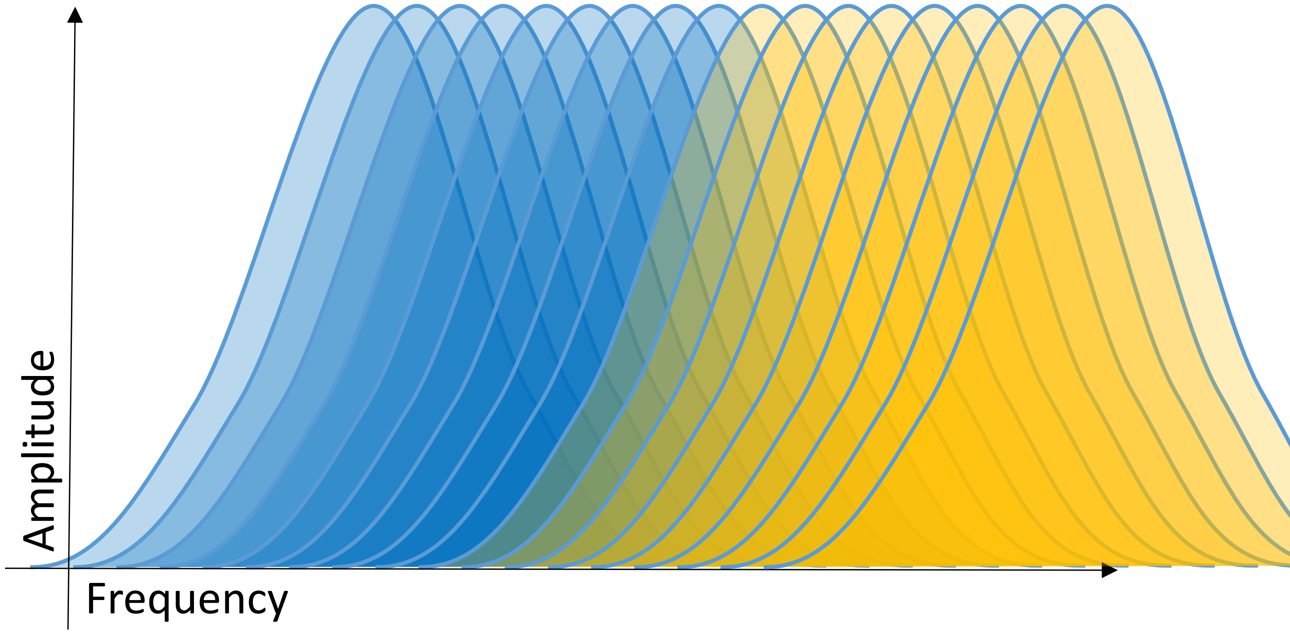


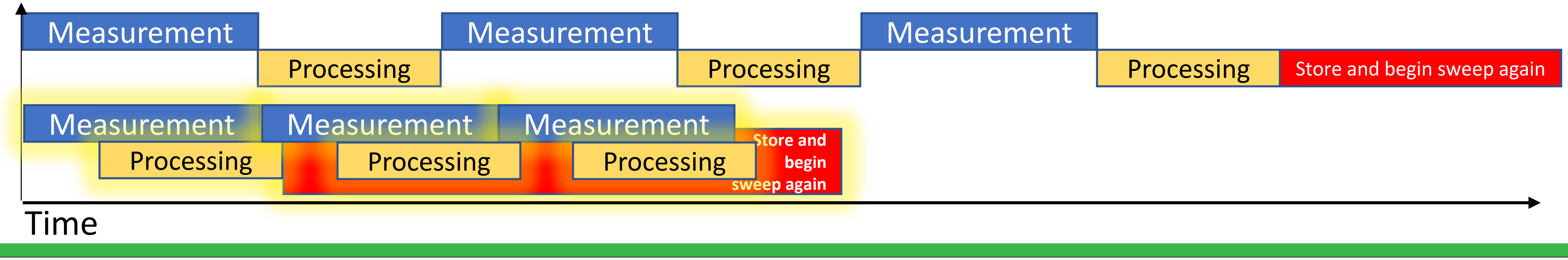
What does FFT give you?

- Traditional



- FFT



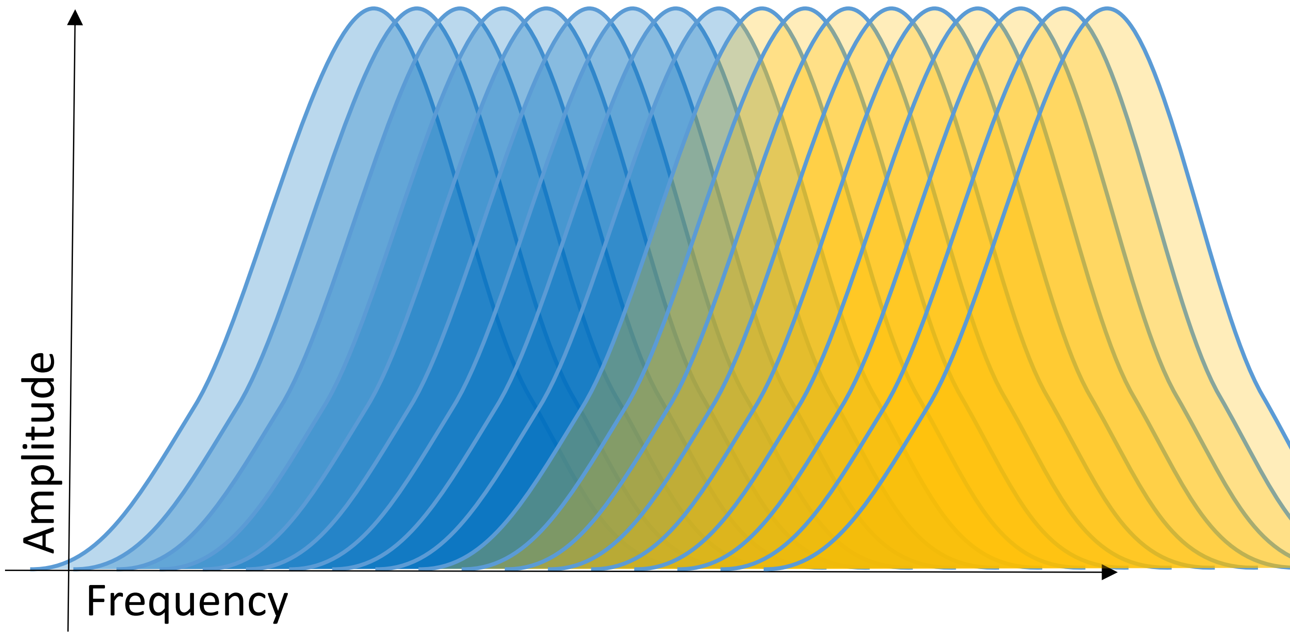


What does FFT give you?

- Real time bandwidth
  - Bandwidth unit can measure instantaneously
  - 2, 10, 40, 80, 156.5, 365, 685MHz, multi GHz
- No more need to compromise
  - Test quality over test time
  - Test all modes
  - Test 100% of products’ cycle time
- Reduce testing from hours to minutes.
- No more need to pre-scan
  - Final scan is so fast, no need to do it twice
- Excellent for trouble shooting & engineering

- Real time bandwidth? Processing time? Compliance?

- FFT



FFT Compliance or just for Analysis

- FFT full compliance needs to meet the same receiver requirements **+**
  - Needs to be gapless during dwell time
    - No missed data
    - Ideally process data real-time for unlimited dwell time
  - Maintain same pre-selectors during FFT use, or a special design
  - No difference from Superhet vs. FFT results!

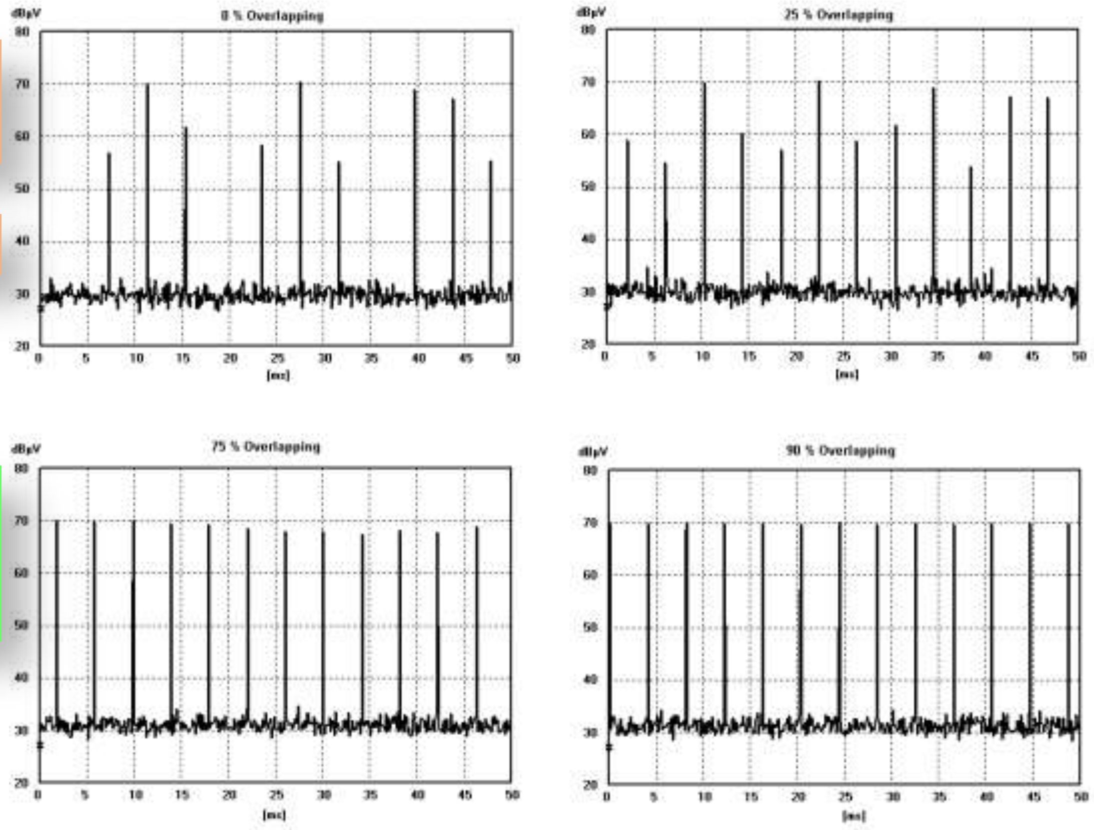
Software based RTSPA

Only for Analysis

Pulse response wrong

Spectrogrammmode
According to CISPR 16-1-1
Full Compliant
POI 300 ps

During the Measurement Time the FFT-based measuring Instrument must perform the evaluation continuously (recommended in realtime)



In CISPR 16-3, Quote: Documentation from GAUSS INSTRUMENTS from 2009 (Simulation)

FFT Compliance or just for Analysis

- Problem when using Conventional Technology with FFT (Time-Domain-Scan)

- Tractability according to ISO 17025 (was the FFT calibrated)

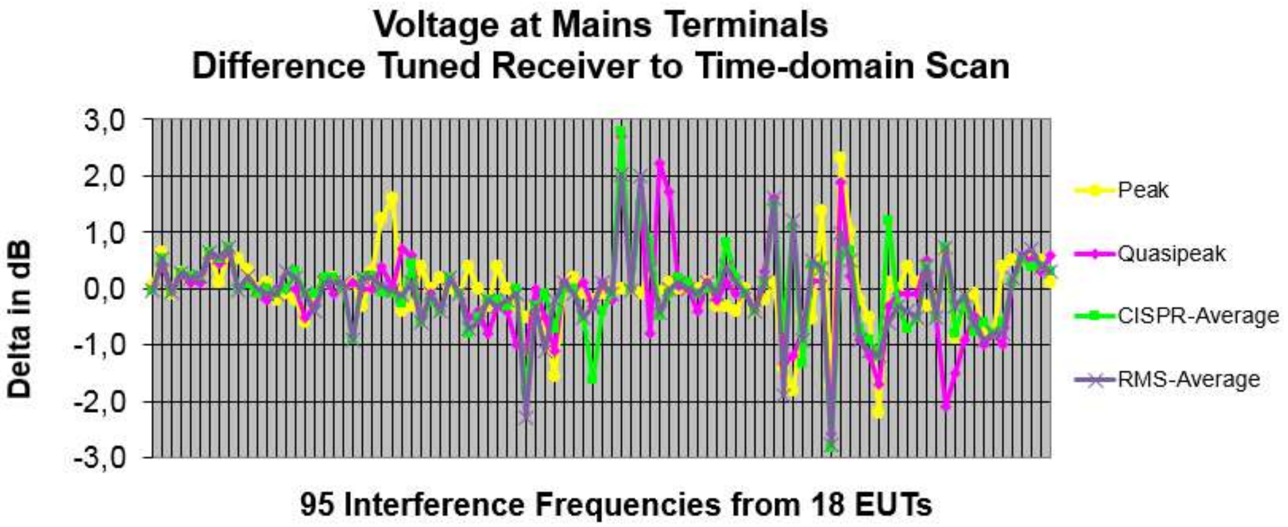
- Goal is still to reduce difference between the test results
  - receiver to receiver --- technology to technology

- Don’t want to Limited Dynamic Range and Measurement Speed

FFT Compliance or just for Analysis

- Published paper to show viability of FFT technology
  - 18 EUTs compared at 95 Frequencies

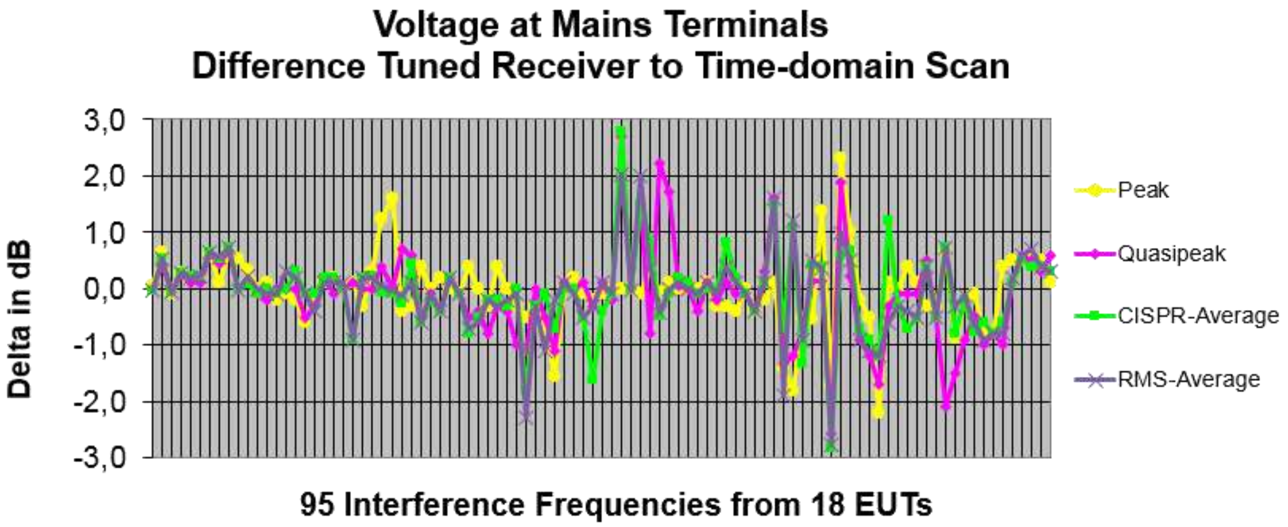
- Typical Requirements between FFT and Superhet of 3 dB (Conventional Technology)
  - This is not idea



Taken from:
Jens Medler*: Use of FFT-based measuring receivers for*
EMI compliance measurements against CISPR 32, APEMC 2017, Copyright IEEE

FFT Compliance or just for Analysis

- Why???
  - Not the same preselection
    - Lost sensitivity
    - Lost dynamic range



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Jens Medler*: Use of FFT-based measuring receivers for*
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FFT Compliance or just for Analysis

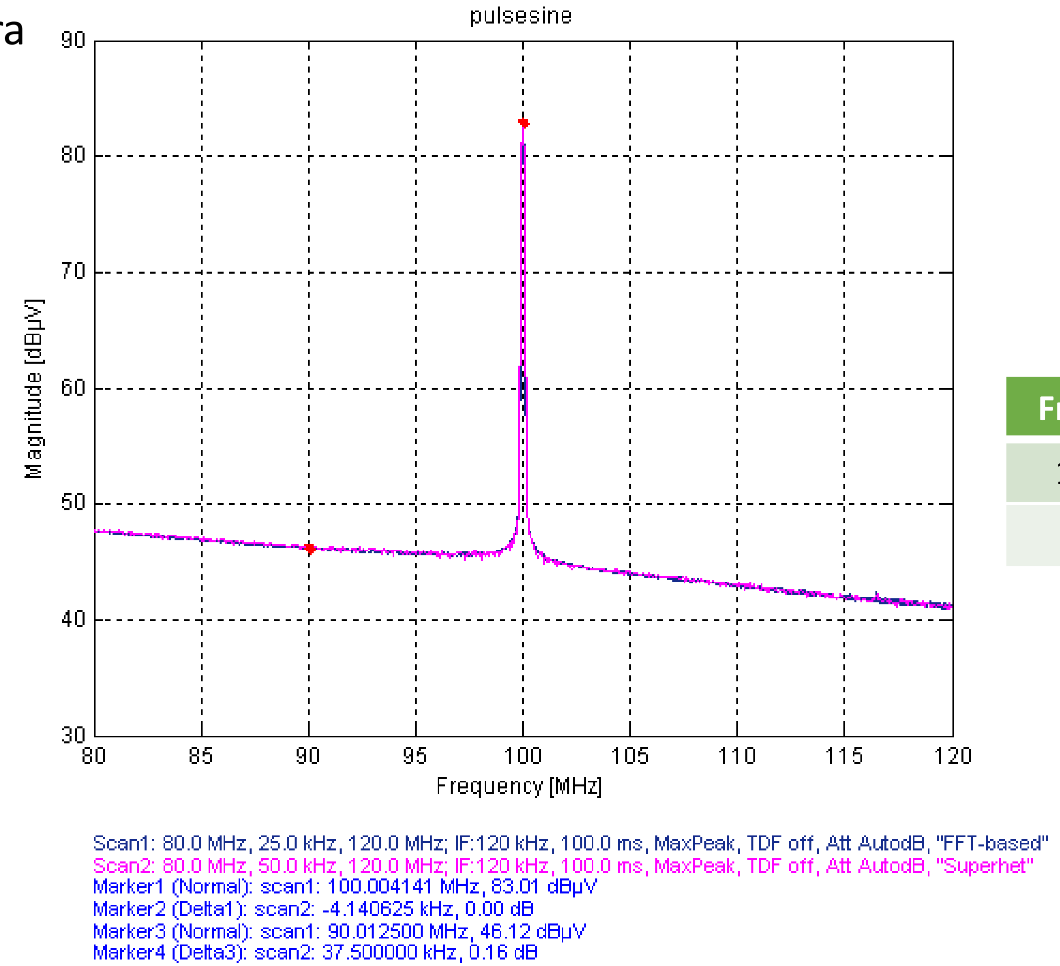
What should be stived for

- Same Measurement result between FFT and Conventional Mode
- Same Noise floor
- Same Pulse Response
- Same Result for FM, AM und Pulse modulated Signals
- Improvement of Measurements Speed and Reliability

New Technology is required that solves this Problem!

Superhet vs. FFT-based Pulse + CW – No Deviation !

TDEMI Ultra



Frequency	Measurement	Δ
100 MHz	83.01 dBµV	0.0 dB
90 MHz	46.12 dBµV	0.16 dB

How does it work?

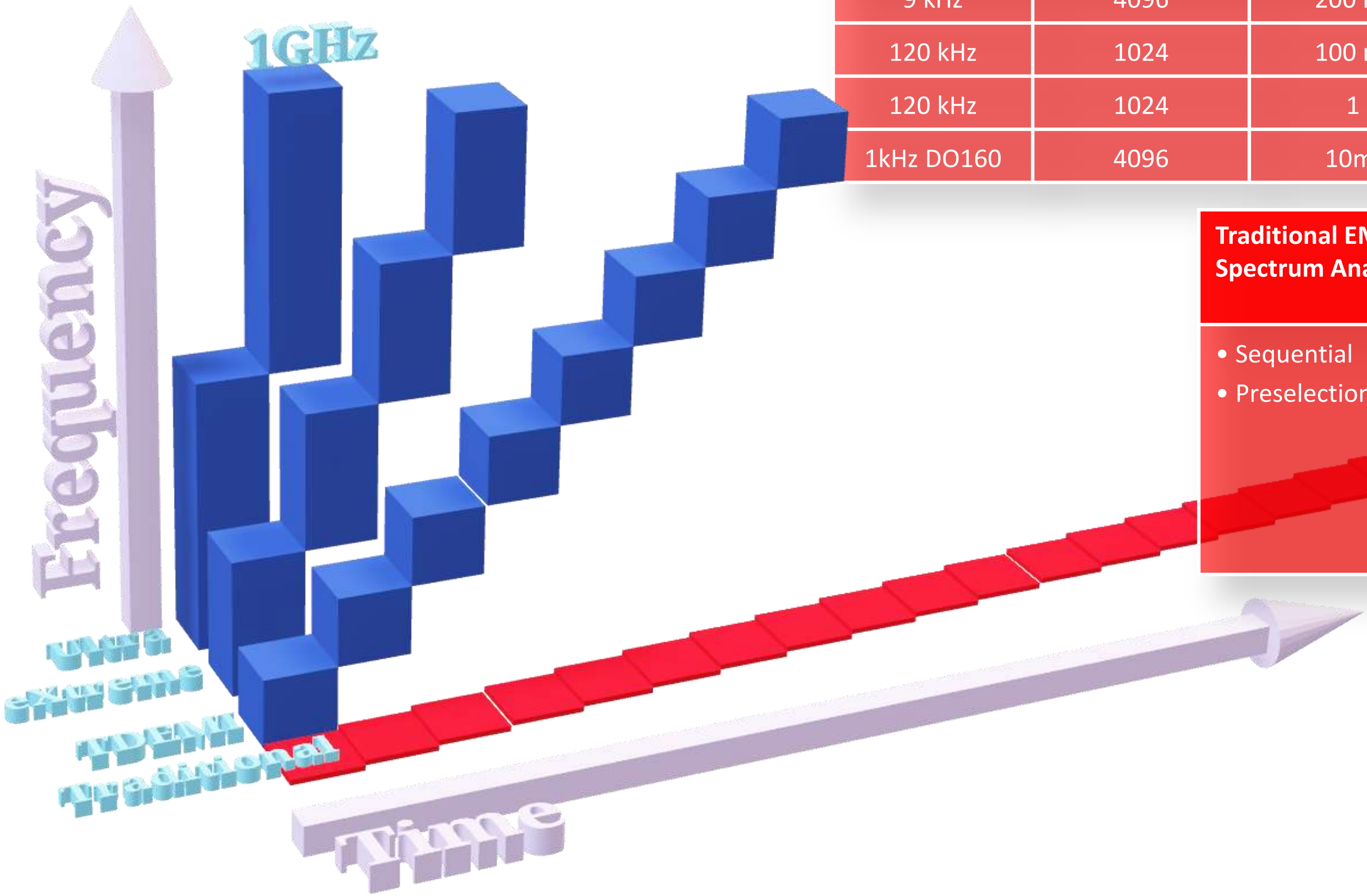
- Exactly the same Mathematics
- Exactly the Same Preselection
- Real-time Processing at all frequencies in parallel
- Huge Computation Power
- Ultra High Dynamic Range
- Calibration and Validation also in FFT Mode

New Hardware
with High Performance ADCs, FPGAs and MMICs

- Its been proven, its been accepted
    - Have confidence in your measurements

Scan-time Comparison

IF-Bandwidth	Frequency points	tdwell	Trad. EMI-Receiver	Real-time TDEMI® U
9 kHz	4096	200 ms	20 min	**< 1 s**
120 kHz	1024	100 ms	33 min	**2 s**
120 kHz	1024	1 s (QP)	9 h	**3 s**
1kHz DO160	4096	10ms	10 min	**< 1 s**



Traditional EMI Receiver / Spectrum Analyzer	Real-time TDEMI®, Real-time Spectrum Analyzer
• Sequential Measurement • Preselection (Option)	• Dwell time unlimited • Ultra-fast measurement • 2-7 frequency Bands (DC - 1 GHz) • Several ADCs • GS/s ADCs

Speed Speed Speed

- Speed gets your testing done quicker
- Speed allows you to test 100% of the EUT cycle time @ 100% of the span
- Speed allows all emissions to be found the first time
- Speed allows you confidence you measured correctly
- Speed allows you to retest and retest quickly and effectively

- If your ever unsure switch modes to compare measurements to superhet

FFT Full requirments for compliance

Specification	Requirement	FFT/Time Domain
Frequency Range	30 Hz – 18 GHz (antenna port up to 40 GHz)	☑
Bandwidths	6 dB down points	☑
6 dB Resolution Bandwidths (RBW)	10, 100 Hz, 1, 10, 100 kHz, & 1 MHz	☑
Steps	½ RBW	☑
Dwell time	≥0.015 – 1 sec	☑
Detector	Peak	☑
Required Interface Input	Input of Frequency, RBW, step size, dwell time, Detector	☑
Low noise floor	>6 dB below limit line (18 dBµV/m 2-100 MHz)	☑
Software	Required to automate factors + sweep	☑
Compliant too	ANSI C63.2	☑
Calibrated in accordance with	ISO/IEC 17025 or ISO 10012	☑
Superhet Scanning mode		☑

FFT Compliance or just for Analysis

If the FFT is not fully compliant; Can it can be used for quicker prescans? Y-E-S???,Maybe??, Or N-O???

- Can it be used for acceptable pre-scans?
  - For CISPR NO
  - Pre-scans need a compliant measurement

Conclusions

FFT is here and it is the future

- With capabilities to improve testing quality and still shorten time
- It is written into & accepted by the testing standards
- Can be calibrated to pre-existing requirements

With all new technologies there are some things to understand

- Not all FFTs are created equal
- Not all conform to the standards
- Don‘t get swept away in the hype

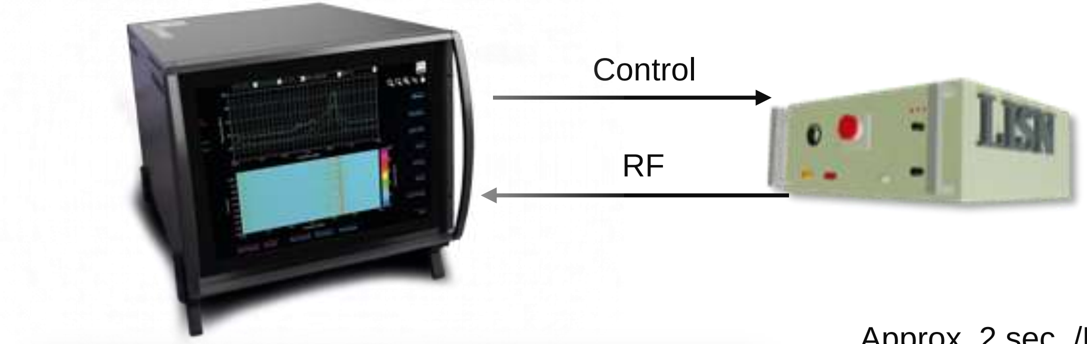
Applications for FFT Technology

- Conducted Emission (LISN) 9kHz-30MHz
  - 9kHz – 30MHz, 4 line 3 phase in 8 seconds with report

- Disturbance Line Measurements CISPR 14
  - Clamp and trolley 30-300 MHz in 30sec
  - CDN Method 1sec

- FCC/CISPR32 30MHz - 1GHz
  - No pre-scan
  - In 2 bands maximization
    - Full EUT rotation @ multiple antenna heights ~1 hour/polarity
- >1GHz multi GHz scans 1-6 real-time ~30 min

Test Setup: Conducted Emission Measurement of 3 Phases (4 lines)



Automated Measurement of L1 ,L2 ,L3, and N

Extraction of Maxima

Report

Approx. 2 sec. /Phase (Band A,B)

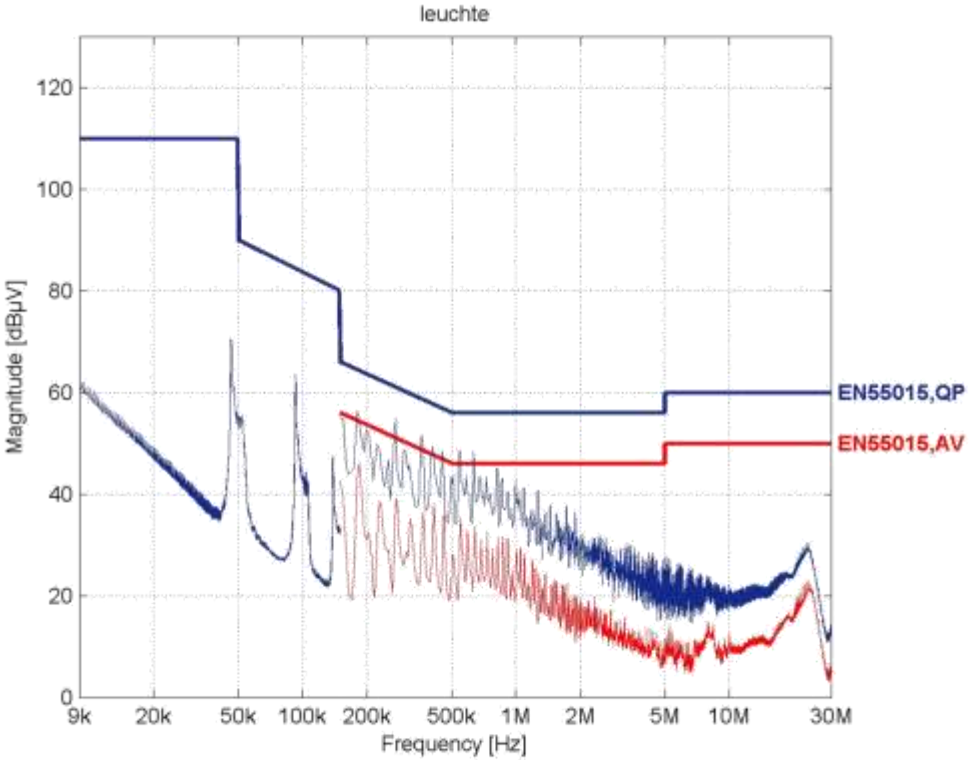
Approx. 1sec. /Phase (Band B)

Extraction of Maximum

~ 8 sec. for full measurement

Application Field Electrical Lighting

Conducted (final QP!) Measurement up to 30 MHz



Scan1: 150.0 kHz, 5.0 kHz, 30.0 MHz; IF:9 kHz, 1.0 s, QP, TDF Standard, Att AutodB,
Scan2: 150.0 kHz, 5.0 kHz, 30.0 MHz; IF:9 kHz, 1.0 s, CAV, TDF Standard, Att AutodB,
Scan3: 9.0 kHz, 100.0 Hz, 150.0 kHz; IF:200 Hz, 1.0 s, QP, TDF Standard, Att AutodB,

Test Setup: Measurement of Disturbance Power

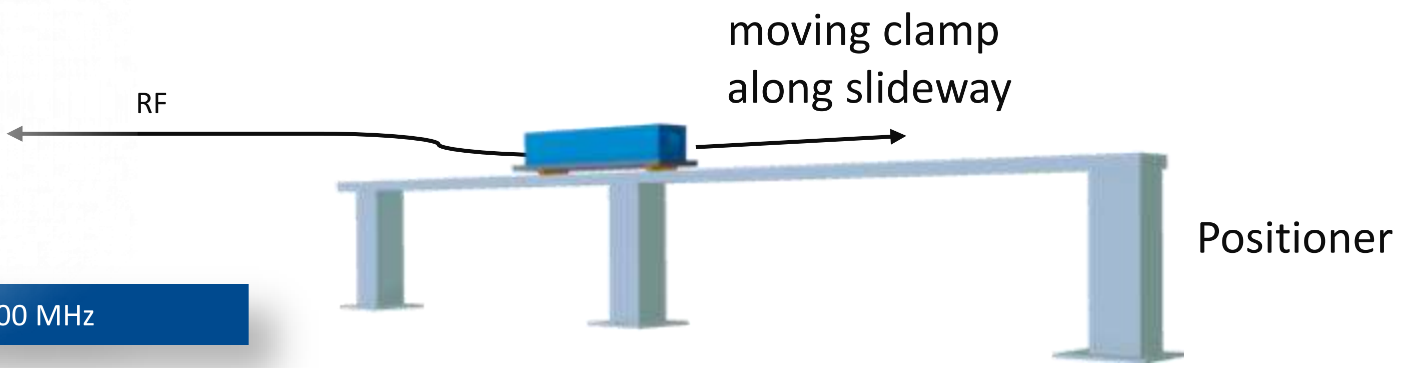
Spectrogram 30 MHz – 300 MHz

↓

Max Hold

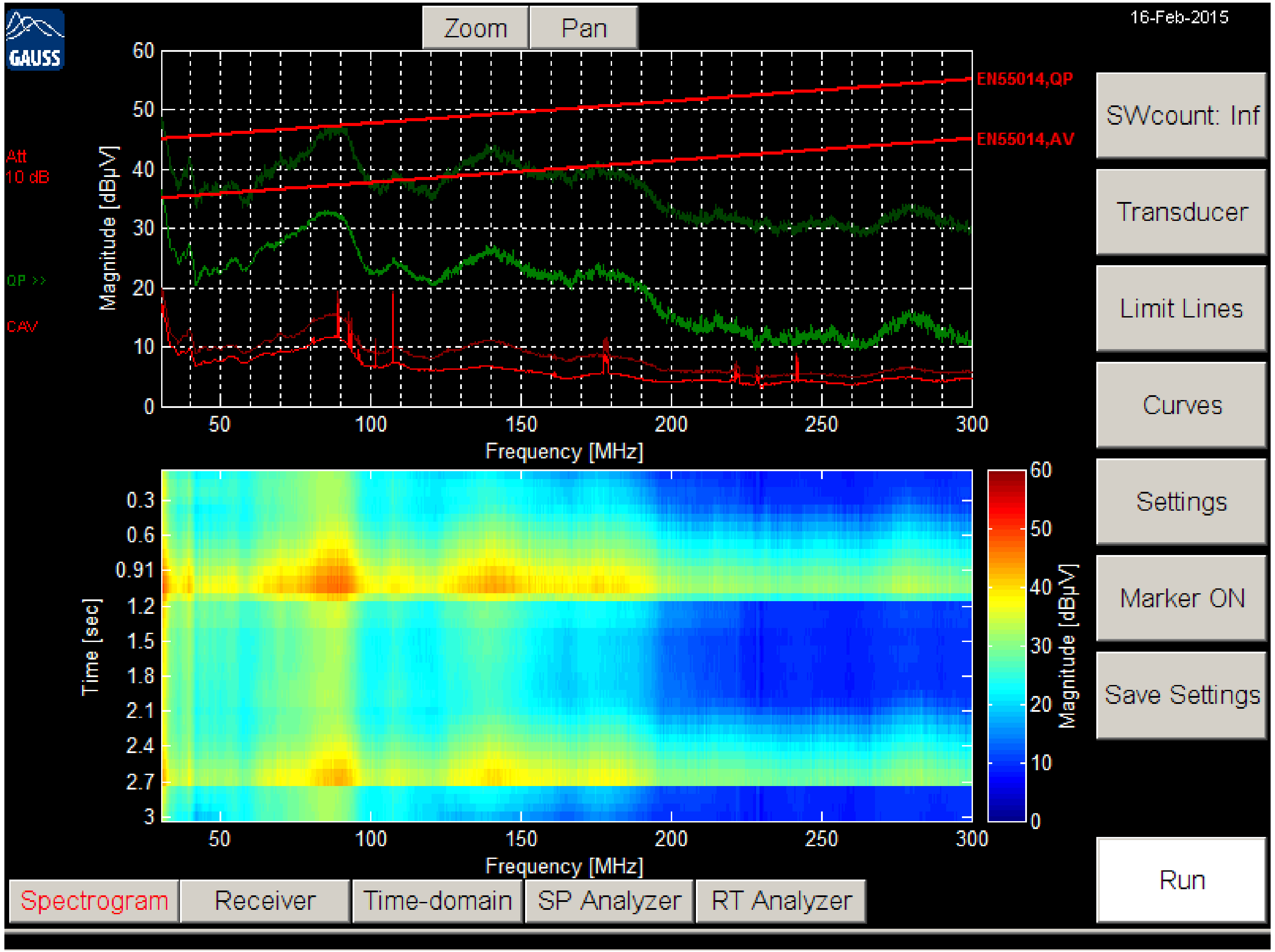
↓

Report

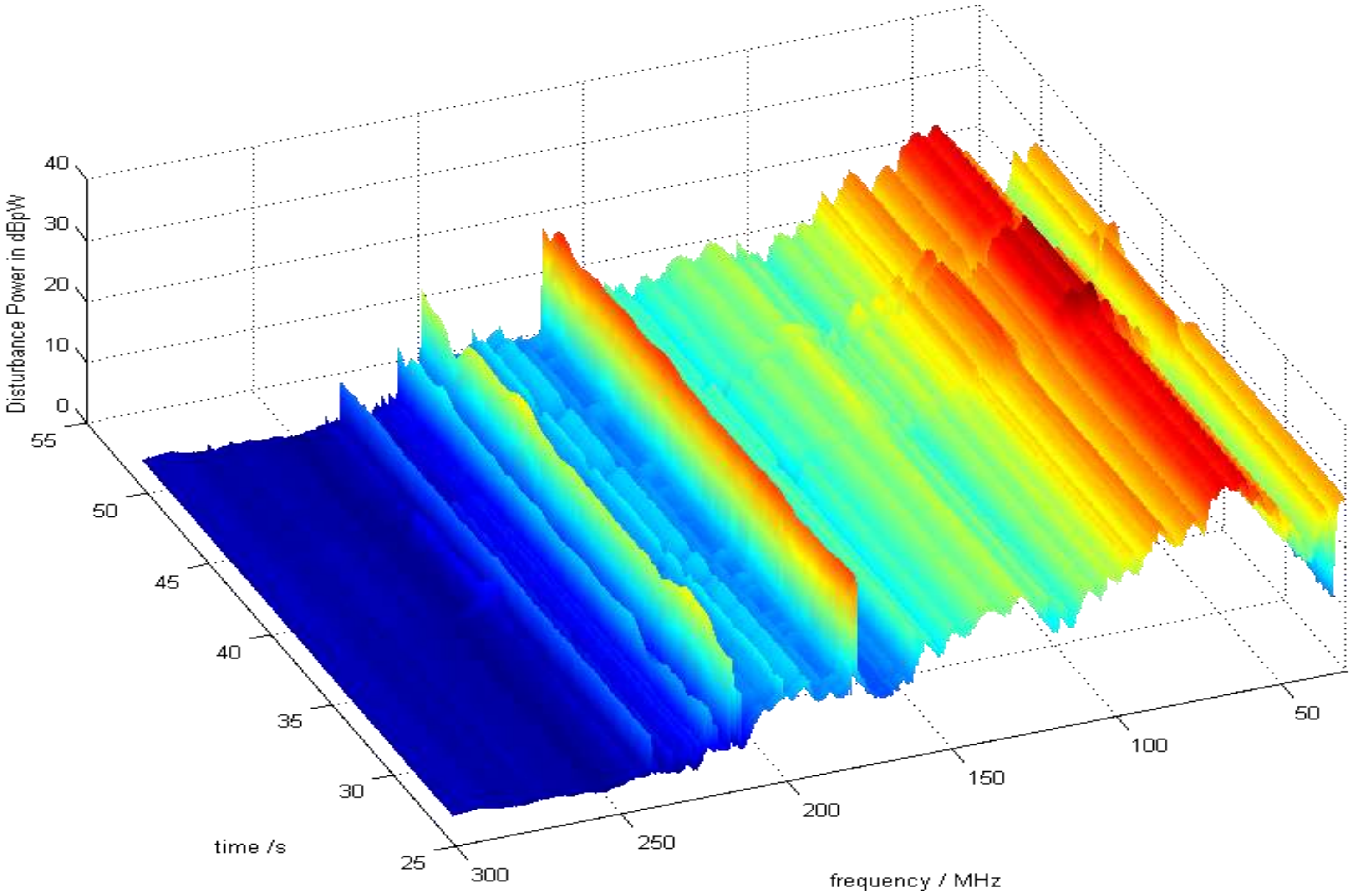


~ 30 s for full measurement

Disturbance Power Measurement 30 MHz – 300 MHz in Real-time



Disturbance Power Measurement 30 MHz – 300 MHz in Real-time



Test Setup: CDNE Method (30 MHz – 300 MHz), EN55015

Spectrogram, Quasi-peak in real-time

↓

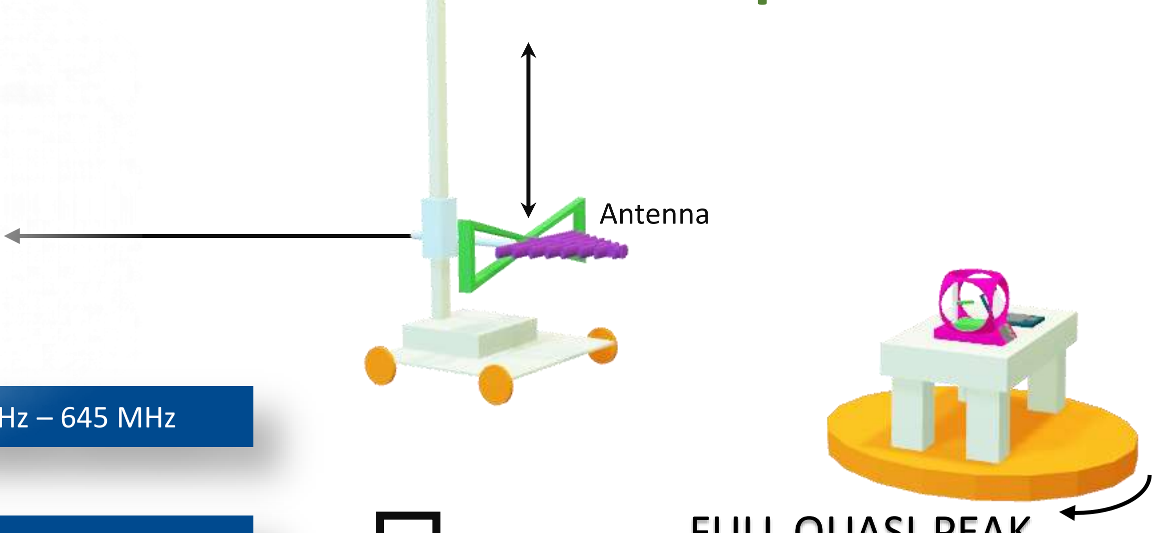
Extraction of Maxima

↓

Report Generator

➡ **~ 1s for full measurement**

Test Setup: Radiated Emissions up to 1 GHz



Quasi-Peak Spectrogram 30 MHz – 645 MHz

1. full rotation of Turntable

Quasi-Peak Spectrogram 645 MHz – 1000 MHz

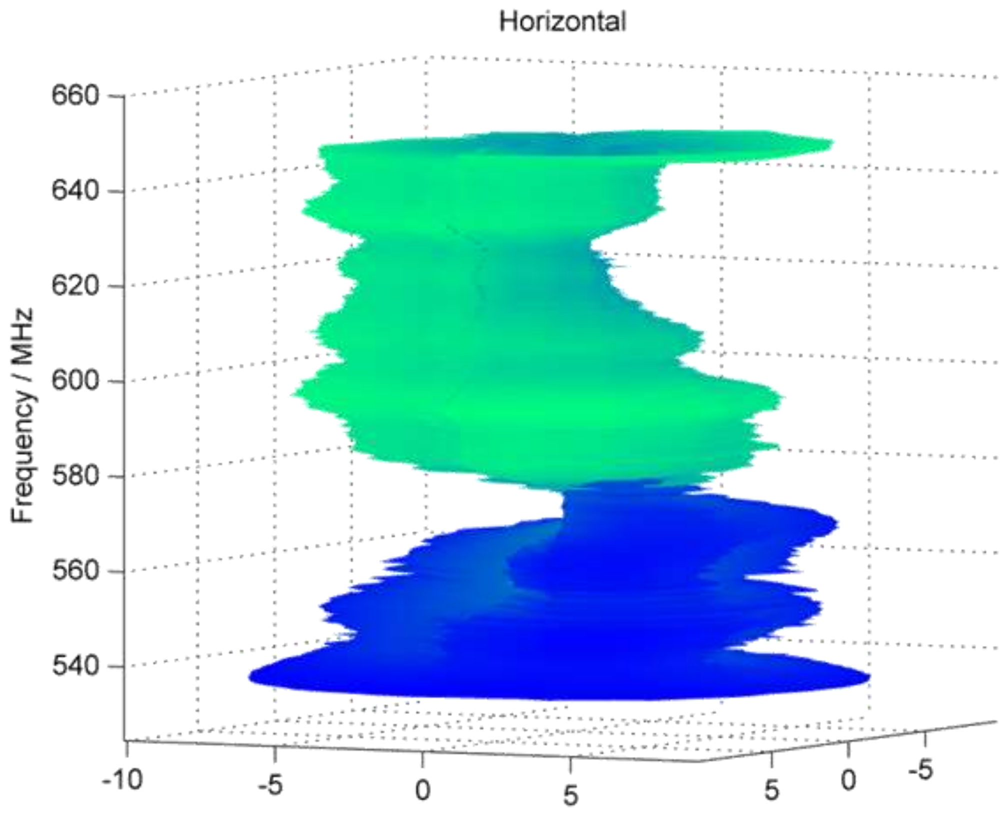
2. full rotation of Turntable

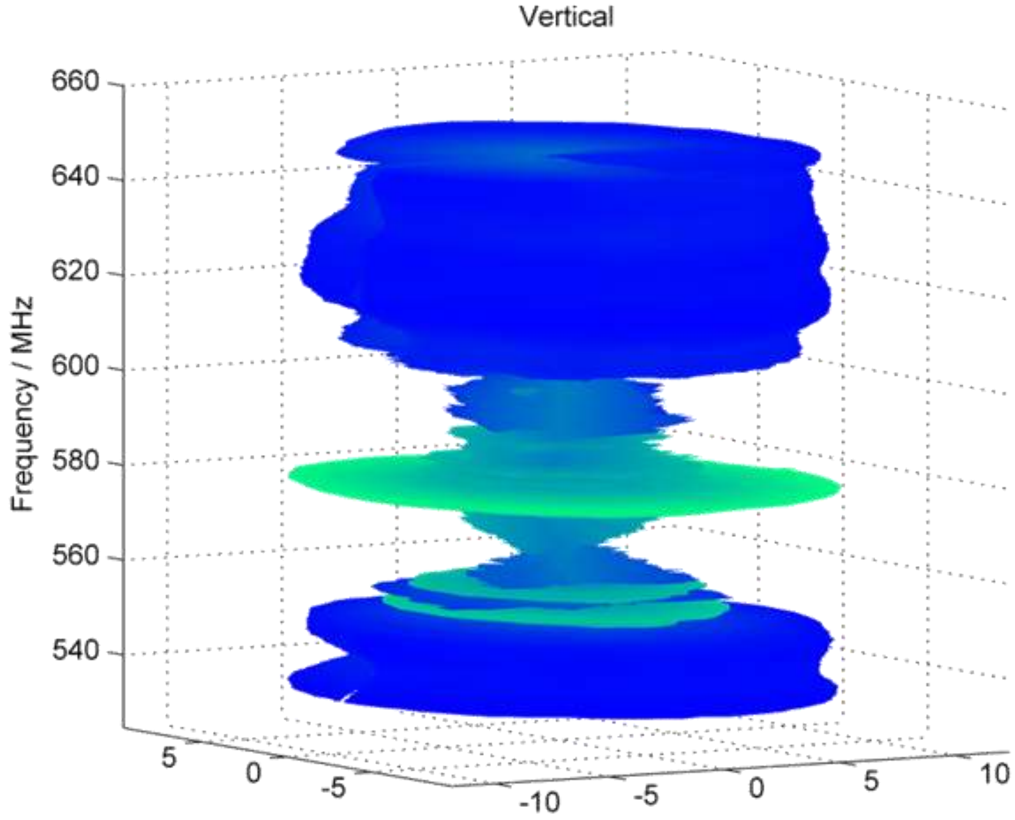
Final Report

FULL QUASI-PEAK
characterization
in
real-time

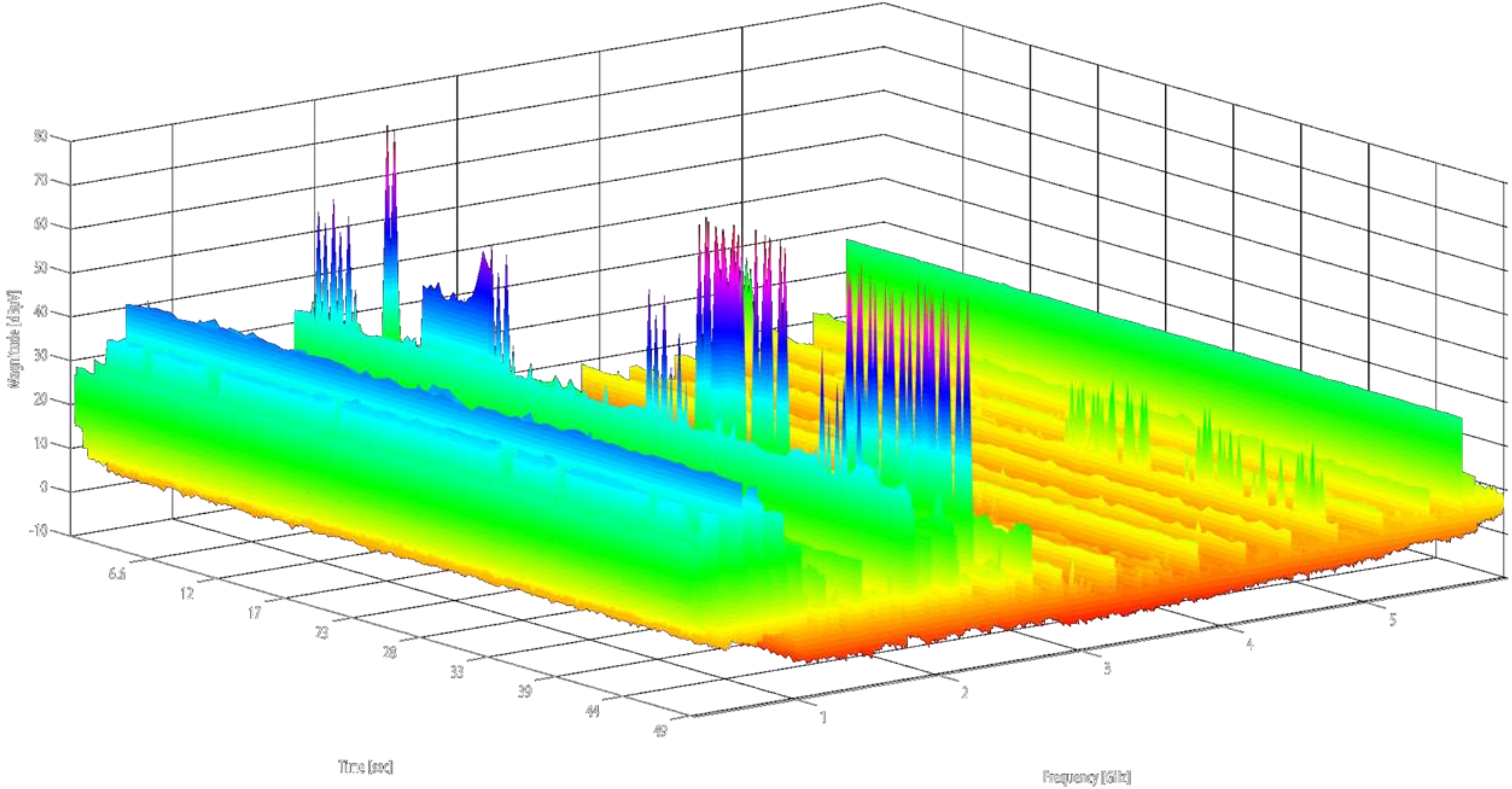
Frequency Range: 535.571 MHz - 649.301 MHz

Emission Measurement of a DUT

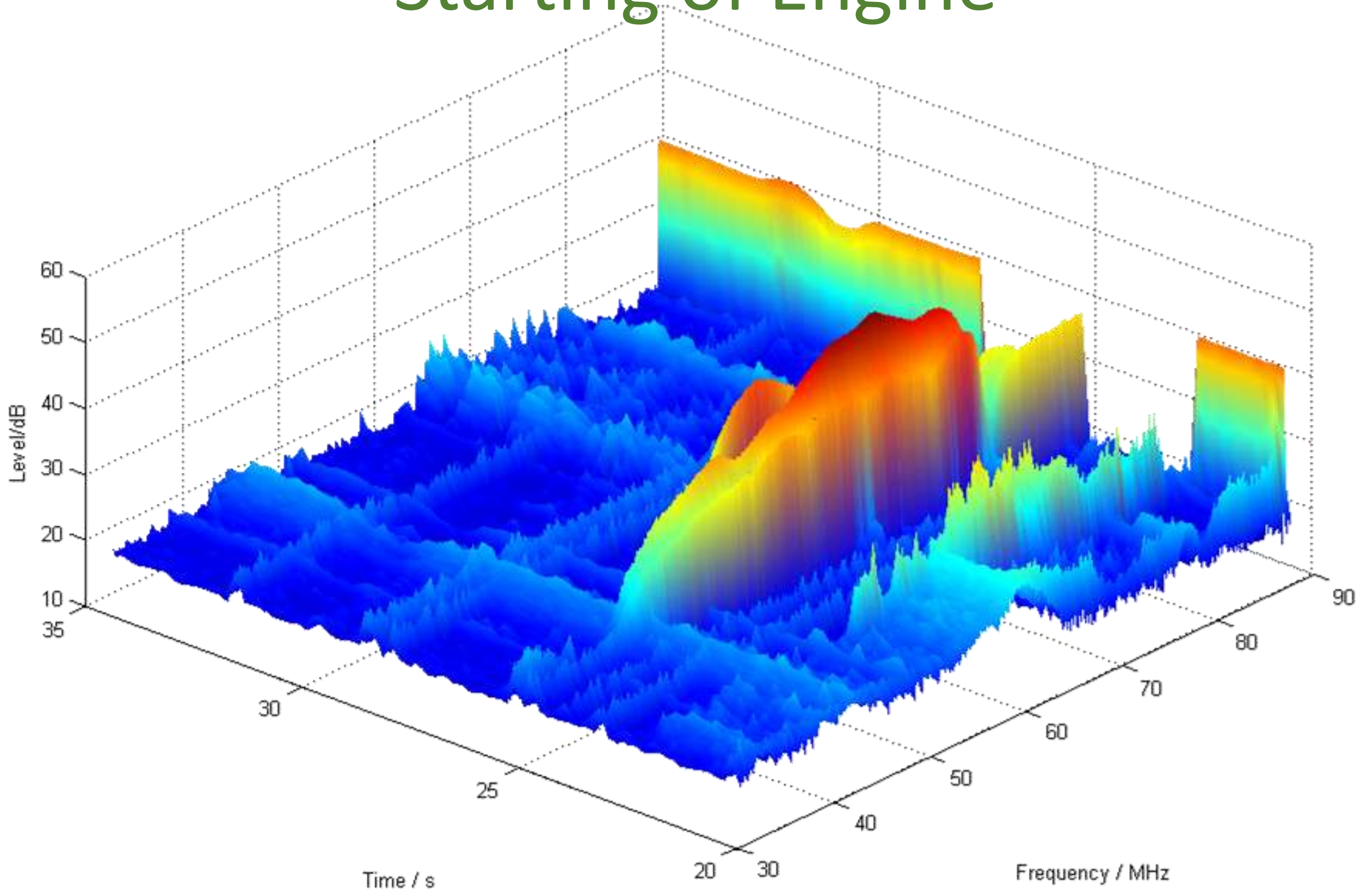




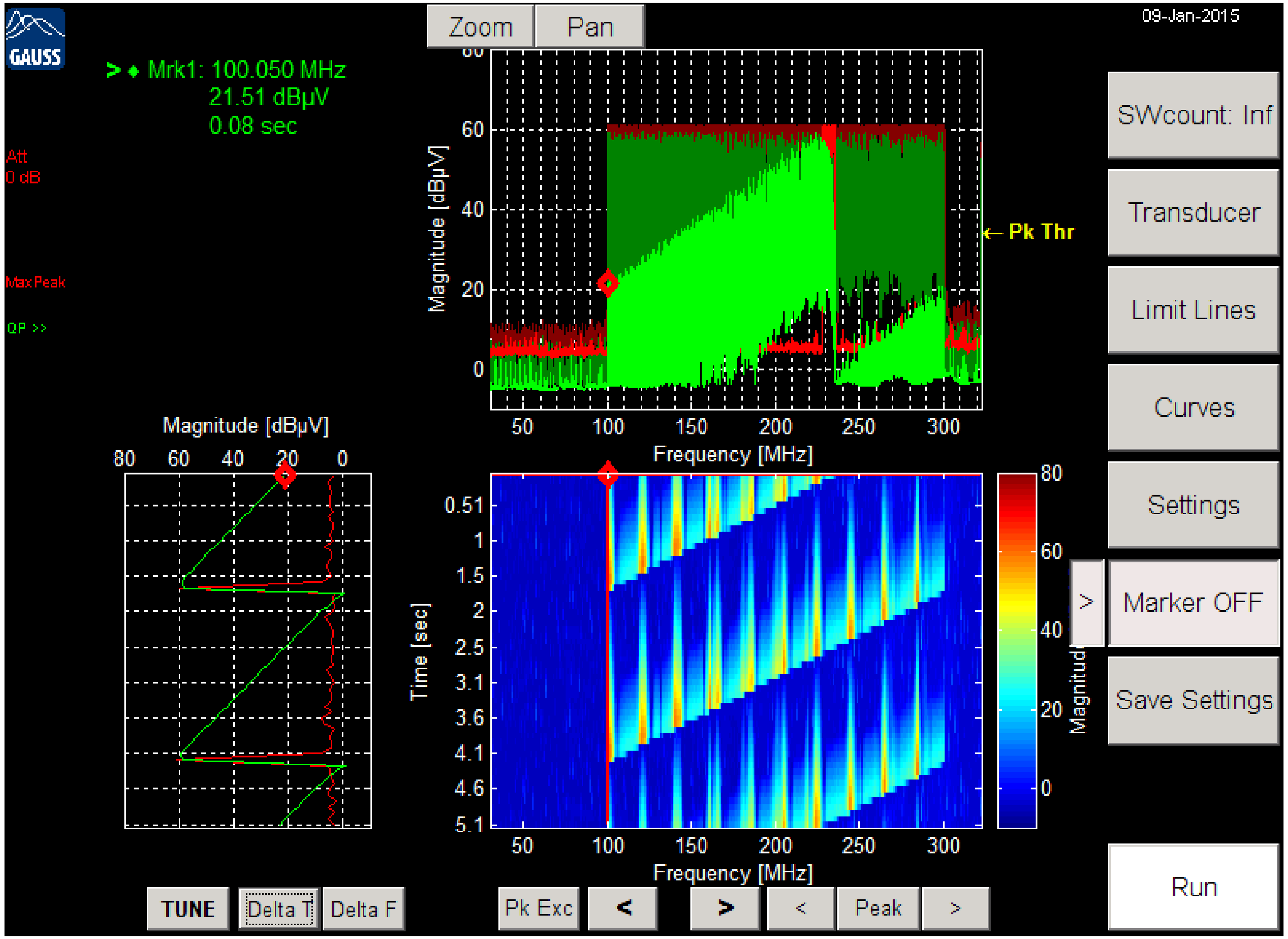
Real-time Scanning with **6** GHz **Bandwidth**



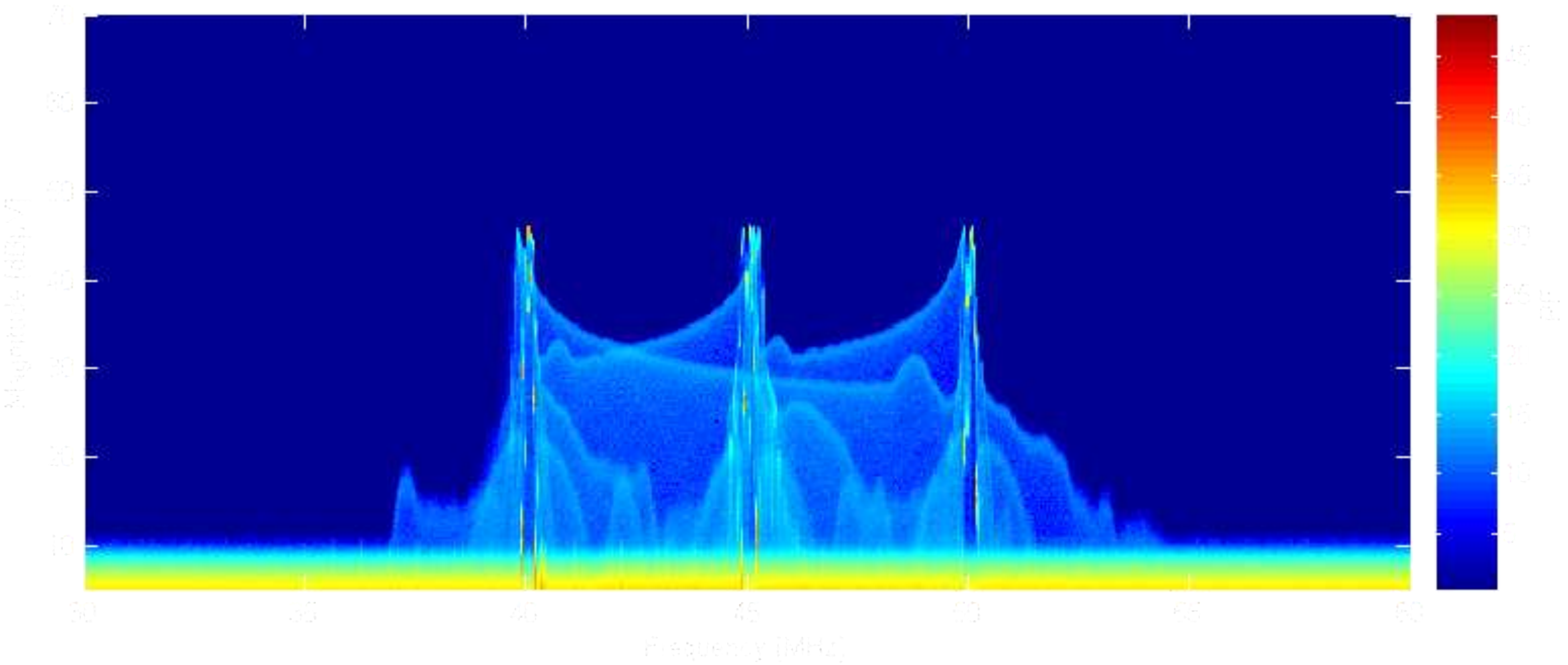
Starting of Engine



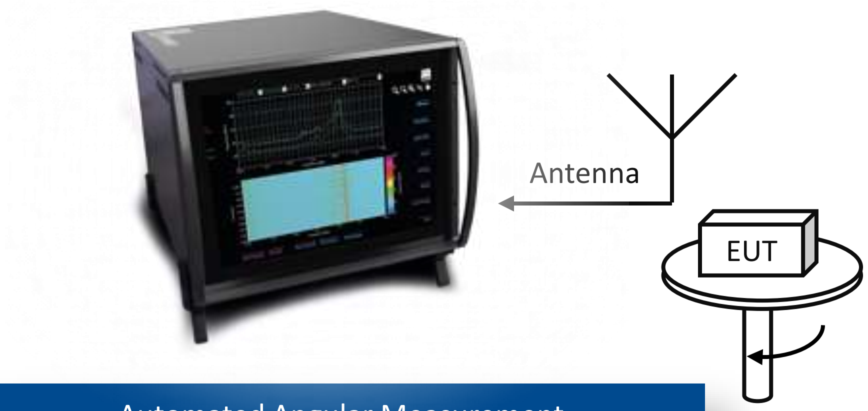
Real-time Spectrogram: Peak and Quasi-peak parallel



APD Measurement Mode / Persistence Mode



Measurement of Radiation Pattern according to ETSI Standards



Automated Angular Measurement

↓

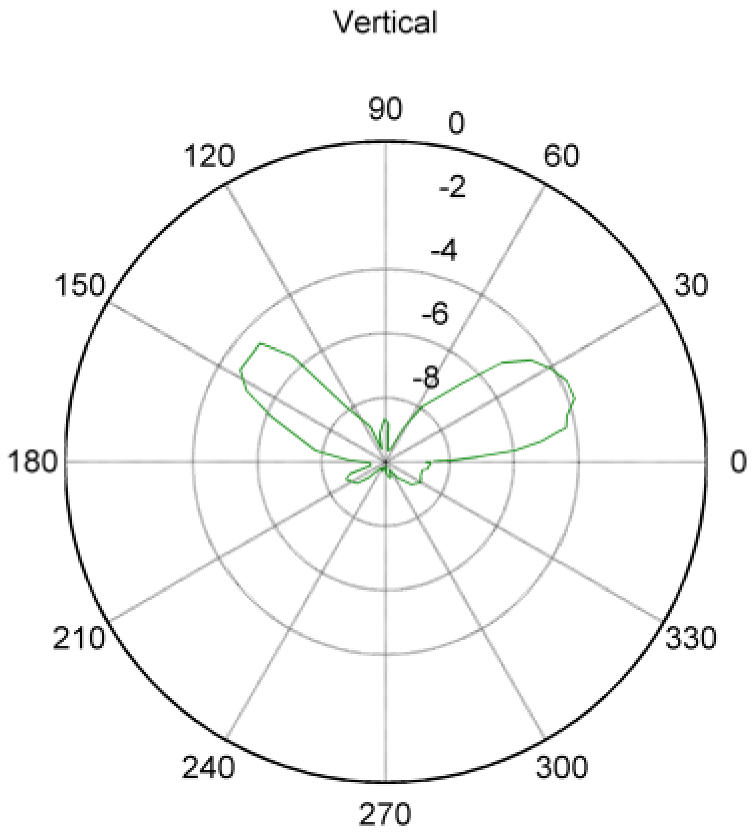
Extraction of Frequencies under Evaluation

↓

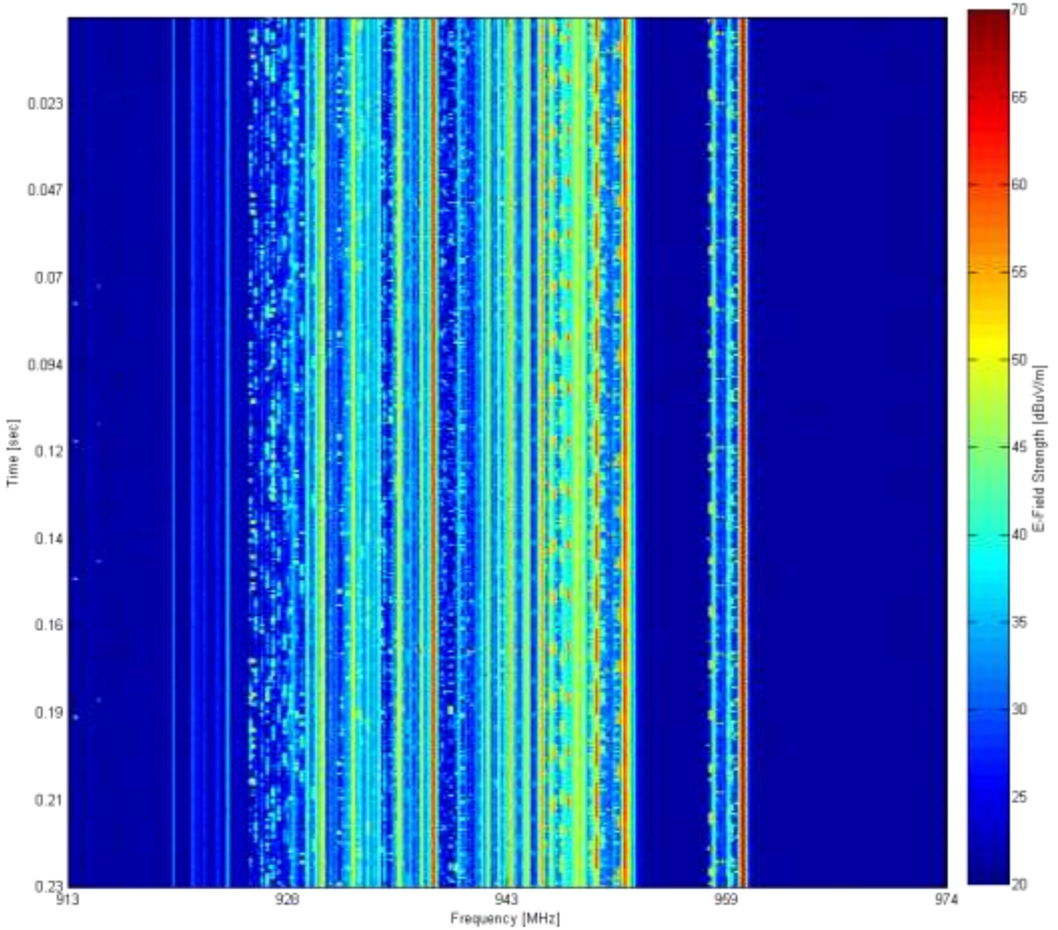
Calculation of Isotropic Radiated Power E.I.R.P.

↓

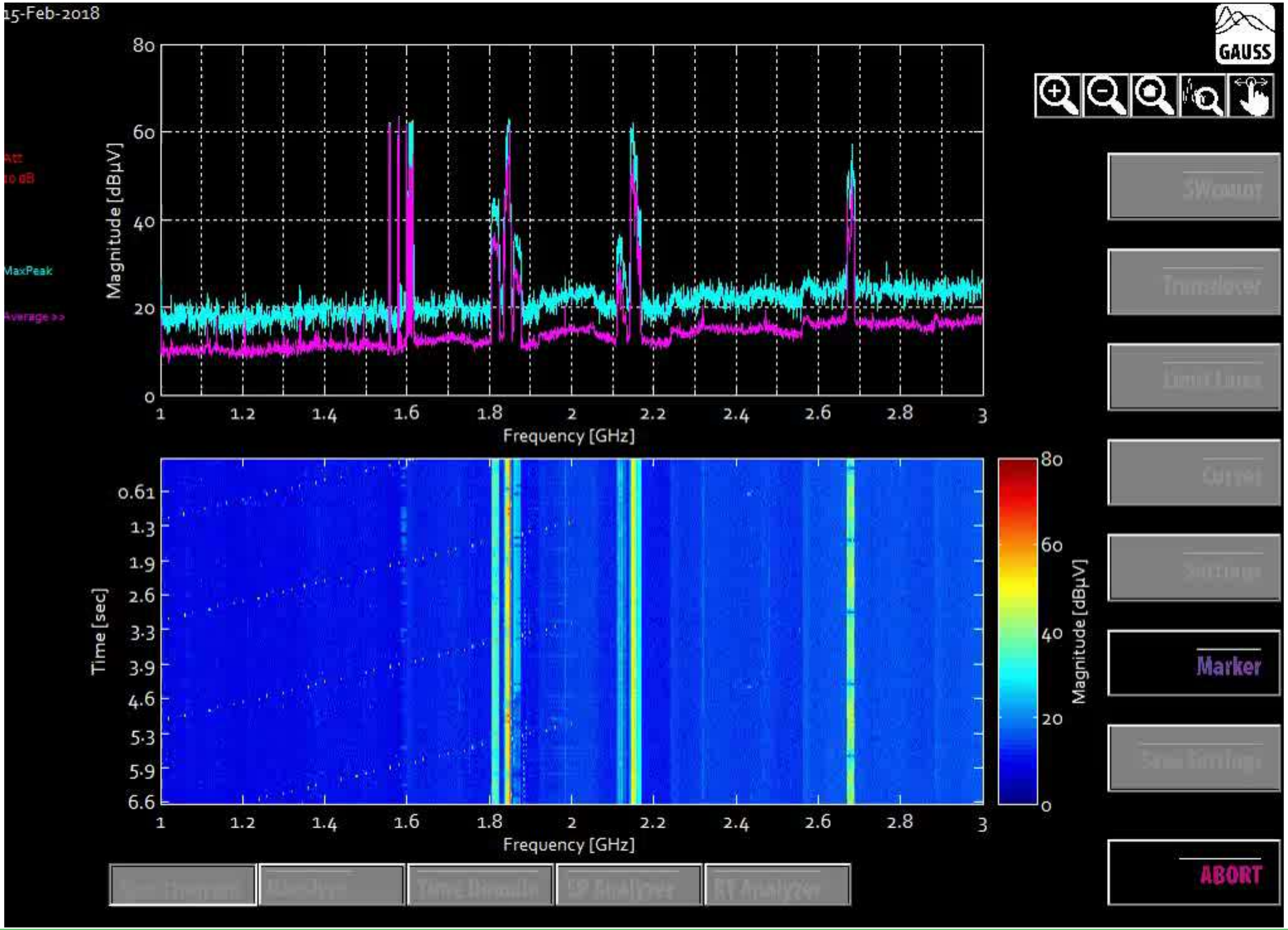
Report



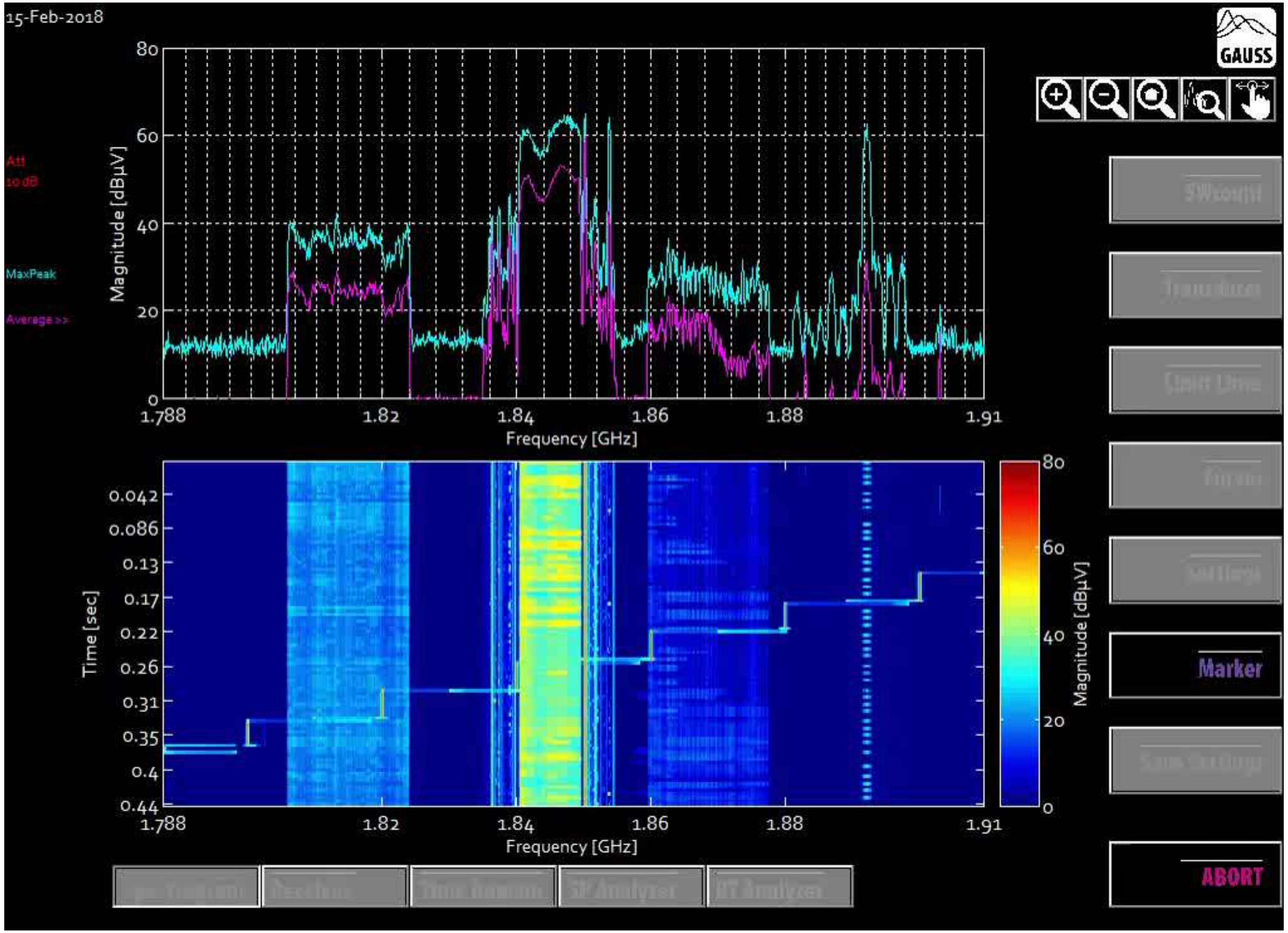
Measurement of Transmitting Time Slots according to ETSI Standards



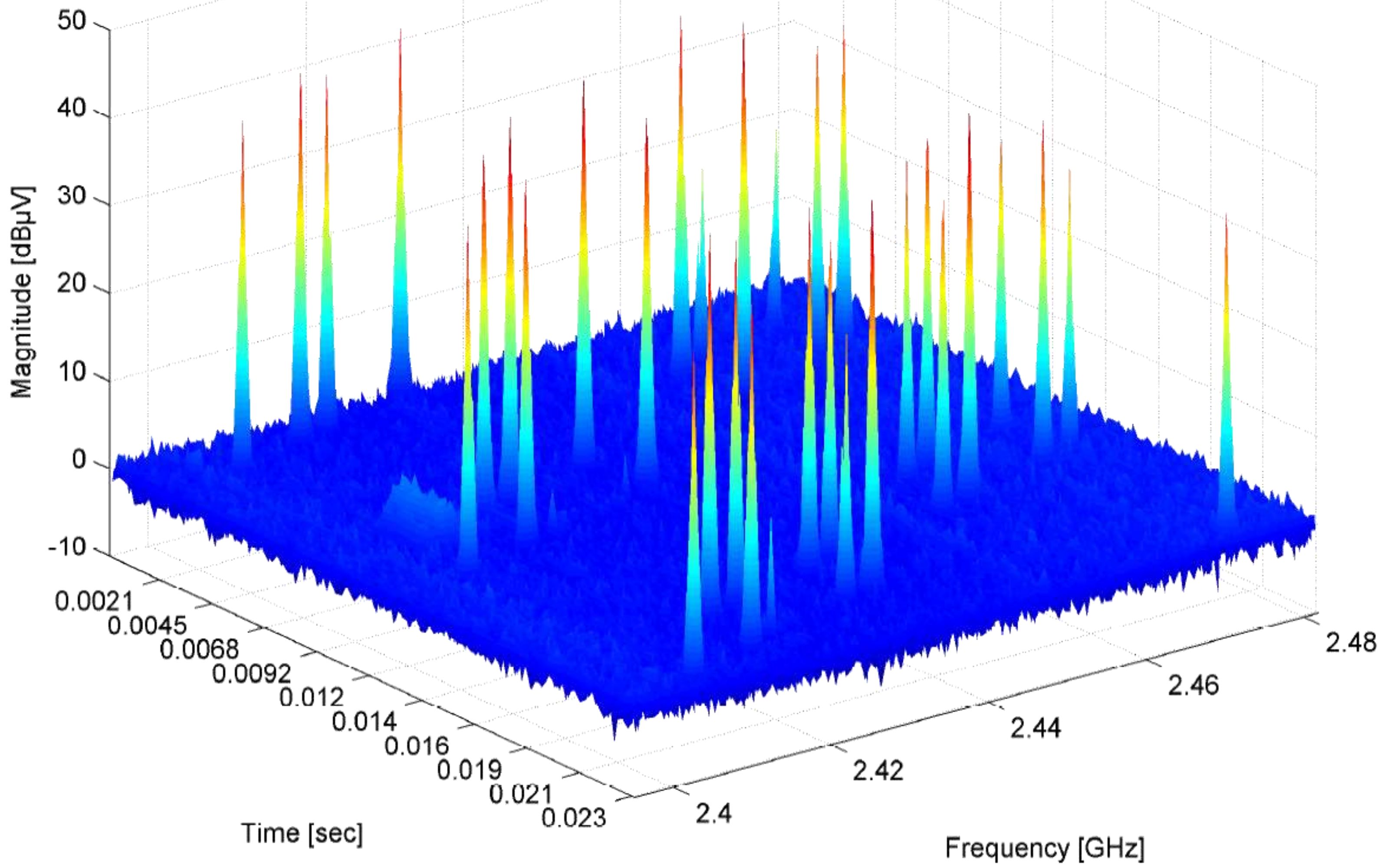
Frequency hopping Signal
(Peak and Average parallel, 2 GHz RTBW) (1)



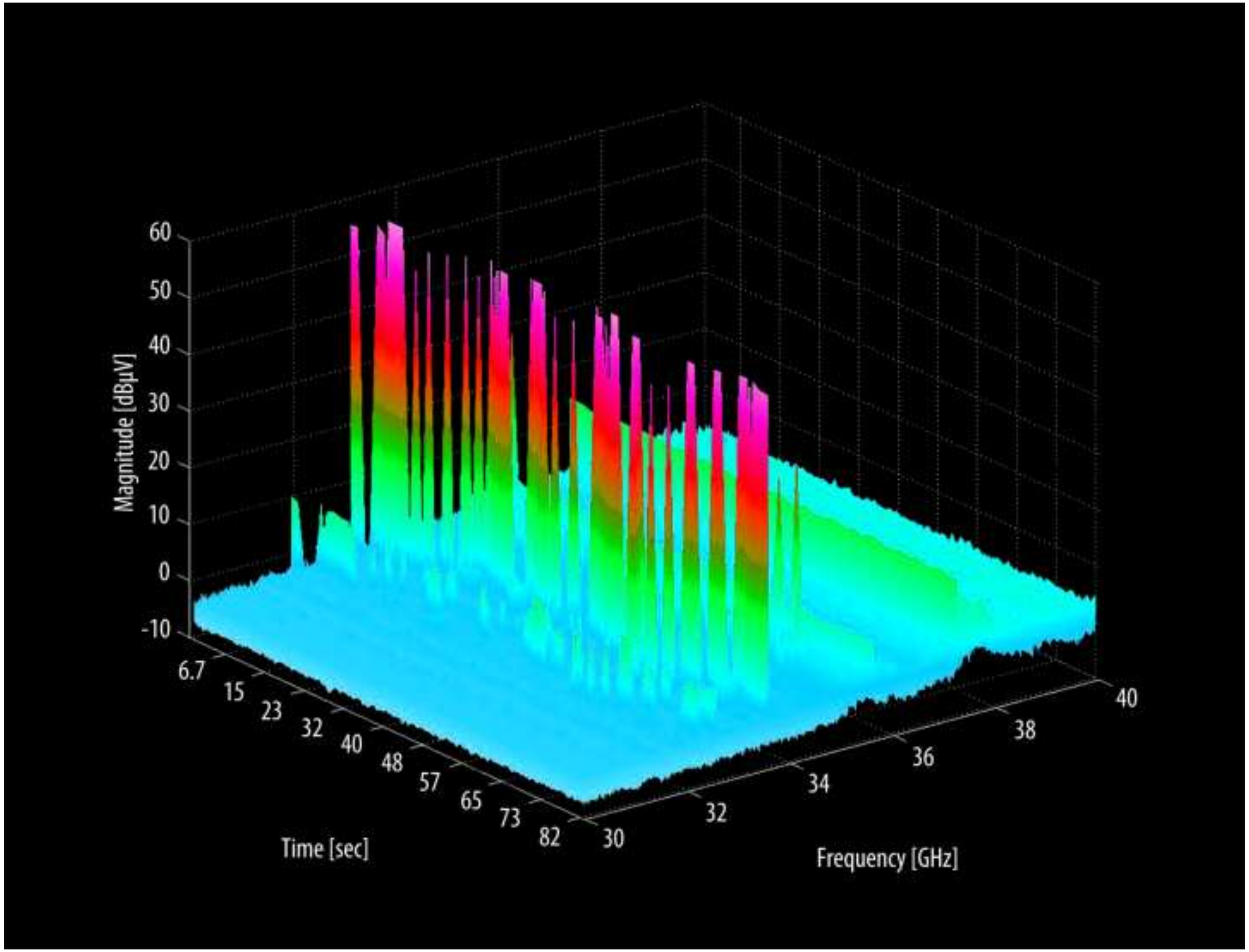
Frequency hopping Signal (Peak and Average parallel, 2 GHz RTBW) (2)



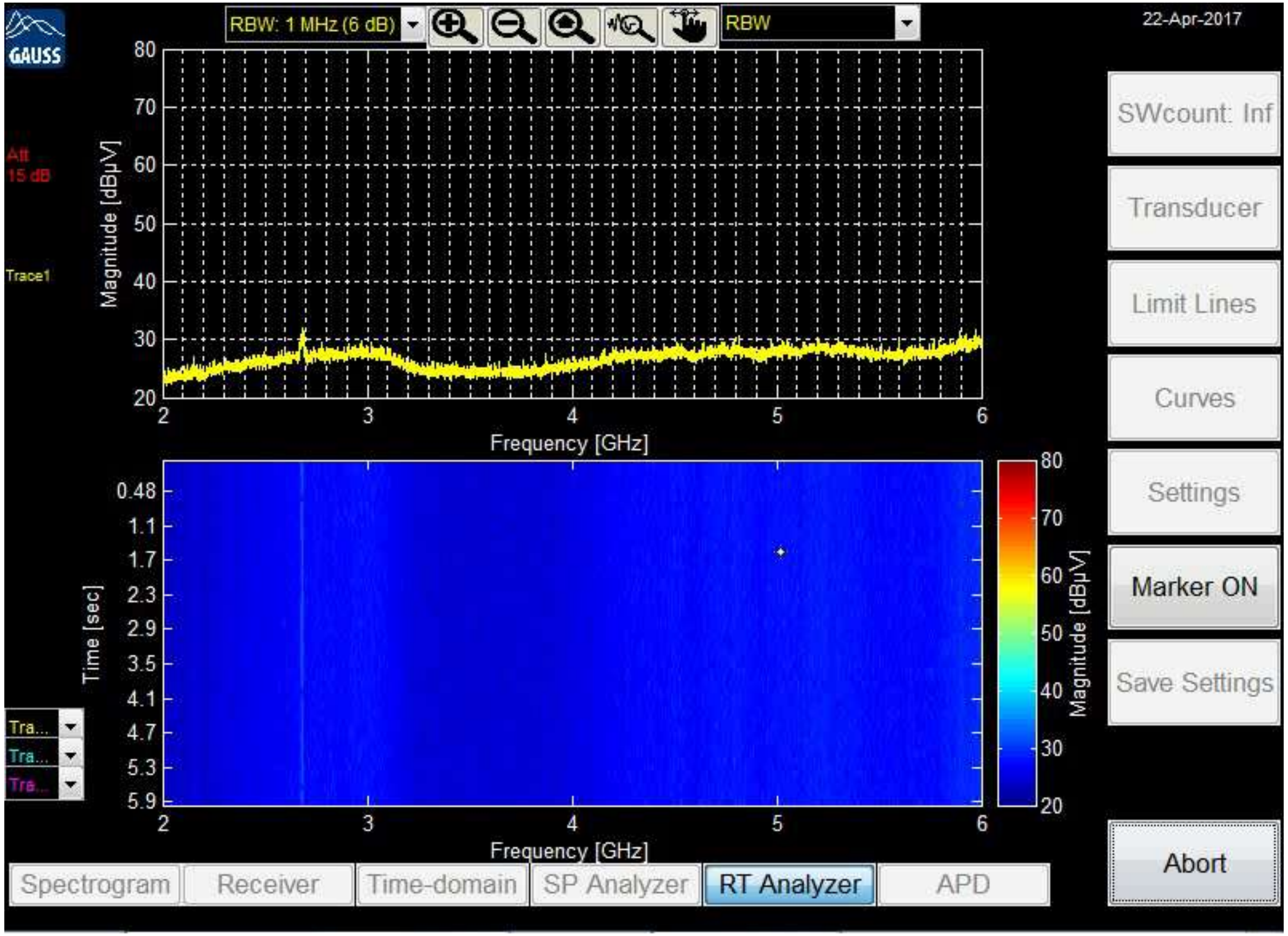
Measurement of a Frequency Hopping Signal at according to ETSI Standards



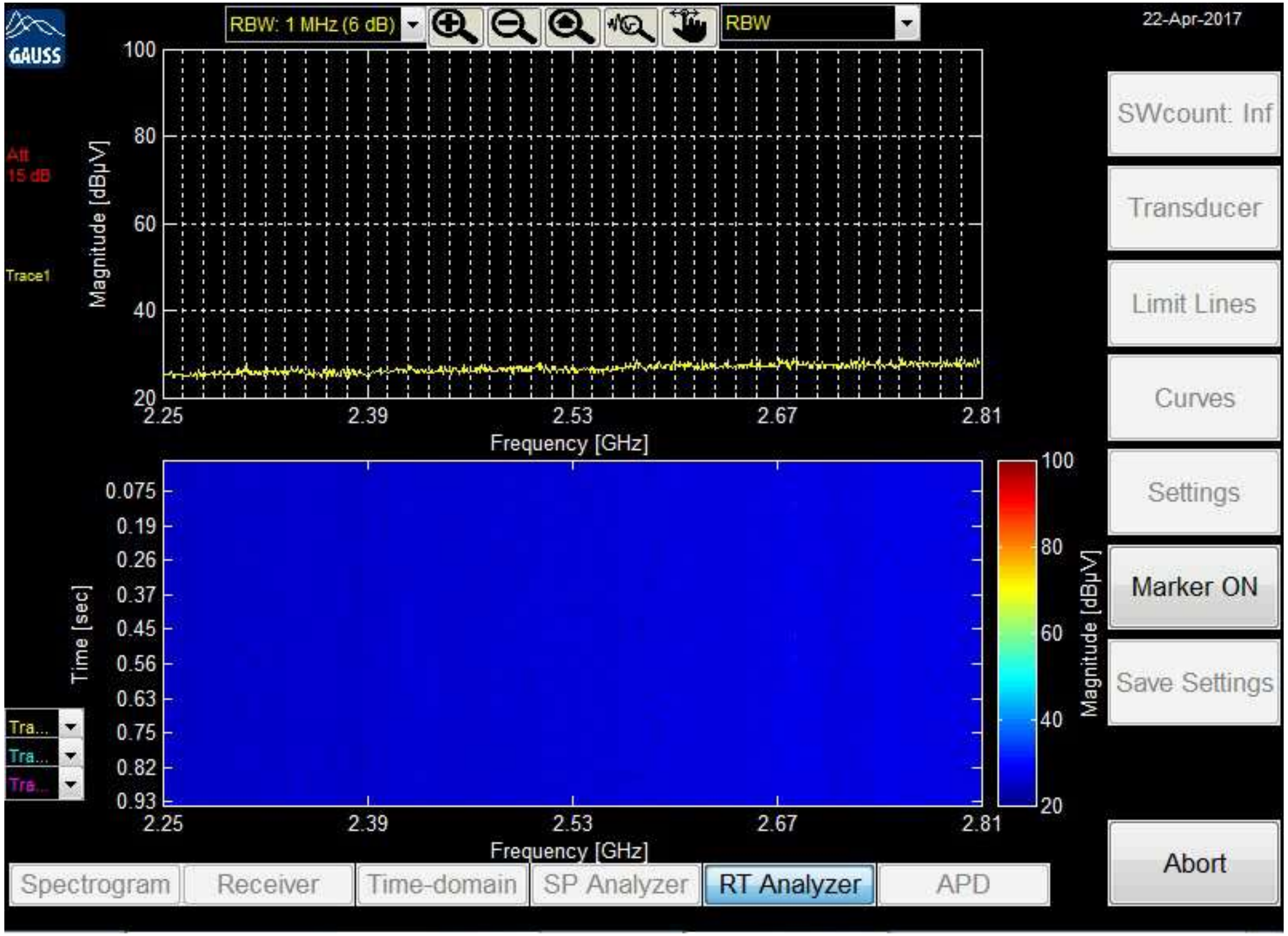
Frequency Hopping Signal @ 38 GHz



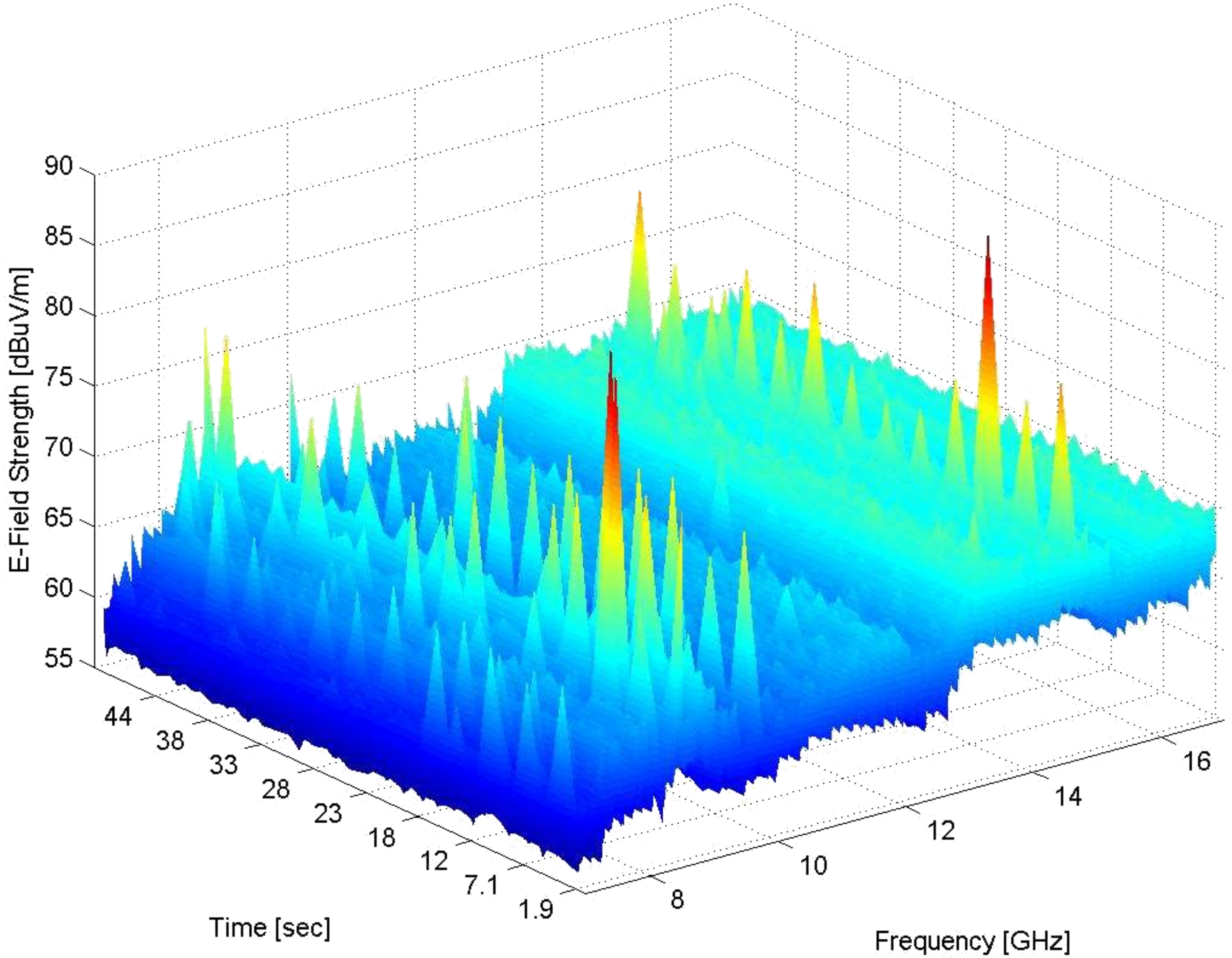
Microwave Oven 2 GHz – 6 GHz



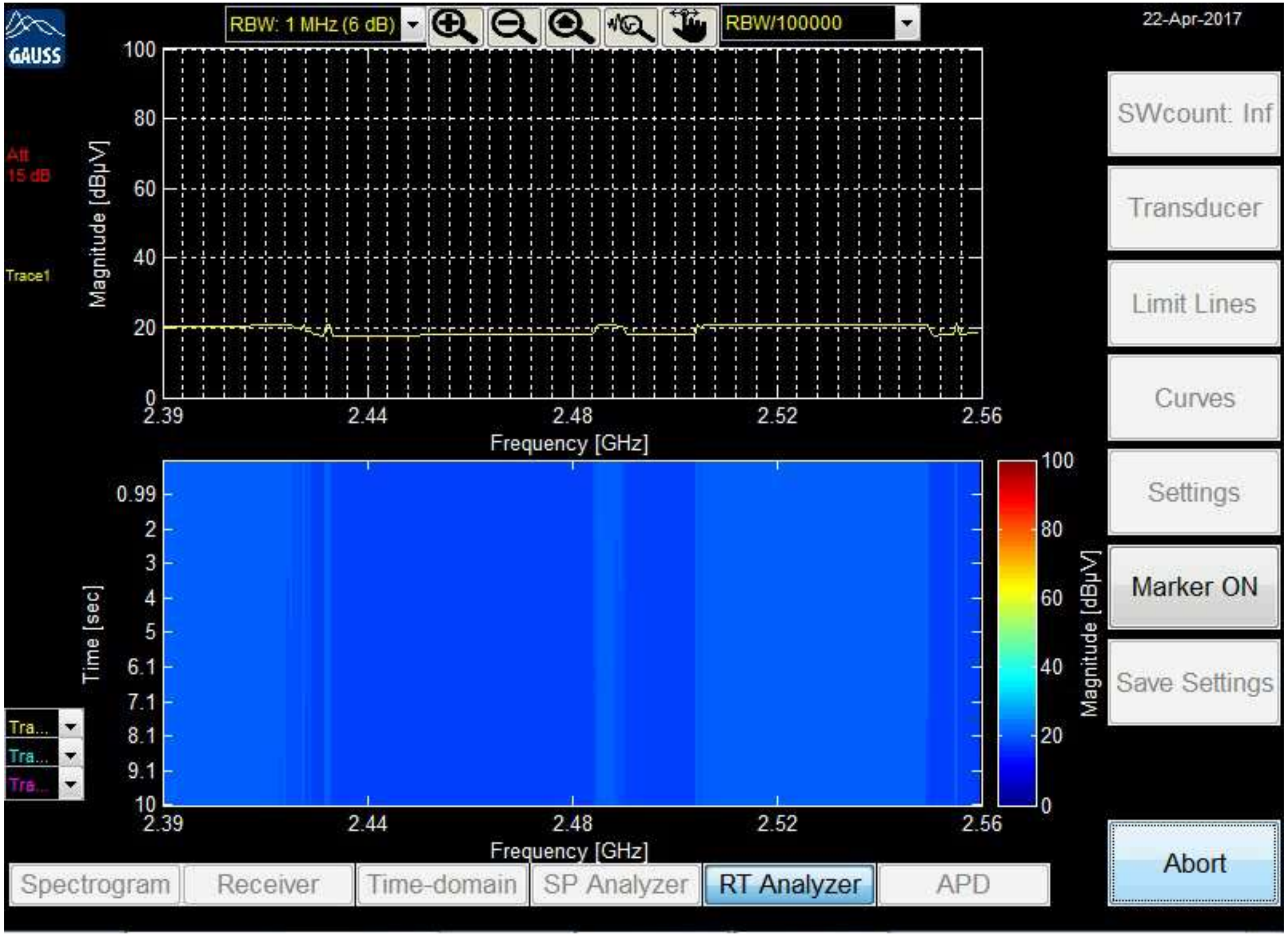
Microwave Oven ISM Band Peak Detector



Radiated Emission of a Microwave oven

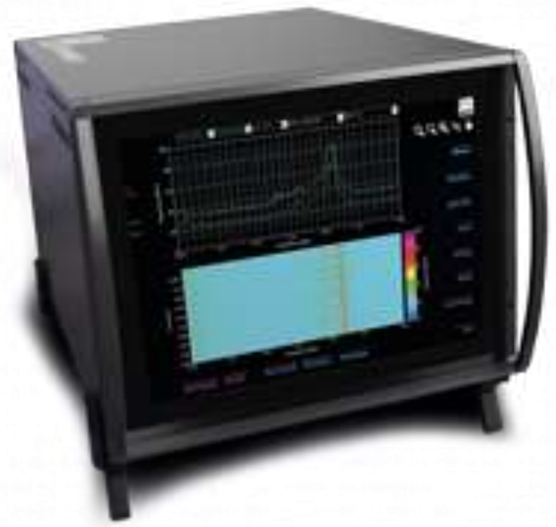


Microwave Oven ISM Band Peak Detector Video Filter according to CISPR

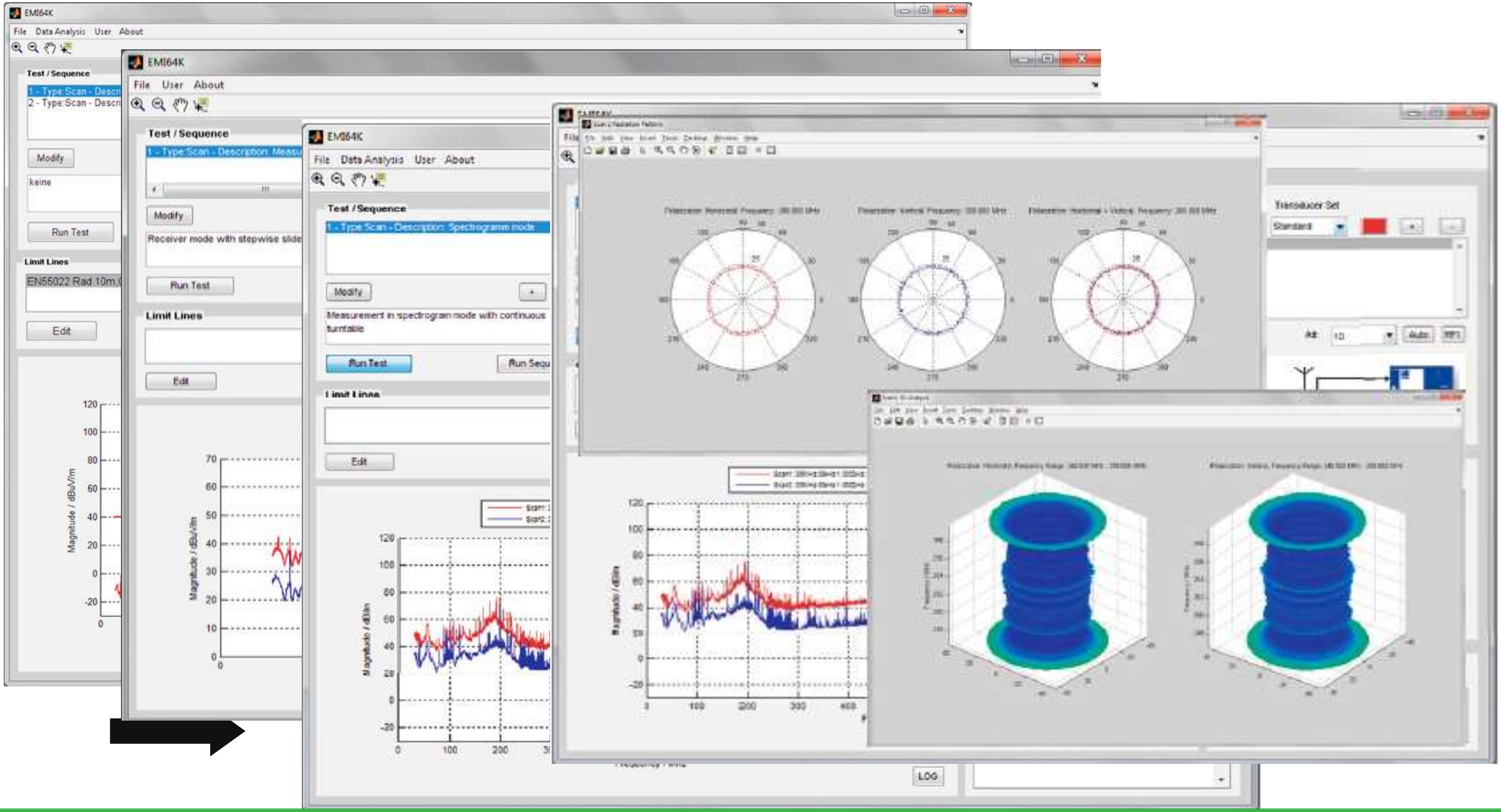


Available Technology e.g. TDEMI Ultra

- Parallel Measurement with Quasi-Peak und C-AVG over 685 MHz Real-time Bandwidth
- Parallel Measurement with Peak und AVG over several GHz in Real-time
- Real-time Mode according to CISPR 16-1-1 and CISPR 16-3
- Modern Spectrum Analyzer / Superhet Mode
- IQ- Data Analysis
- Measurement of Communication Devices
- Multi GHz Real-time Scanning
- Analysis of Frequency Hopping Signals
- Mobile Usage 12V Supply and Battery Pack
- Preselection in all Operating Modes



Total Automation Software Suite EMI64k



Thank you

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