EMI Test Receivers: Past, Present and Future

Andy Coombes – EMC Product Manager
Rohde & Schwarz UK Ltd

9th November 2016

ROHDE&SCHWARZ

Introduction

- **Andy Coombes – EMC Product Manager**
- 20 years experience in the field of EMC Testing and EMC Lab Management
- Joined Rohde & Schwarz in 2007 as UK EMC Product Manager, support the UK, Ireland and Benelux countries
- Previous life: RFI Global Services (UL) 12 years (8 years as EMC Test Engineer / 4 years as EMC Lab Manager)
- Testing background is primarily EMC and Radio Approval of Wireless devices (GSM, WiFi, BT, uWave, SRD) and Consumer Electronics, but also have a reasonable understanding of Automotive, Military and Aerospace.

Professional Summary:

Diploma in Electrical Electronics Engineering

Agenda

- **EMI Test Receivers: Past, Present and Future**
  - **In the Beginning**
    - A short background
    - Standards introduction
  - **The Analogue Years**
    - The Stepped Scanning Receiver
    - The Formulation of the modern test method
  - **The Digital Beginnings**
    - Frequency Swept vs Frequency Stepped
    - Combining technologies to improve results
  - **Time Domain Emerges**
    - What, Why and How
    - Challenges
  - **Real Time and Beyond**
    - Next level testing for the future

In the Beginning

Definition of ElectroMagnetic Compatibility (EMC)

EMC is defined as:

"The ability of devices and systems to operate in their electromagnetic environment without impairing their functions and without faults and vice versa, i.e. to ensure that operation does not influence the electromagnetic environment to the extent that the functions of other devices and systems are adversely affected".

EMC testing is a means of verifying devices and systems abilities to stand up to this principle…

CISPR16-2 -1 / -2 / -3 Minimum Scan Times

Table x – Minimum scan times for the three CISPR bands with peak and quasi-peak detectors

Frequency band		Scan time T_s for peak detection	Scan time T_s for quasi-peak detection
A	9 kHz to 150 kHz	14,1 s	2 820 s = 47 min
B	0,15 MHz to 30 MHz	2,985 s	5 970 s = 99,5 min = 1 h 39 min
C and D	30 MHz to 1 000 MHz	0,97 s	19 400 s = 323,3 min = 5 h 23 min

The scan times in Table x apply to the measurement of CW signals. Depending on the type of disturbance, the scan time may have to be increased – even for quasi-peak measurements. In extreme cases, the measurement time T_m at a certain frequency may have to be increased to 15 s, if the level of the observed emission is not steady (see 6.5.1). However isolated clicks are excluded.

Scan rates and measurement times for use with the average detector are given in Annex Y

Many sections of the 3 standard parts have the same content. Numbering and indices are different.

x *Table #1 in CISPR16-2-1 and -3. Table #2 in CISPR16-2-2.*

Y *Annex C in CISPR16-2-1 and -3. Annex D in CISPR16-2-2.*

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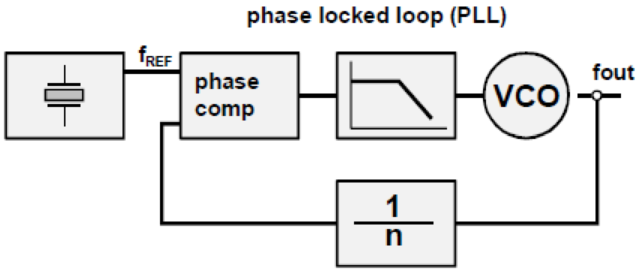
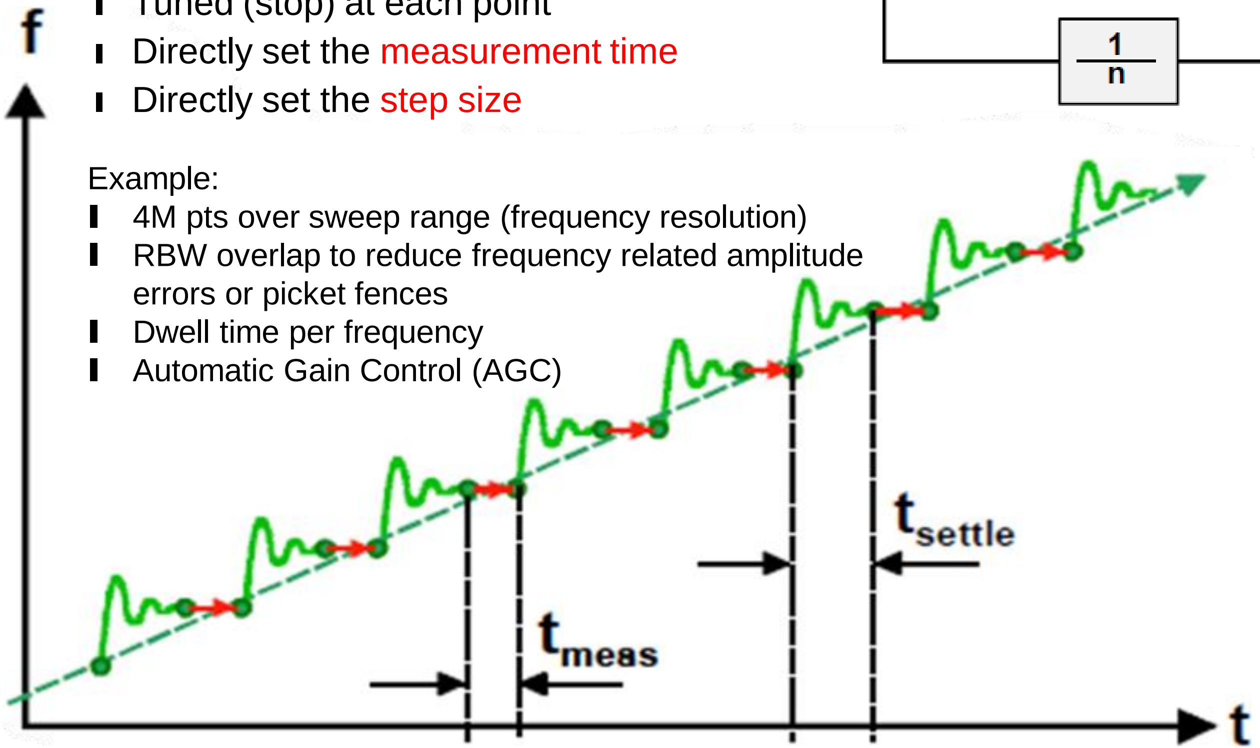
80s and 90s – the Analogue Days

Scanning Receiver



- Tuned (stop) at each point
- Directly set the measurement time
- Directly set the step size



Example:

- 4M pts over sweep range (frequency resolution)
- RBW overlap to reduce frequency related amplitude errors or picket fences
- Dwell time per frequency
- Automatic Gain Control (AGC)

Outcome…

- The very long scan and observation times required to satisfy the standards have lead to a practicable (compromised) test method

- You may be familiar with it….

Formulation of a Test method

Preview / Pre-scan
(automated / semi-automated)

well-known
procedure

Formulation of a Test method

Preview / Pre-scan
(automated / semi-automated)

Data Reduction / Critical Frequencies

well-known procedure

Formulation of a Test method

well-known procedure

Preview / Pre-scan
(automated / semi-automated)

↓

Data Reduction / Critical Frequencies

↓

Final
(automated / semi-automated)

CISPR16-2 all parts – since edition 1

6.5.2 Scan rates for scanning receivers and spectrum analyzers

One of two conditions need to be met to ensure that signals are not missed during automatic scans over frequency spans:

1) for a single sweep: the measurement time at each frequency must be larger than the intervals between pulses for intermittent signals;
2) for multiple sweeps with maximum hold: the observation time at each frequency should be sufficient for intercepting intermittent signals.

CISPR16-2 all parts – since edition 1

During a sweep….
…measurement time at each frequency?

6.5.2 Scan rates for scanning receivers and spectrum analyzers

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CISPR16-2 all parts – since edition 1

…intervals between pulses
for intermittent signals?

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CISPR16-2 all parts – since edition 1

for multiple sweeps…
…observation time at each frequency?

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Formulation of a Test method

manual

Timing Analysis of EUT
to find Measurement Time

Very often omitted!

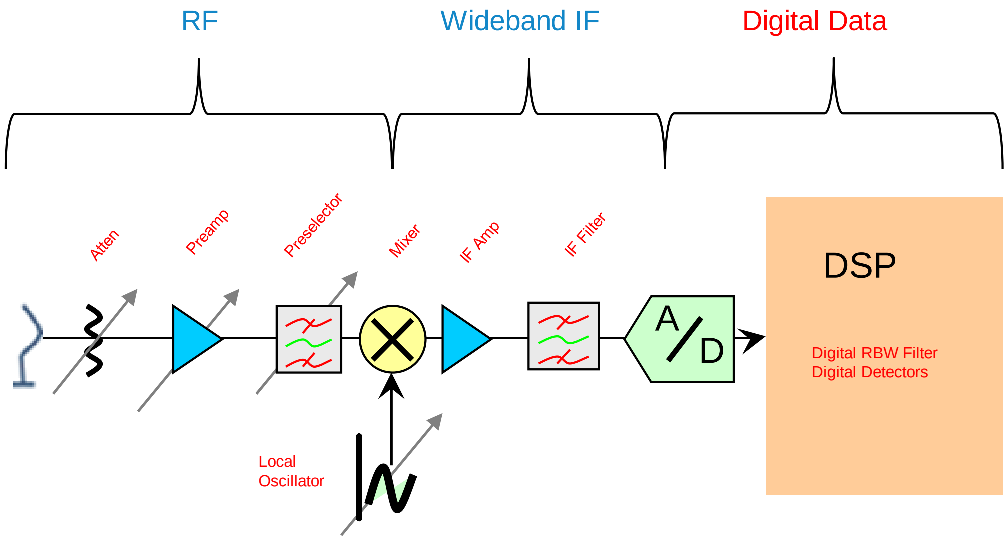
Preview / Pre-scan
(automated / semi-automated)

Data Reduction / Critical Frequencies

Final
(automated / semi-automated)

90’s and 00’s – The Digital beginnings

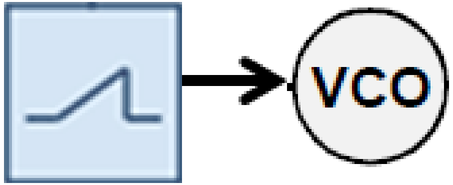
Typically Modern EMI Receiver Design



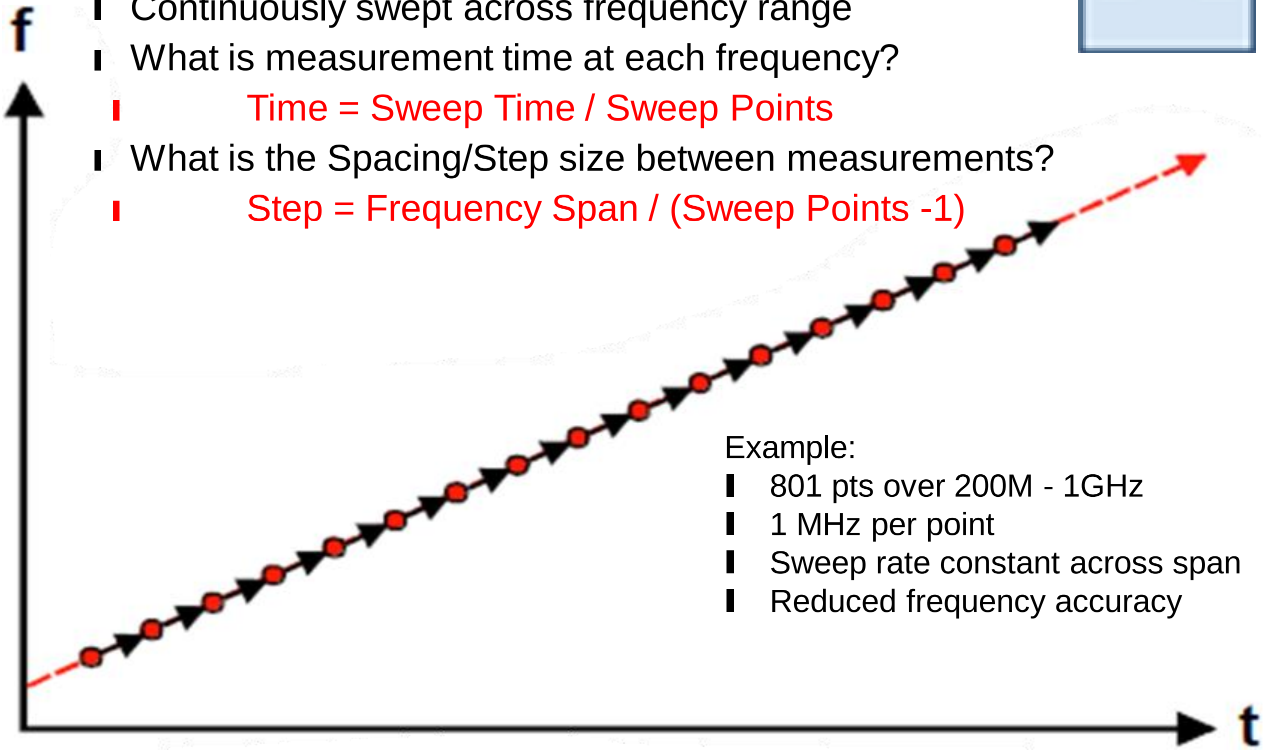
IF into ADC and digital signal processing provide for a entire new level of feature / functionality including:

- Revolutionary New Displays

Sweeping Spectrum Analyzer



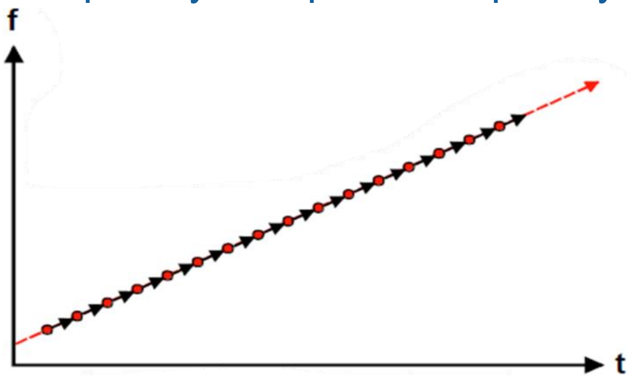
- Continuously swept across frequency range
- What is measurement time at each frequency?
  - Time = Sweep Time / Sweep Points
- What is the Spacing/Step size between measurements?
  - Step = Frequency Span / (Sweep Points -1)

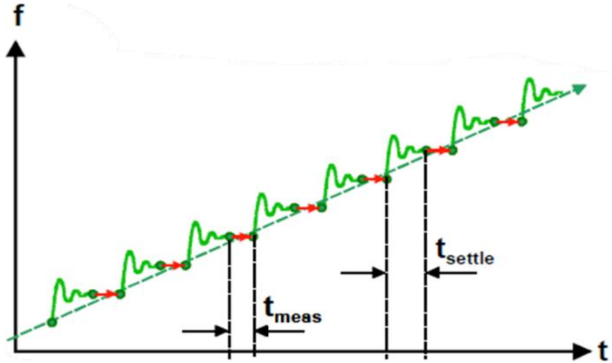


Example:
- 801 pts over 200M - 1GHz
- 1 MHz per point
- Sweep rate constant across span
- Reduced frequency accuracy

Spectrum Analyzer vs EMI Receiver

Frequency Swept vs Frequency Stepped





Spectrum Analyzer (Traditional Swept)

- Continuously swept across frequency range
- What is measurement time at each frequency?
  - Time = Sweep Time / Sweep Points
- What is the Spacing/Step size between measurements?
  - Step = Frequency Span / (Sweep Points -1)

EMI Test Receiver (Tuned Receiver)

- Frequency tuned (stop) at each point
- Directly set the measurement time
- Directly set the frequency step size

- Removes most opportunities for user configuration error via user interface designed for EMI measurements

Frequency Swept - Capture Pulsed Event (1:34)

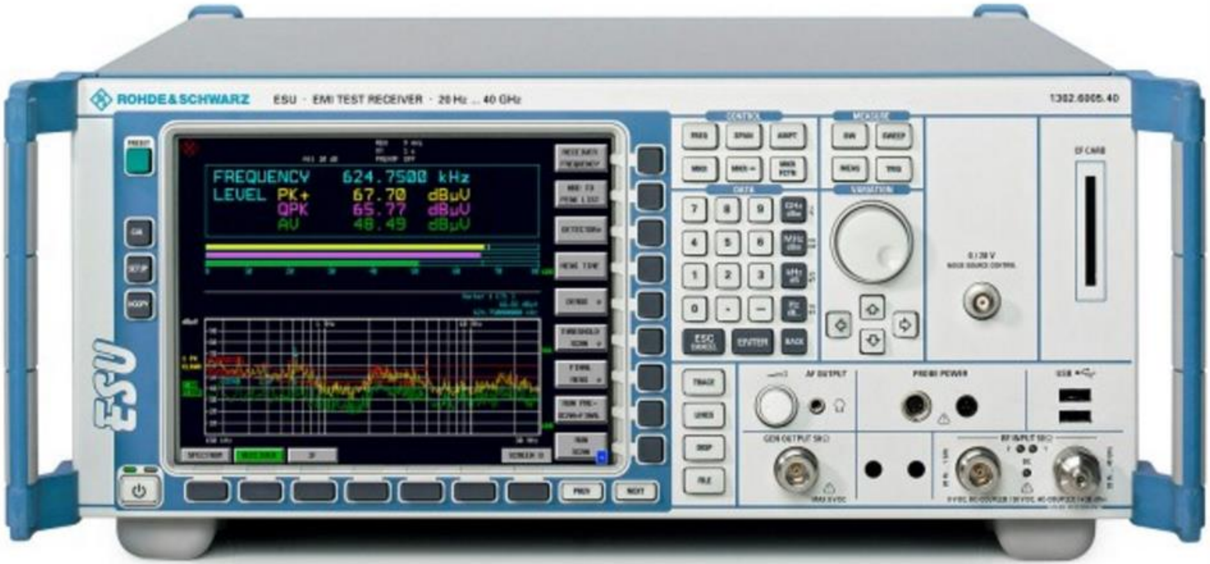
Fast Sweep with Max Hold

- **Conditions**
  - 10ms PRI with 10us pulse duration @ 700MHz
  - Sweep from 30MHz to 1GHz
  - RBW = 100kHz (6dB MIL-STD 461 filters)
  - Default Sweep Time = 194ms
    - MIL-STD461 sweep time spec is 145.5sec*
      - (1GHz – 30MHz) * 0.15sec/MHz = 145.5sec

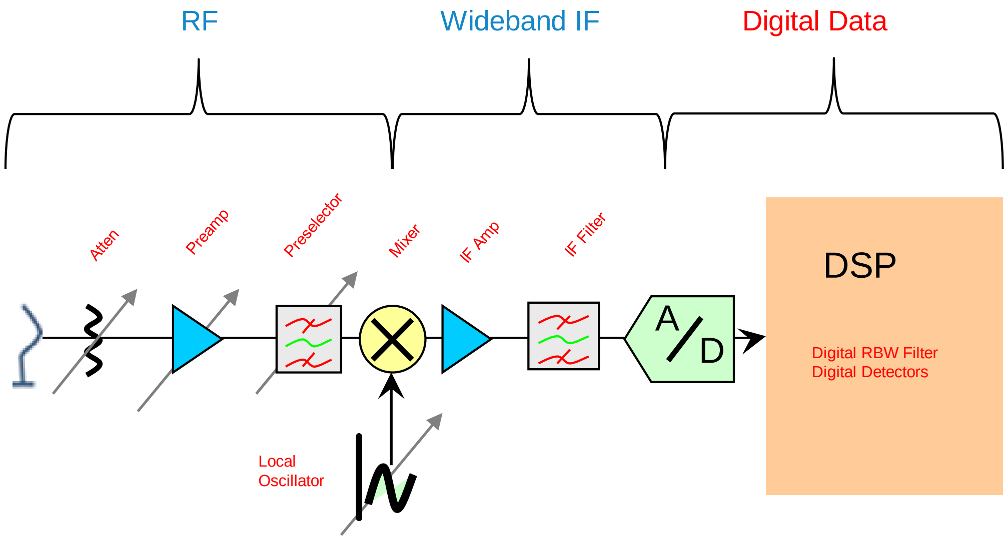
- **Observations**
  - Takes almost 4 minutes to capture
  - Almost have to know it's there, can be misleading

- * Interpretation of MIL-STD461F vs E may result in double the sweep time, i.e. 291sec vs. 145.5sec

2006 – 2017 – Time Domain Scan Emerges



Typically Modern EMI Receiver Design

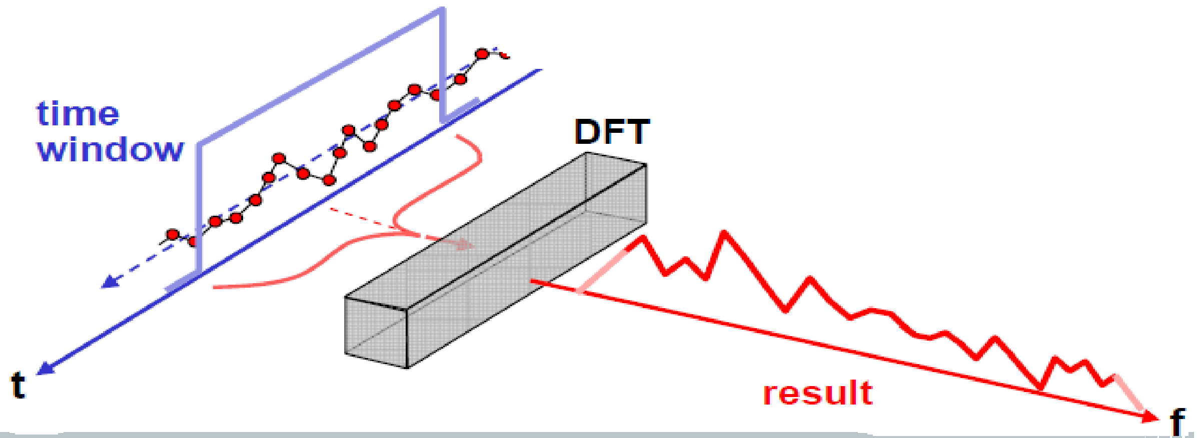


Wideband IF into ADC and digital signal processing provide for a entire new level of feature / functionality including:

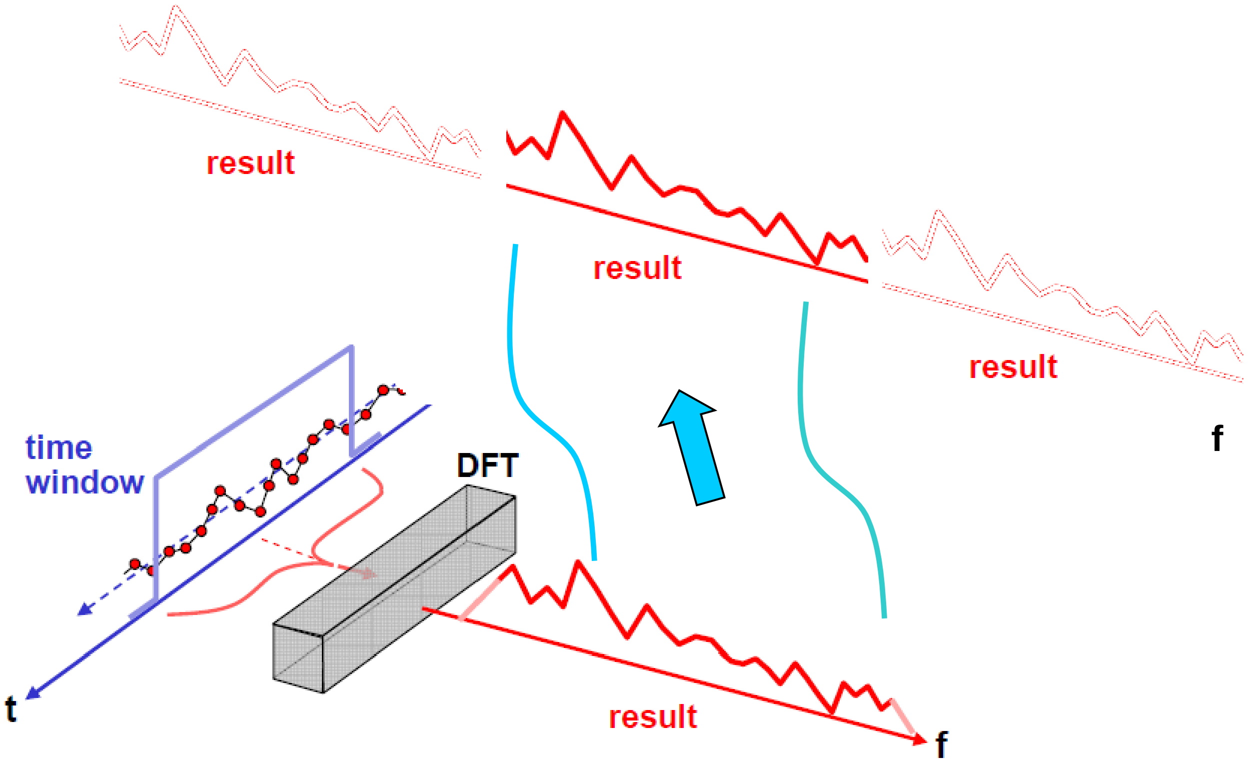
- Time Domain Scan
- Revolutionary New Displays

Time Domain Scan

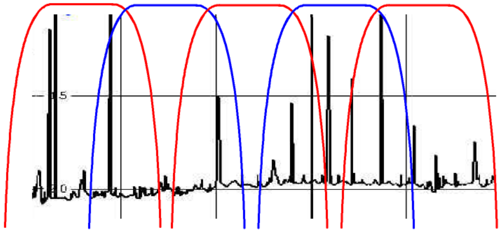
- The Discrete Fourier Transform (DFT) is a numerical mathematical method that calculates the spectrum for a periodic signal
- Use DFT to simultaneously measure many frequencies in parallel
- The Fast Fourier Transform (FFT) is an efficient algorithm to compute the DFT using symmetry and repetition properties
- FFT is much faster than DFT due to reduced number of multiplications

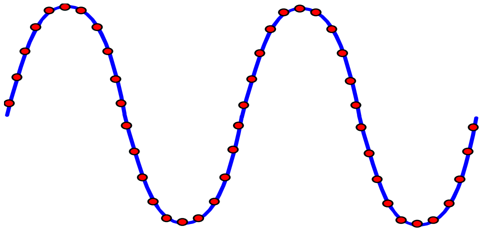


Time Domain Scan



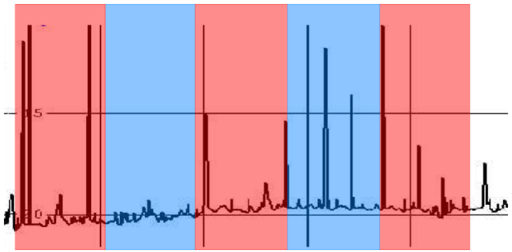
Time Domain Scan

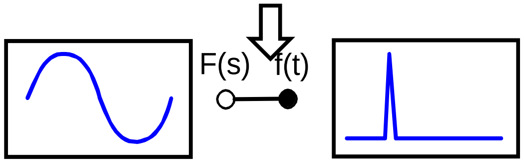




Frequency domain
Split the measured frequency range into consecutive frequency intervals

Time-domain
Sample the frequency interval with high sampling rate

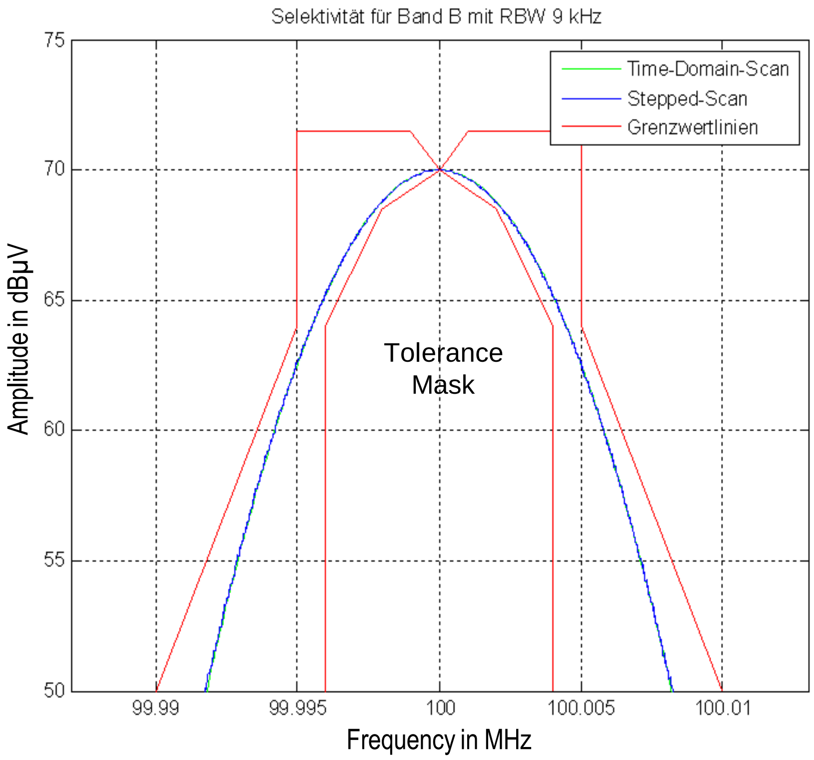




Frequency domain
Merge the spectra of all frequency blocks

Fast-Fourier transformation
Transform the signals from time domain to frequency domain

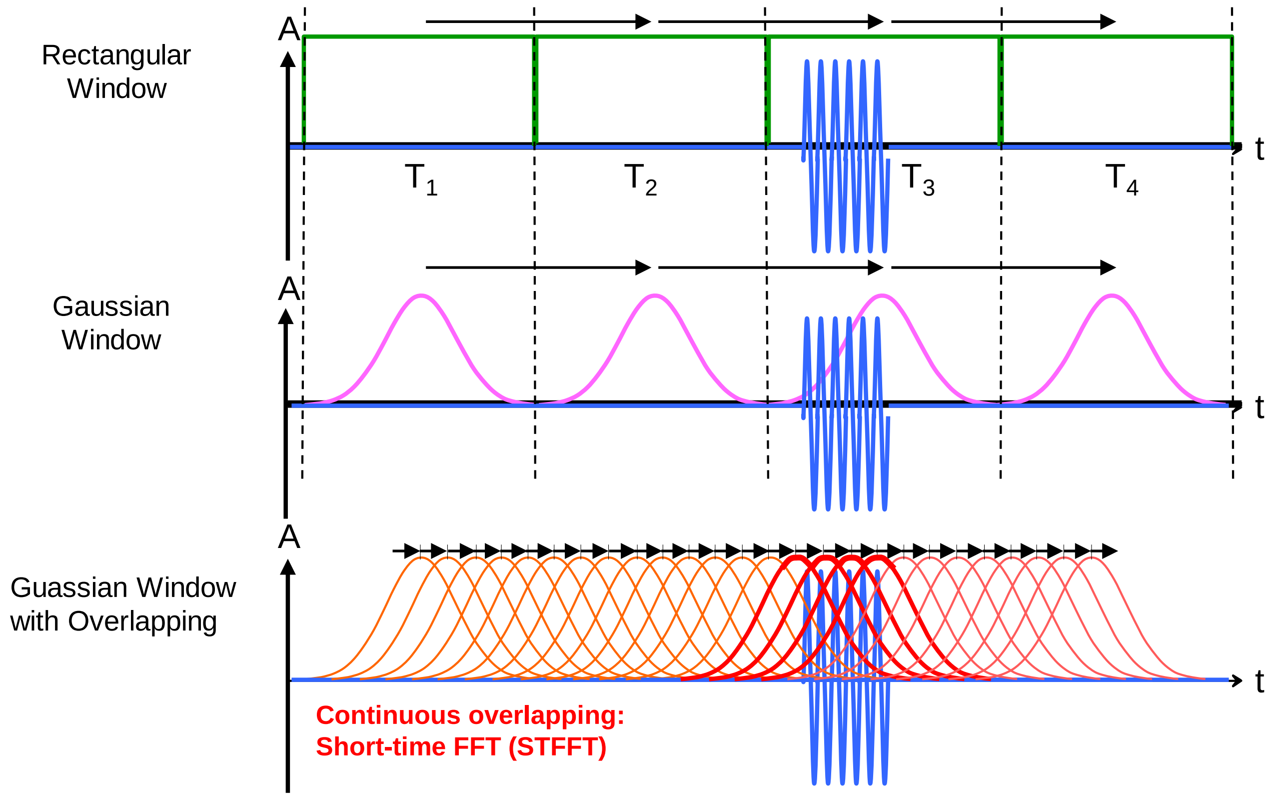
Windowing - Measurement BW



- Selectivity for CISPR Band B
- Measurement BW 9 kHz

- Do you see the Time Domain Scan filter response in green?

FFT Time Overlap



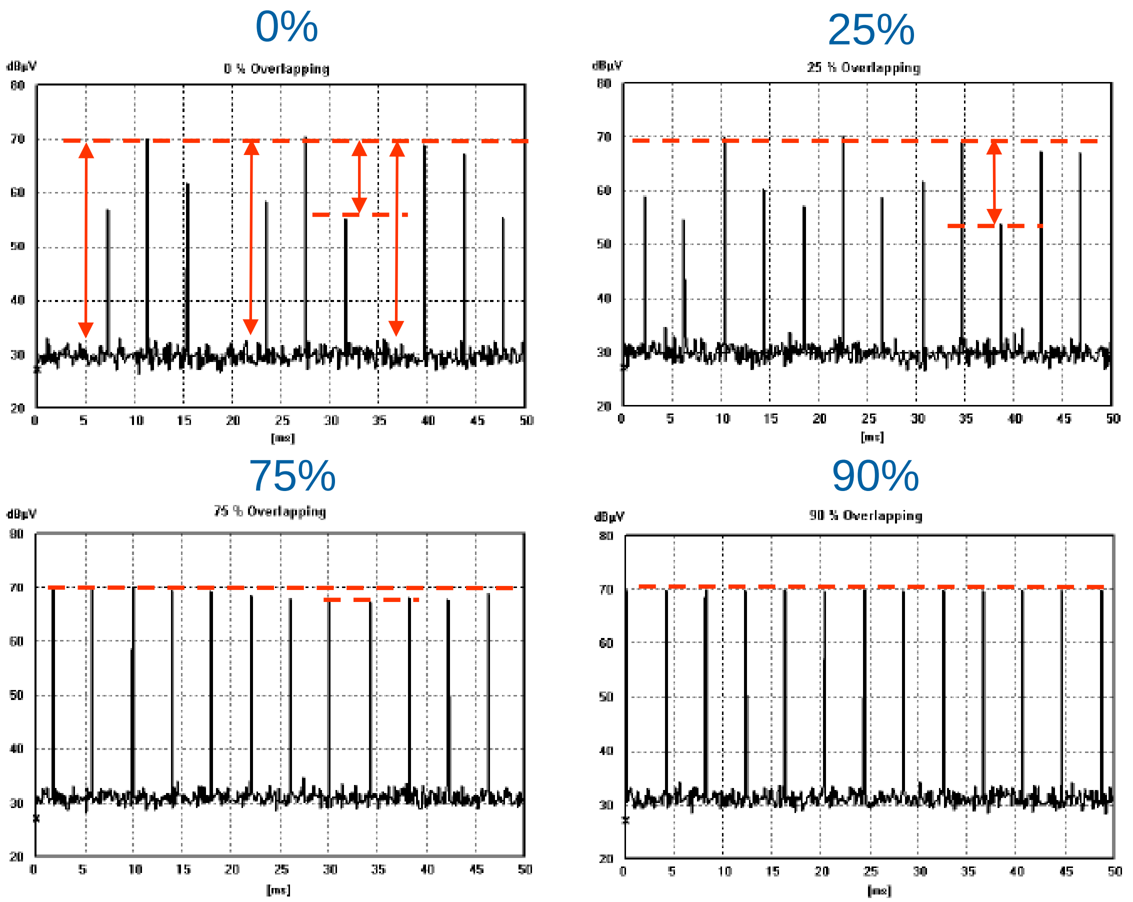
FFT Time Overlap

Source:

TR CISPR 16-3 @ IEC 2010

4.10 Background on the definition of an FFT-based receiver

4.10.5.4 Measurement error for sequence of pulses

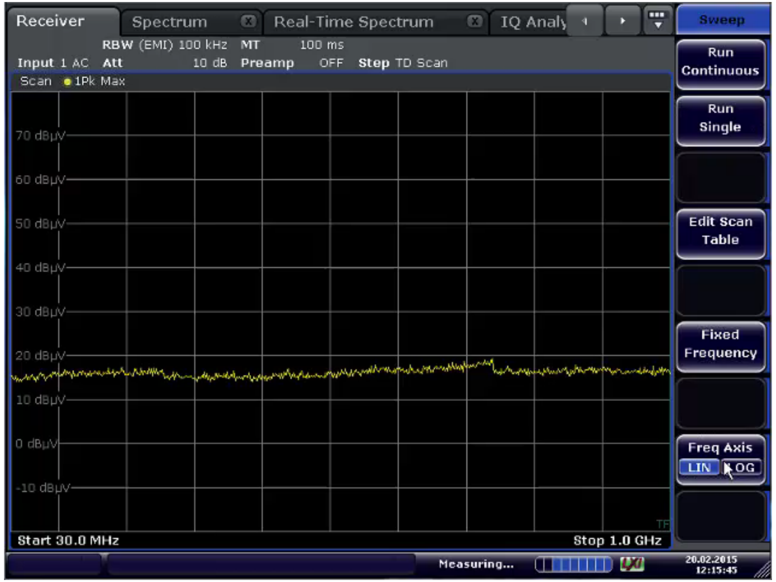


Time Domain- Capture Pulsed Event (0:08)

MIL-STD 461 Spec'd Dwell Time

- **Conditions**
  - 10ms PRI with 10us pulse duration @ 700MHz
  - Sweep from 30MHz to 1GHz
  - RBW = 100kHz (6dB MIL-STD 461 filters)
  - Spec'd Dwell Time = 0.015sec = 15ms

- **Observations**
  - Event detected and captured in just a few seconds
  - Time Domain is much faster and less likely to miss intermittent event



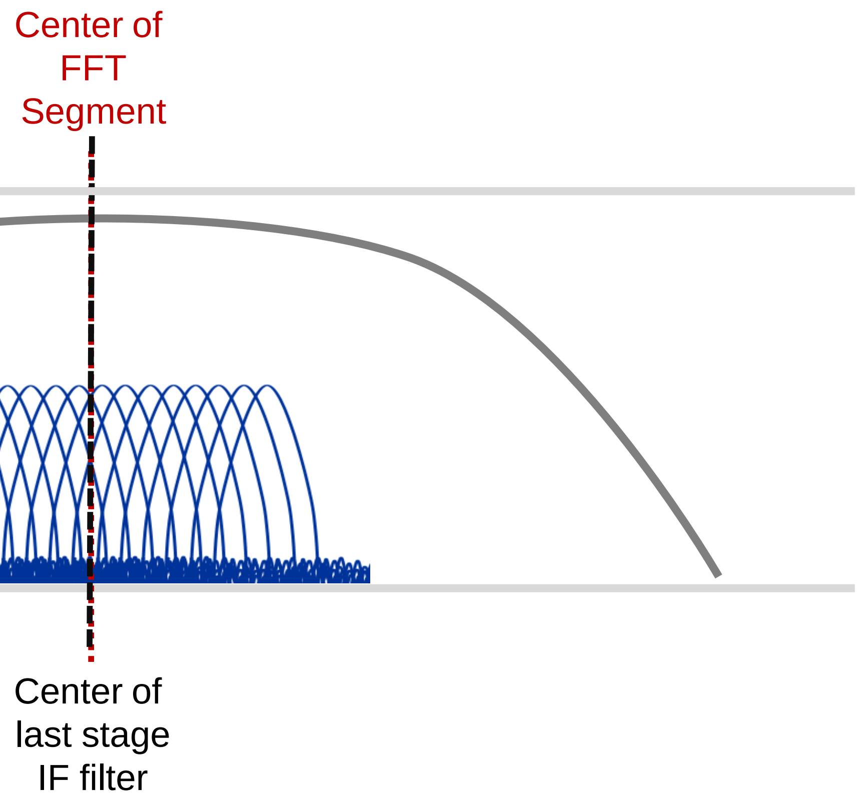
Times are changing

Frequency range	Weighting detector; measurement time; IF bandwidth; step width for stepped scan (SS) and Time Domain Scan (TD)	FFT-based measuring instrument R&S ESW 	
		Stepped Scan	Time-domain Scan
CISPR Band B 150 kHz to 30 MHz	P; 10 ms; 9 kHz; SS: 4 kHz, TD: 2.25 kHz	82 s	0.12 s (683 x)
CISPR Band B 150 kHz to 30 MHz	QP, 1 s, 9 kHz SS: 4 kHz, TD: 2.25 kHz	approx. 3.8 h	2 s (6 940 x)
CISPR Bands C/D 30 to 1000 MHz	Pk, 10 ms, 120 kHz SS: 40 kHz, TD: 30 kHz	255 s	0.8 s (318 x)
CISPR Bands C/D 30 to 1000 MHz	Pk, 10 ms, 9 kHz SS: 4 kHz, TD: 2.25 kHz	3 693 s	1.1 s (3 357 x)
CISPR Bands C/D 30 to 1000 MHz	QP, 1 s, 120 kHz / 9 kHz SS: 40/4 kHz, TD: 30/2.25 kHz	approx. 10 h / 100 h	80 s / 67 s (450 x / 5370 x)

Challenges

You don’t get something for nothing…

Segment Alignment + Signal Processing



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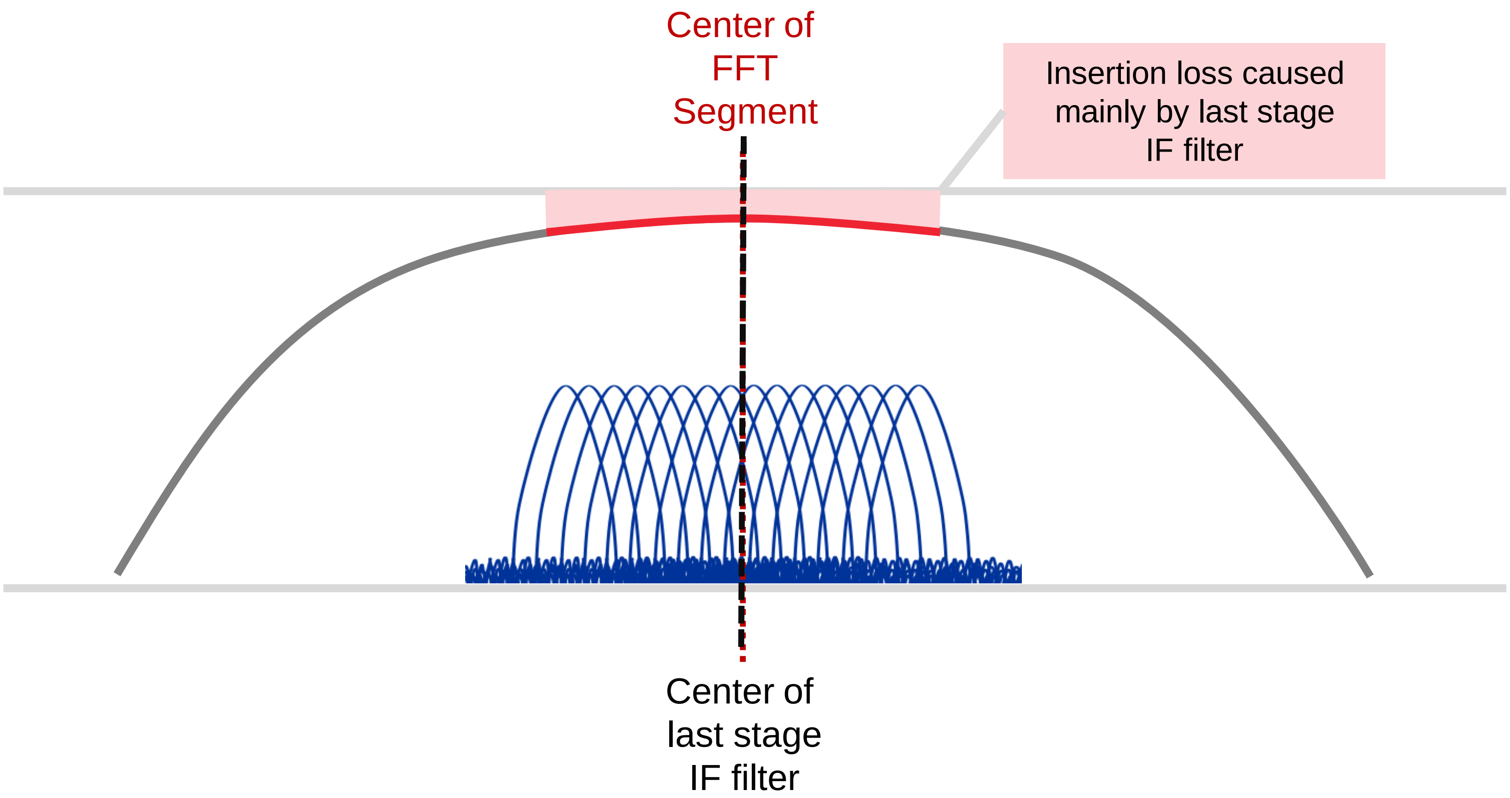

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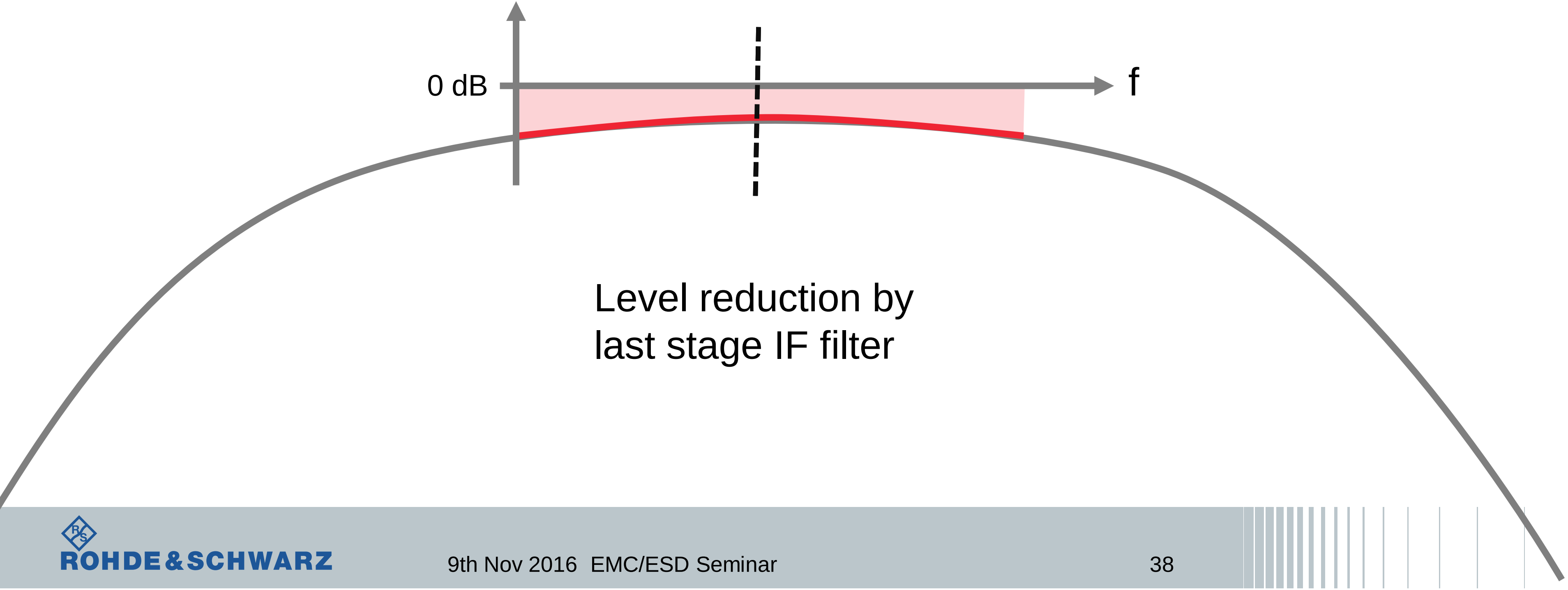
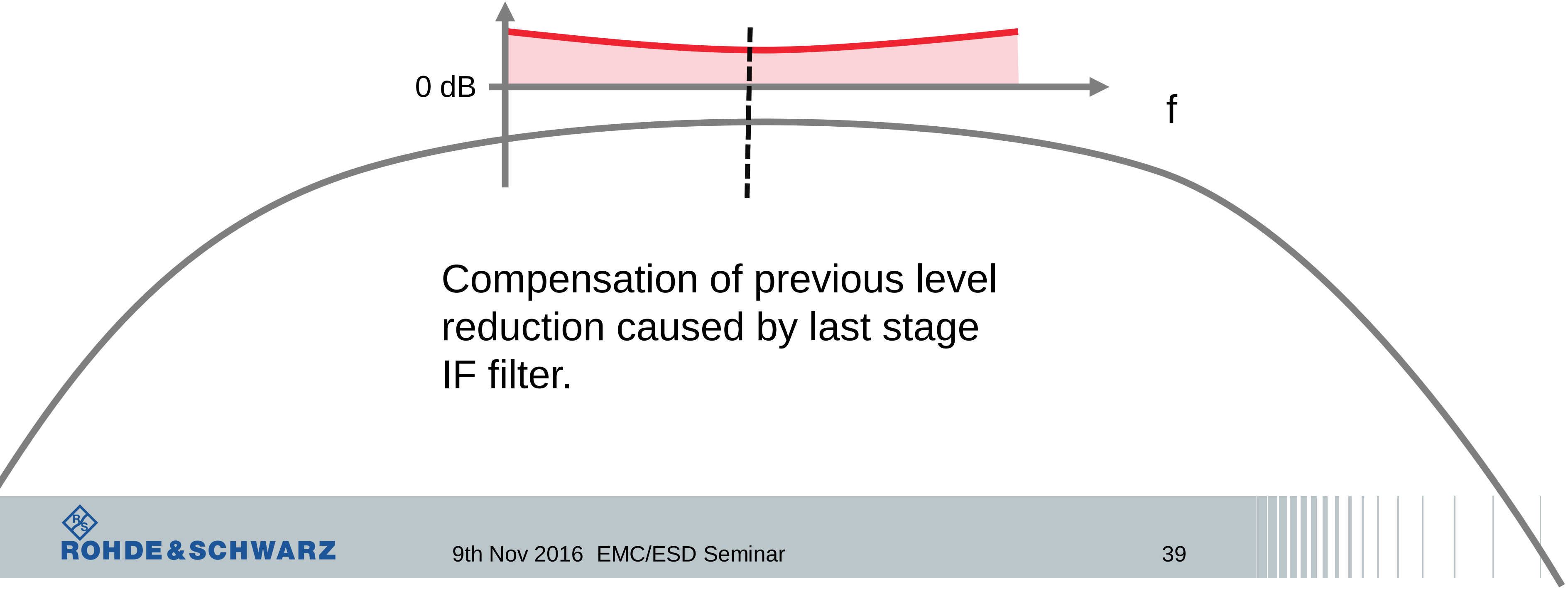


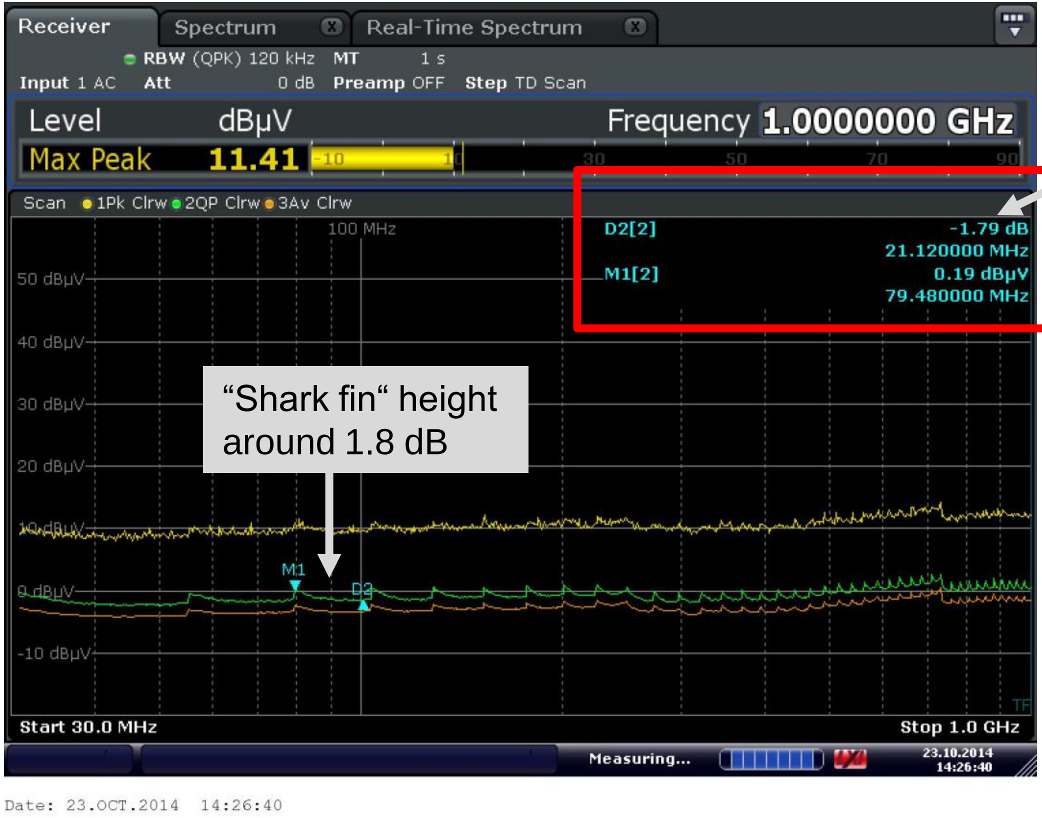
Level reduction by
last stage IF filter

Segment Alignment + Signal Processing

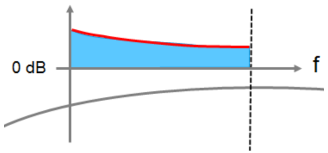


Compensation of previous level reduction caused by last stage IF filter.

Noise Floor Indication in TDS Mode

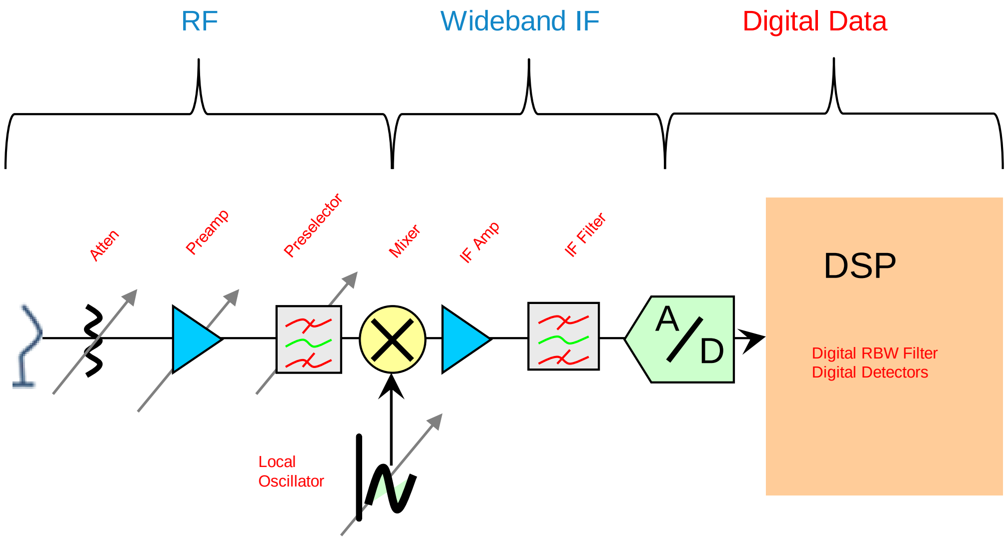


"Shark fin" height around 1.8 dB



2016 – Real Time and Beyond

Typically Modern EMI Receiver Design



Wideband IF into ADC and digital signal processing via dedicated **FPGA** provide for a entire new level of feature / functionality including:

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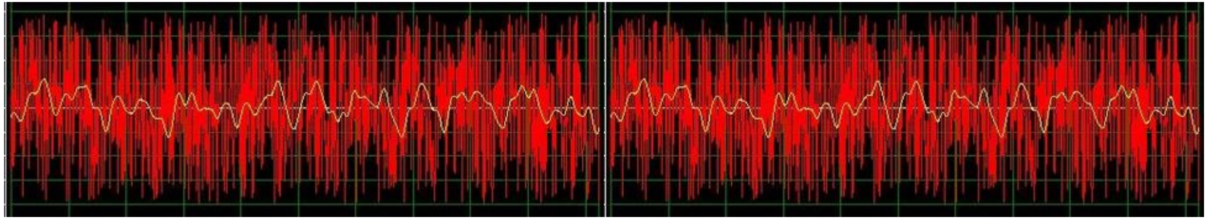
- Real-Time Processing
- Revolutionary New Displays

Analyzing Intermittent Signals

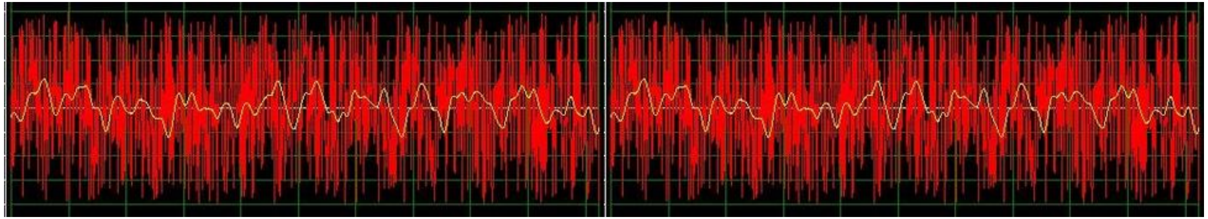
Real-time Introduction

Live
Spectrum



Analyzing Intermittent Signals
Real-time Introduction

Live Spectrum

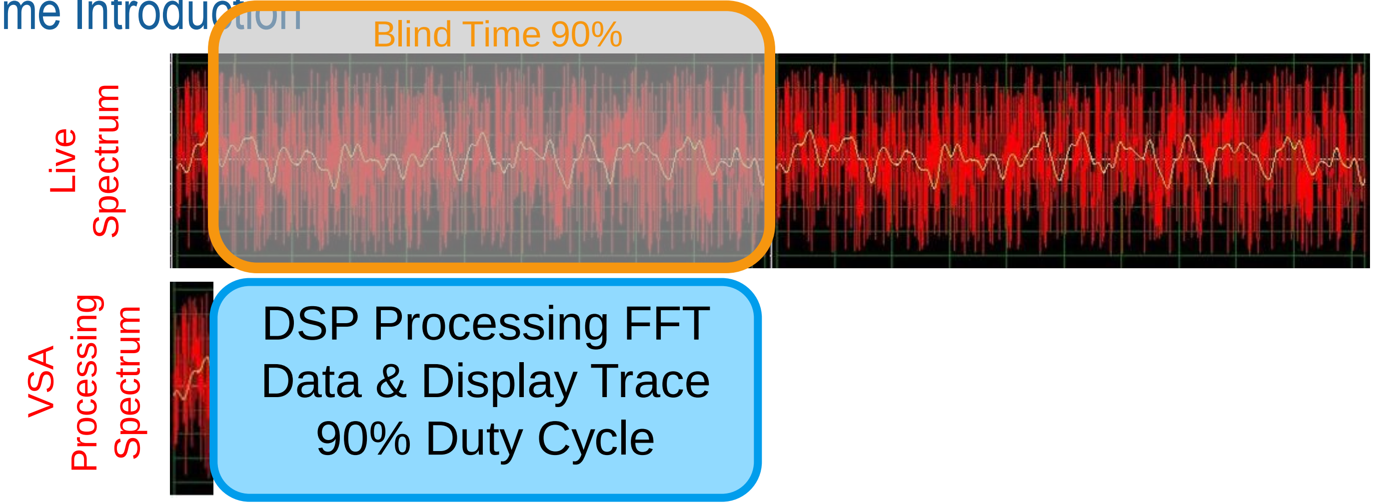


VSA Processing Spectrum

1. Acquire

Analyzing Intermittent Signals

Real-time Introduction

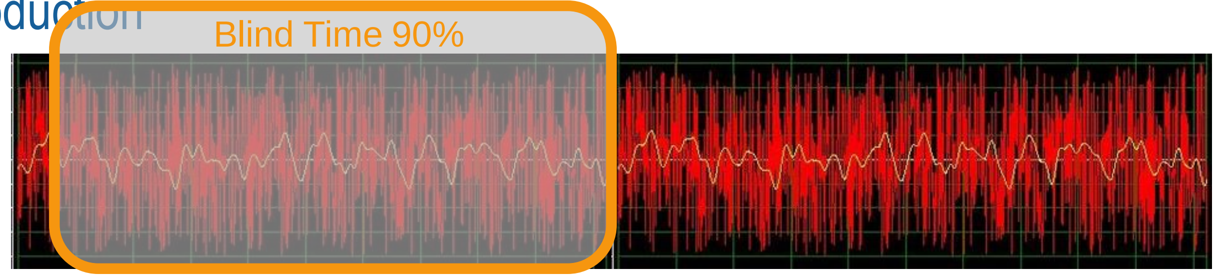


1. Acquire
2. Process

Analyzing Intermittent Signals

Real-time Introduction

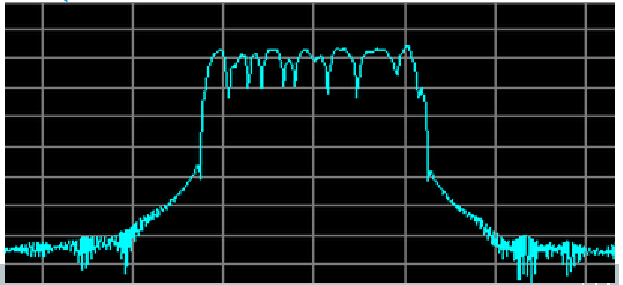
Live Spectrum



VSA Processing Spectrum

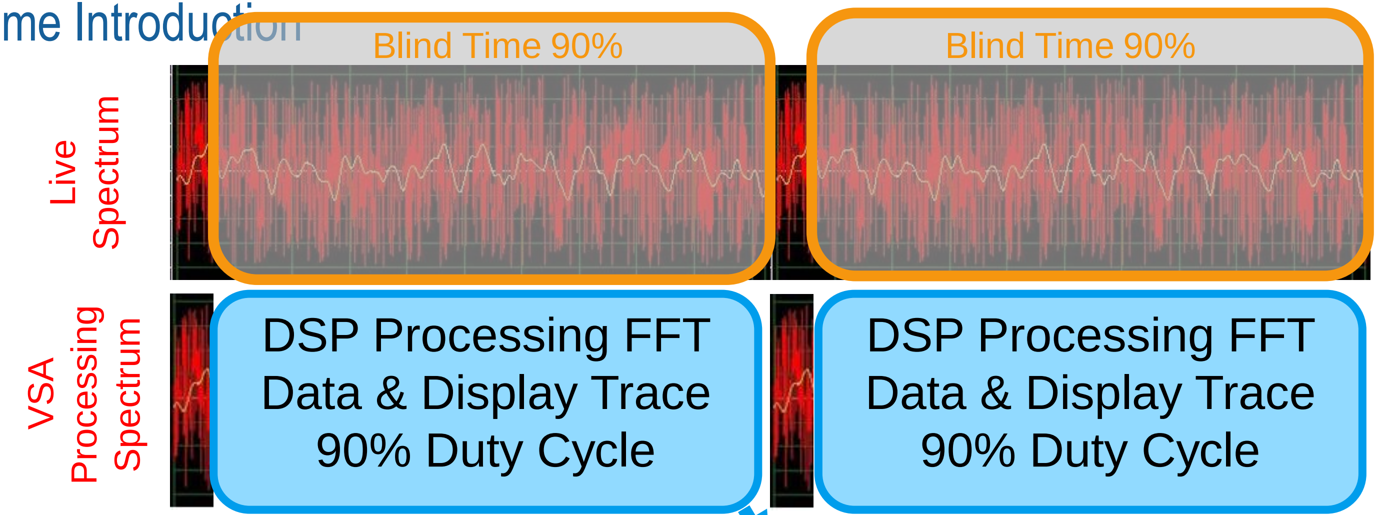
DSP Processing FFT Data & Display Trace 90% Duty Cycle

1. Acquire
2. Process
3. Display

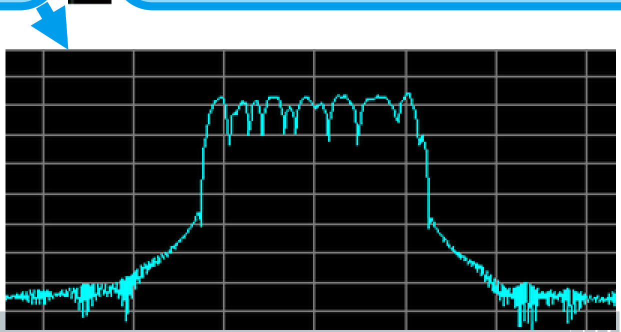


Analyzing Intermittent Signals

Real-time Introduction



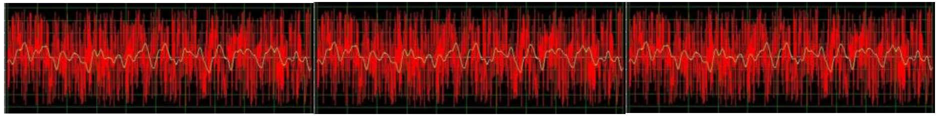
1. Acquire
2. Process
3. Display



Analyzing Intermittent Signals

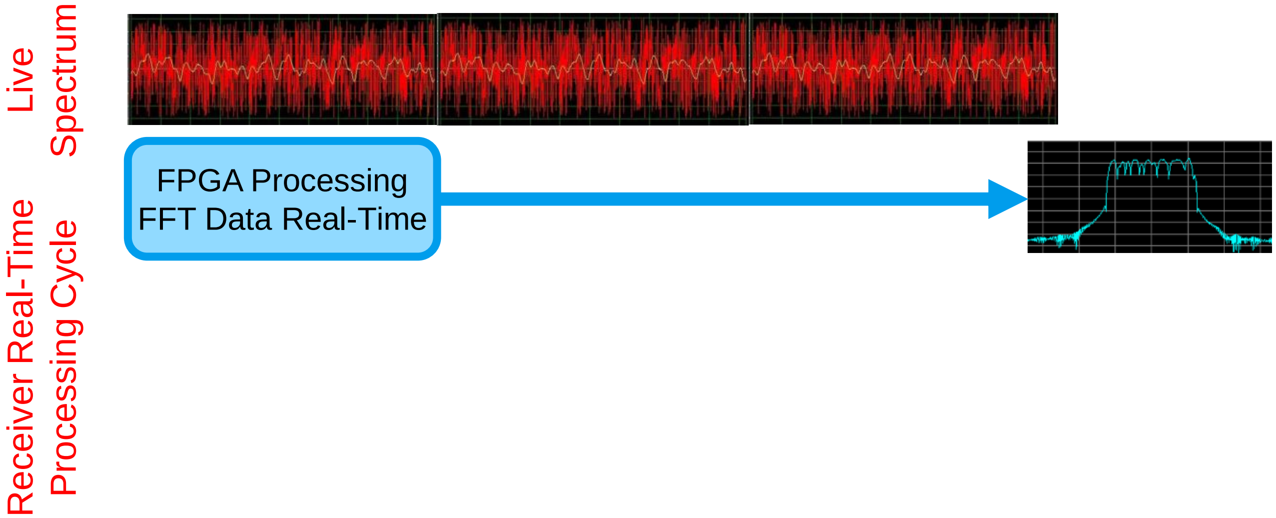
Real-time Introduction

Live Spectrum

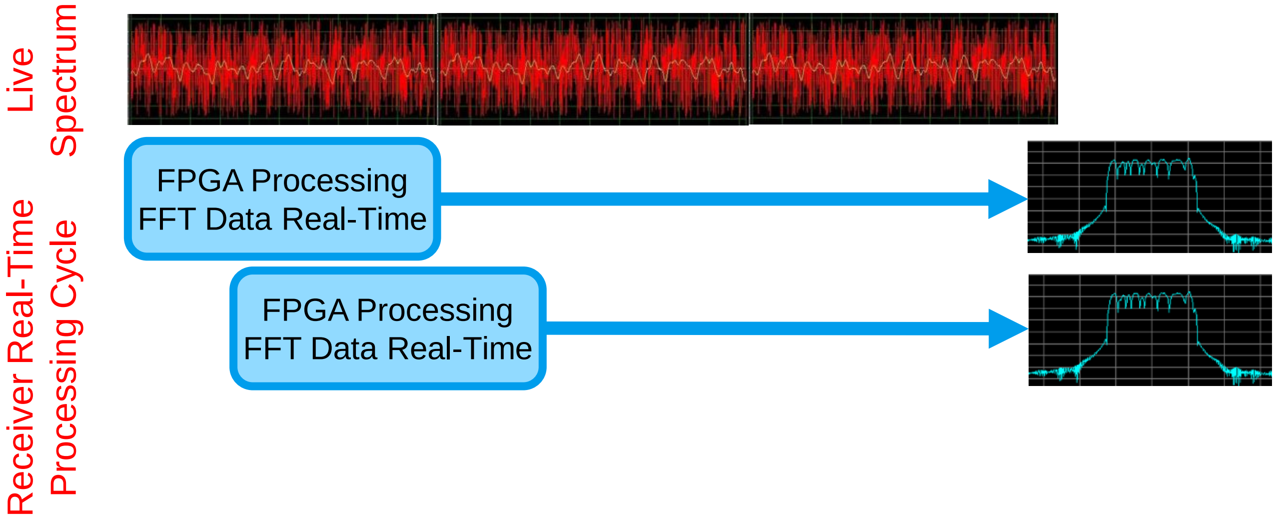


Analyzing Intermittent Signals

Real-time Introduction

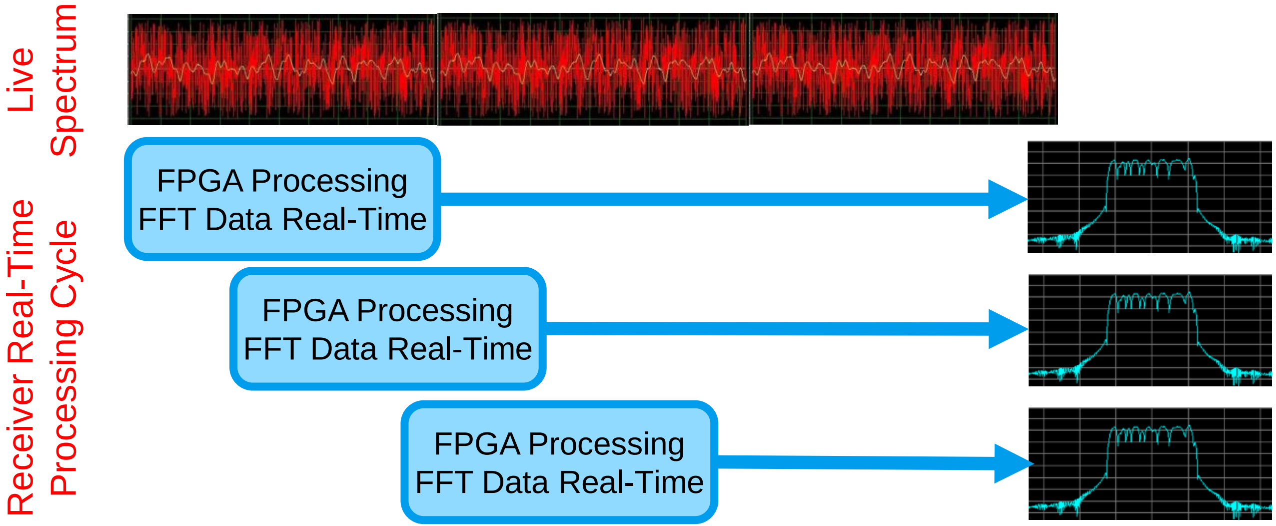


Analyzing Intermittent Signals
Real-time Introduction

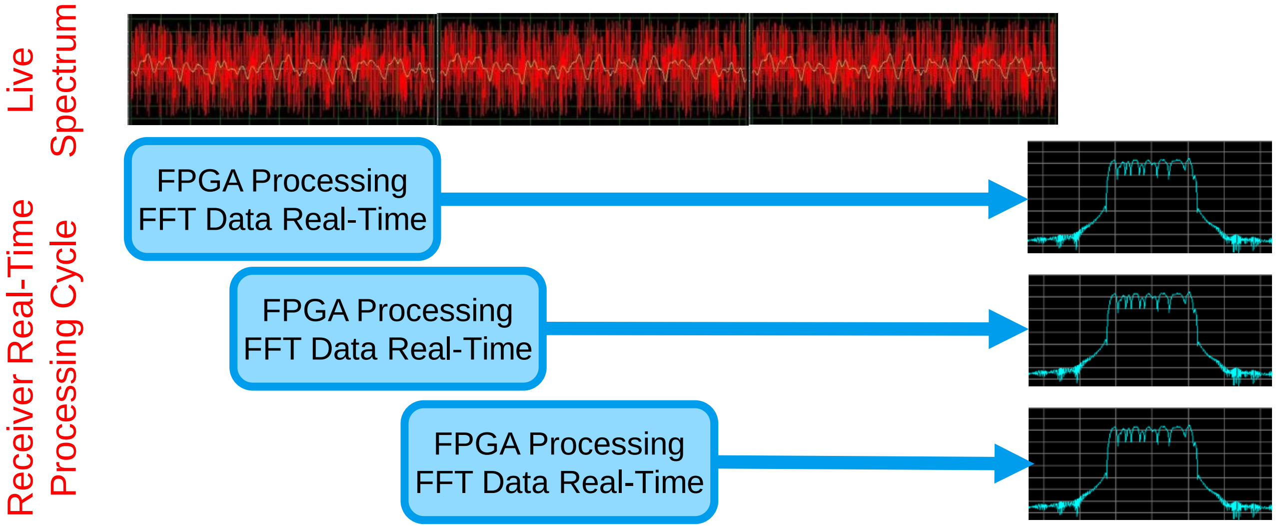


Analyzing Intermittent Signals

Real-time Introduction



Analyzing Intermittent Signals
Real-time Introduction

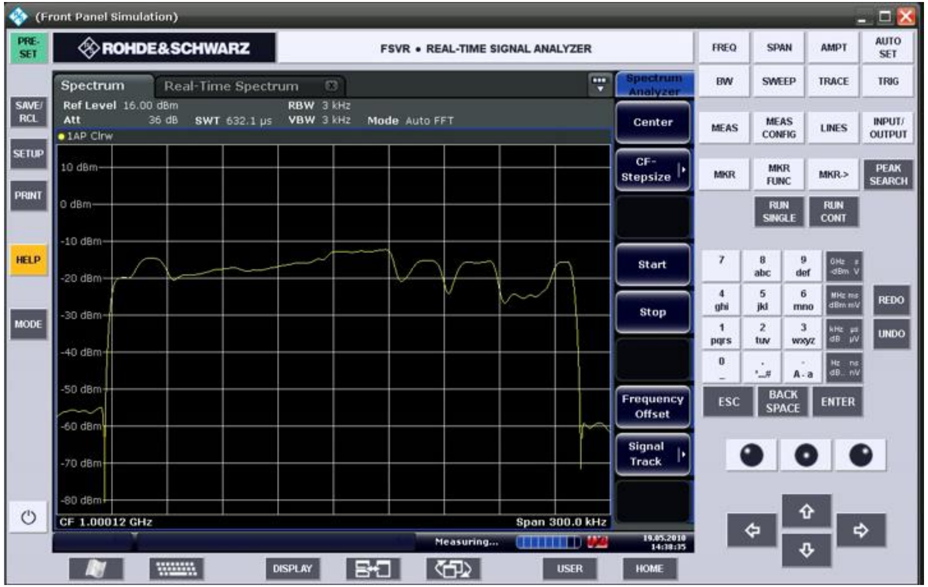


- Processing in FPGA allows data to be processed as fast as it can stream in
- 100% Acquisition Cycle – NO Blind Time
- Overlapping catches any events lost or attenuated by Windowing
- 1000’s of spectrums processed

Analyzing Intermittent Signals

Real-time Spectrogram Display

- The Spectrogram Display provides information on the time nature of the signal
- Information on the time varying nature of the signal provides a wealth of information in understanding what the signal is and what is generating the signal

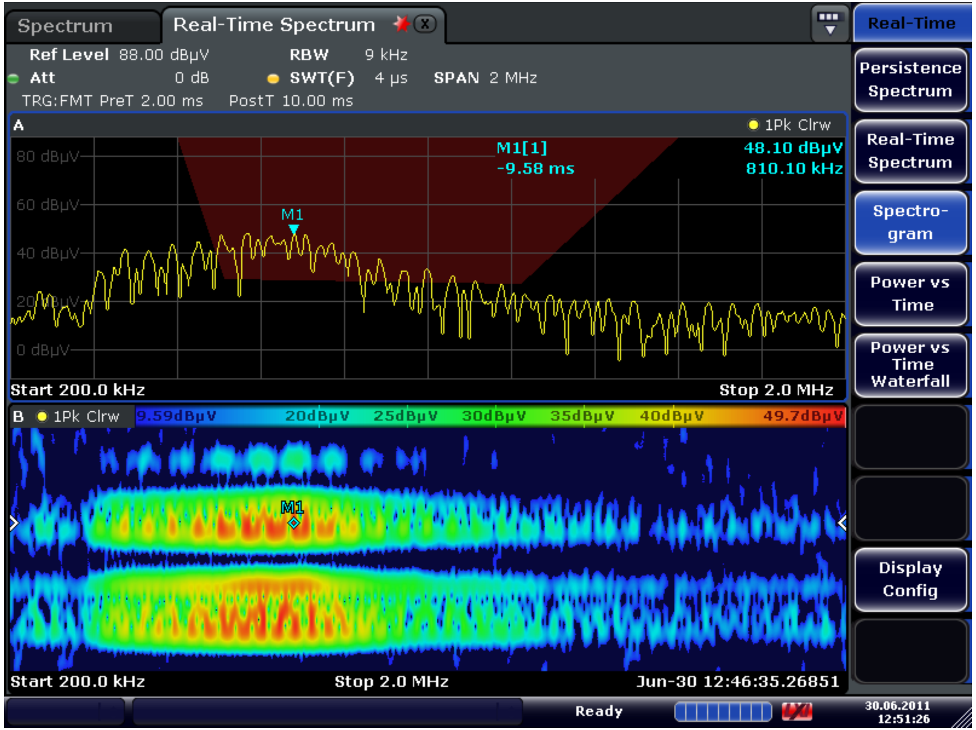


Analyzing Intermittent Signals
Real-time Spectrogram Display

Spectrogram

3 dimensional display

- X axis: frequency
- Y axis: time
- Color: signal level

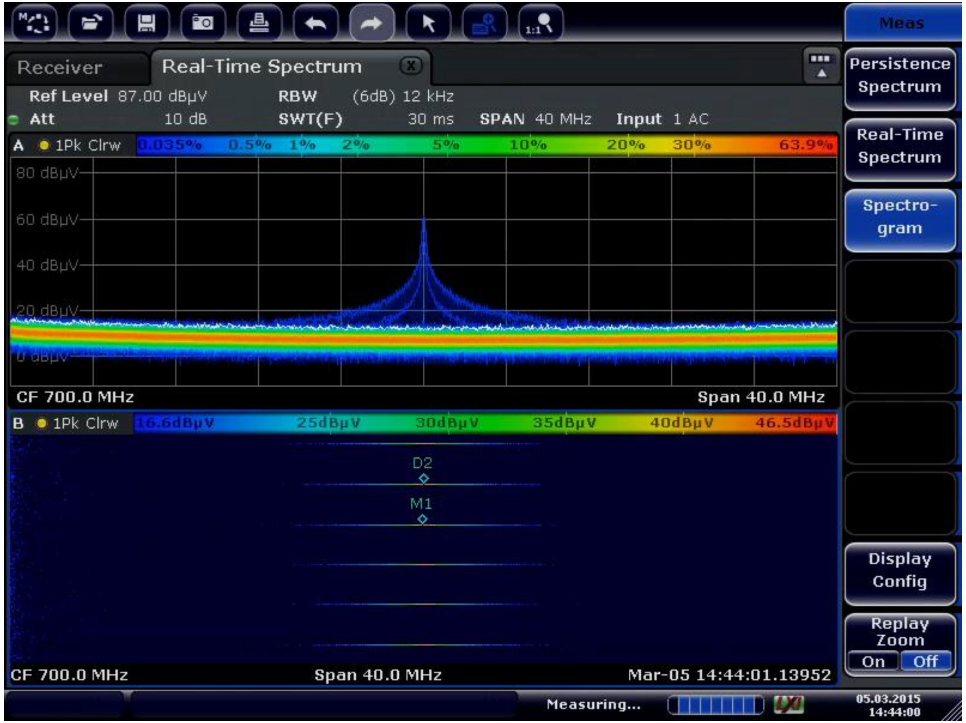


- EUT is a laptop power supply
- Different load conditions change the spectrum over time

Analyzing Intermittent Signals

Real-time Spectrogram Display

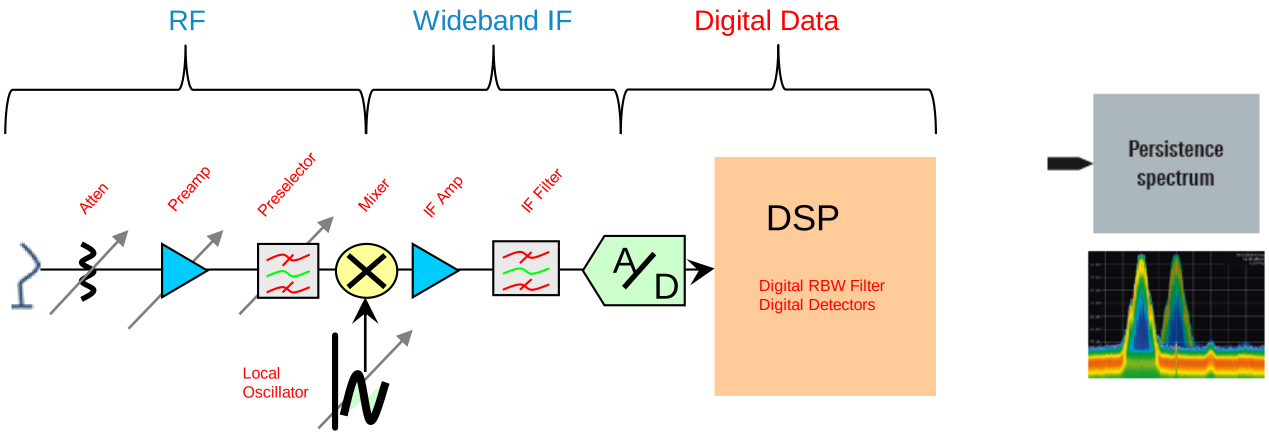
- Ability to measure PRI



Analyzing Intermittent Signals
Persistence Display

Benefits for EMI Diagnostics

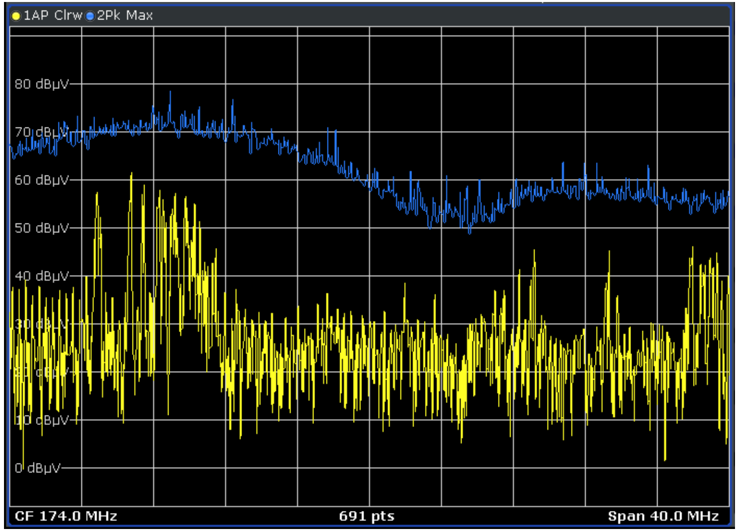
- Valuable aid for examining signals that change over time
- Impulsive interferers are clearly contrasted with continuous interferers
- Different impulsive interferers can be easily distinguished
- Shows signals that are not detectable with conventional analyzers



Analyzing Intermittent Signals

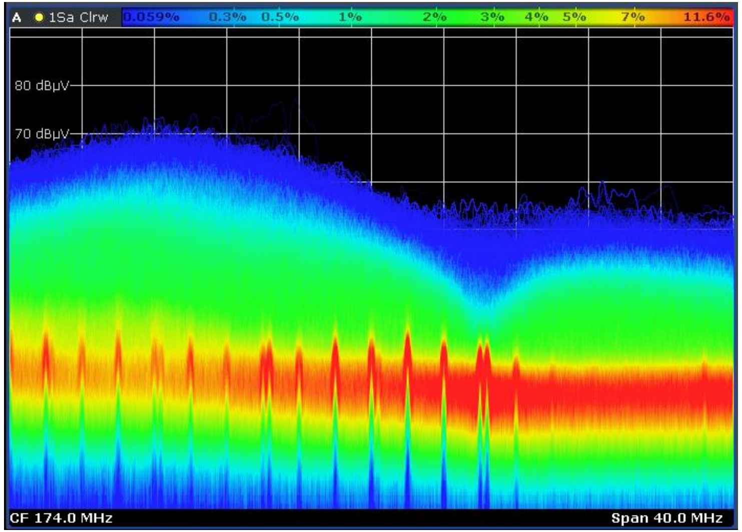
Persistence Display of Windshield Wiper Motor

Conventional Spectrum Analysis



Yellow Trace: Clear write display
Blue Trace: Max hold display

Real-time Persistence Display

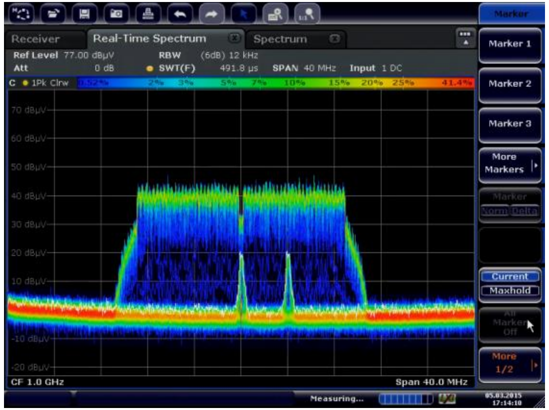


2nd pulsed disturbance signal hidden by the broadband noise, not detectable by conventional spectrum analysis

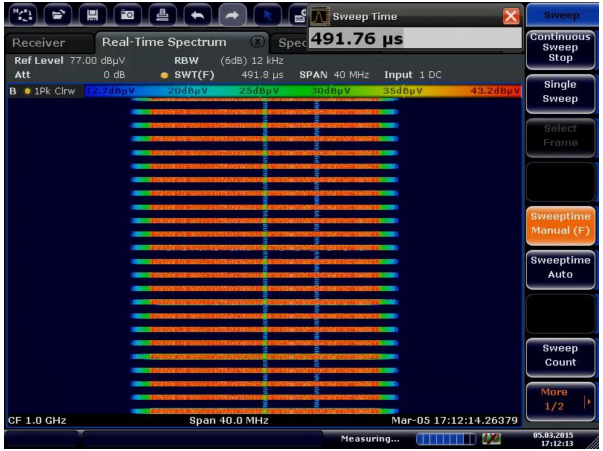
Analyzing Intermittent Signals
Persistence Display

Conventional Spectrum Analysis

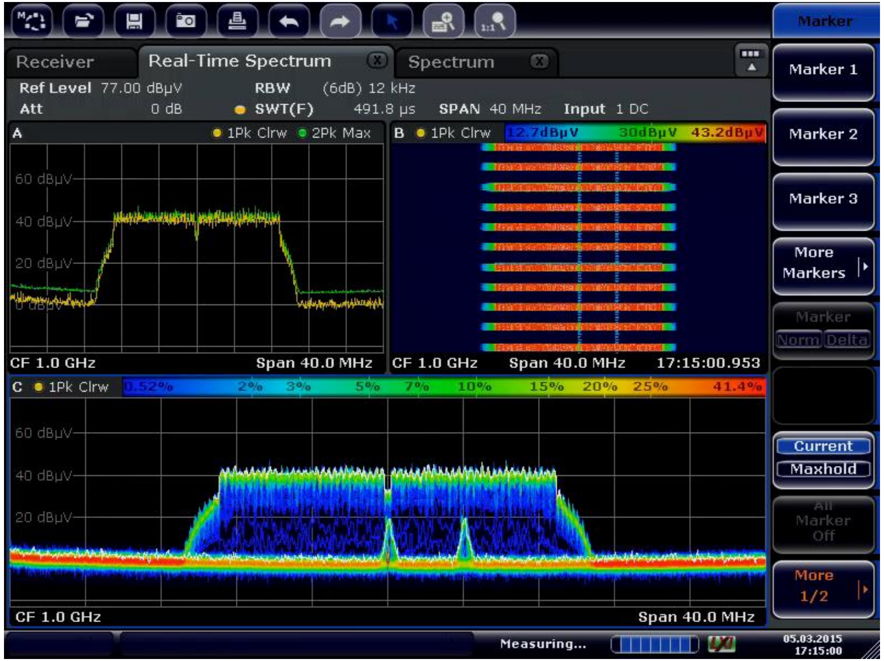
Persistence Display



Spectrogram Display



Analyzing Intermittent Signals
Simultaneous Displays: Powerful Analysis



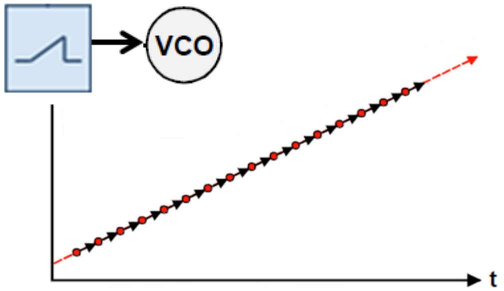
Summary

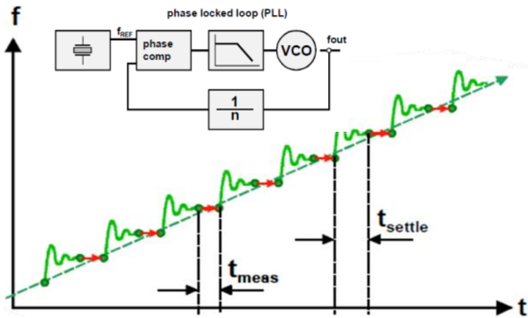
- **Frequency Swept**: Limitations must be understood to yield proper results
  - Sweep time, # of points, frequency resolution
  - Must be very careful to verify intermittent signals are being properly captured – LOTS of room for error

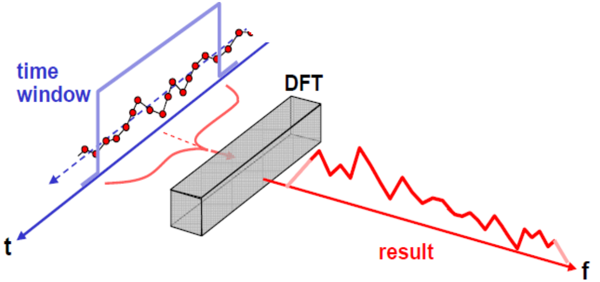
- **Frequency Stepped**: (Receiver Mode) eliminates much of the sources of error existing in frequency swept mode
  - Direct input dwell time and frequency step, no manual calculations

- **Time Domain Scan**: Method of calculating the spectrum from a time series of samples and is enabled by advances in DSP/FPGA technology

- **Time Domain Scan is very powerful methodology for detecting and characterizing pulsed / intermittent signals**
  - Time Domain Scan is significantly faster than frequency stepped

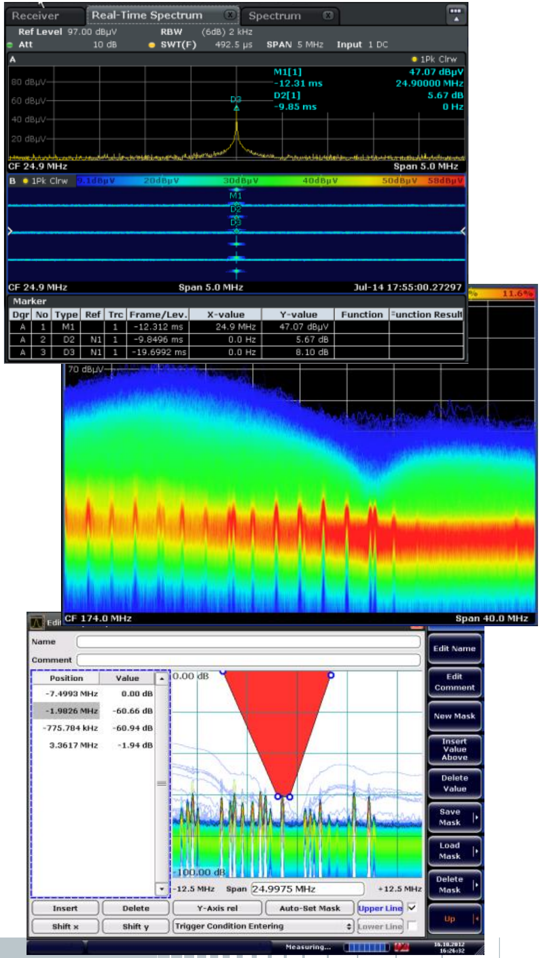






Summary

- **Real-time is the next BIG thing in EMI diagnostics**
- **Real-time data acquisition is critical to accurately display signal**
- **Advances in DSP/FPGAs provide enhanced capability in analysing intermittent signals via intuitive graphical representation**
  - **Spectrogram Display**
    - 3 dimensional display; frequency on X axis, time on Y axis, color is signal level
  - **Persistence Display**
    - 3 dimensional display: frequency on X-axis, signal level on Y-axis, color is percentage of time the signal was at that amplitude level
  - **Frequency Mask Trigger**
    - Very useful for capturing / recording intermittent signals
- **The EMC Community will benefit significantly from these advances**
- **Real-time data acquisition is critical to accurately characterize signals**



Thank you for your interest !