EMI Test Receivers: Past, Present and Future

Andy Coombes – EMC Product Manager
Rohde & Schwarz UK Ltd

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

<table>
<thead>
<tr>
<th>Frequency band</th>
<th>Scan time $T_s$ for peak detection</th>
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<tr>
<td>A 9 kHz to 150 kHz</td>
<td>14.1 s</td>
<td>2 820 s = 47 min</td>
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<td>2,985 s</td>
<td>5 970 s = 99.5 min = 1 h 39 min</td>
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<td>0.97 s</td>
<td>19 400 s = 323.3 min = 5 h 23 min</td>
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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.
## Minimum Scan Times

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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)
Formulation of a Test method

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

Data Reduction / Critical Frequencies
Formulation of a Test method

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

Data Reduction / Critical Frequencies

Final (automated / semi-automated)

well-known procedure
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.
During a sweep....
...measurement time at each frequency?

6.5.2 Scan rates for scanning receivers and spectrum analyzers

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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.
...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

Timing Analysis of EUT
manual
to find Measurement Time

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*
    - \((1GHz - 30MHz) \times 0.15\text{sec/MHz} = 145.5\text{sec}\)

**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 ScanEmerges
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
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.
- **Fast-Fourier transformation**: Transform the signals from time domain to frequency domain.

**Frequency domain**
- Merge the spectra of all frequency blocks.

**EMC/ESD Seminar**
- 9th Nov 2016
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

Rectangular Window

Gaussian Window

Gaussian Window with Overlapping

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

You don't get something for nothing…
Segment Alignment + Signal Processing

Center of FFT Segment

Center of last stage IF filter
Insertion loss caused mainly by last stage IF filter.

Center of FFT Segment

Center of last stage IF filter
Segment Alignment + Signal Processing

Level reduction by last stage IF filter
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:

- Time Domain Scan
- Real-Time Processing
- Revolutionary New Displays
Analyzing Intermittent Signals
Real-time Introduction
Analyzing Intermittent Signals

Real-time Introduction

1. Acquire
Analyzing Intermittent Signals

Real-time Introduction

1. Acquire
2. Process
Analyzing Intermittent Signals

Real-time Introduction

1. Acquire
2. Process
3. Display

DSP Processing FFT
Data & Display Trace
90% Duty Cycle

Blind Time 90%

Live Spectrum

VSA Processing Spectrum

EMC/ESD Seminar 46
9th Nov 2016
Analyzing Intermittent Signals

Real-time Introduction

1. Acquire
2. Process
3. Display

VSA Processing Spectrum

Live Spectrum

DSP Processing FFT Data & Display Trace 90% Duty Cycle

Blind Time 90%

Blind Time 90%

EMC/ESD Seminar
9th Nov 2016

ROHDE & SCHWARZ
Analyzing Intermittent Signals

Real-time Introduction
Analyzing Intermittent Signals
Real-time Introduction

FPGA Processing
FFT Data Real-Time

Live Spectrum
Receiver Real-Time Processing Cycle

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Analyzing Intermittent Signals
Real-time Introduction

FPGA Processing FFT Data Real-Time

Receiver Real-Time Processing Cycle

Live Spectrum

EMC/ESD Seminar
50th Nov 2016
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

RF
Wideband IF
Digital Data

DSP
Digital RBW Filter
Digital Detectors

Persistence spectrum

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Analyzing Intermittent Signals
Persistence Display of Windshield Wiper Motor

Conventional Spectrum Analysis

Real-time Persistence Display

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

2nd pulsed disturbance signal hidden by the broadband noise, not detectable by conventional spectrum analysis
Analyzing Intermittent Signals
Persistence Display

Conventional Spectrum Analysis

Spectrogram Display

Persistence 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
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!