Time-domain Techniques in EMI Measuring Receivers

Technical and Standardization Requirements

ROHDE&SCHWARZ

CISPR = Huge, Slow, Complex,

- **CISPR = International Special Committee on Radio Interference**
  - Technical committee within International Electrotechnical Commission (IEC)
  - CISPR was established in 1933
  - Today CISPR is one of the 95 technical committees of the IEC
  - 7 sub-committees: A,B,D,F,H,I,S and 15 working groups
  - CISPR has liaisons and special working arrangements with technical committees of the IEC, ISO, CENELEC, CEPT, ETSI and ECMA.
  - CISPR is composed of the following Member bodies:

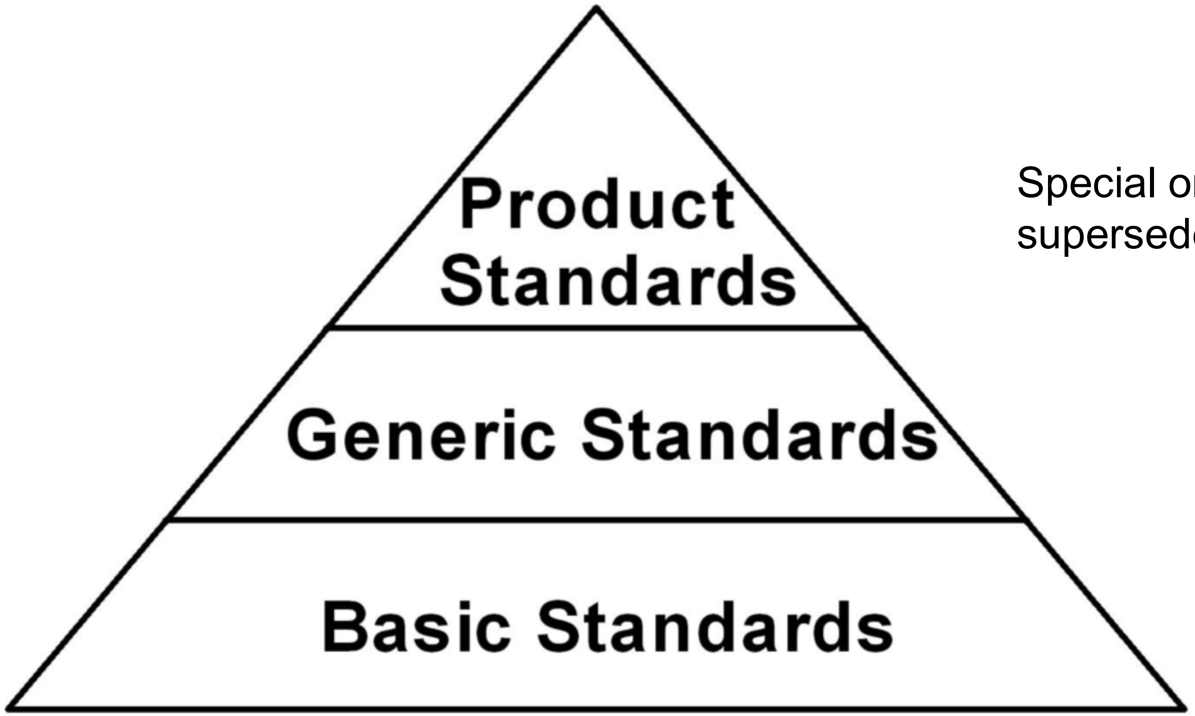
National Committees of the IEC (IEC has 59 full members and 21 associated members)

European Broadcasting Union (EBU)
European Telecommunication Standards Institute (ETSI)
International Conference on Large Electric Systems (CIGRE)
International Amateur Radio Union (IARU)
International Telecommunications Union, Radio Sector (ITU-R)
International Telecommunications Union, Telecom Sector (ITU-T)

- Thousands of people, committees and documents to explain
  - What to test / against which limits
  - How to test, environment and equipment

CISPR Publication Levels

- **CISPR publications are structured into 3 levels**



Special or specific conditions apply, supersedes the generic standards

Apply to everything not covered by product standard

Foundation items that apply to everyone

- **CISPR 11**: Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement.
- **CISPR 22**: Information technology equipment - Radio disturbance characteristics - Limits ar methods of measurement
- **CISPR 24**: Information technology equipment - Immunity characteristics - Limits and metho of measurement.

IT / ISM

- **CISPR 12**: Vehicles, boats and internal combustion engine driven devices - Radio disturbance characteristics - Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/devices.
- **CISPR 25**: Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers"

autos

- **CISPR 14**: Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission / Part 2: Immunity - Product family standard.

appliances and tools

- **CISPR 16**: **Specification for radio disturbance and immunity measurement apparatus and methods**
  - Part 1: Radio disturbance and immunity measuring apparatus
  - Part 2: Methods of measurement of disturbances and immunity
  - Part 3: Reports and recommendations of CISPR
  - Part 4: Uncertainties, statistics and limit modeling

meas devices

Structure of Basic Standard CISPR 16 (2010)

CISPR 16-1	Radio disturbance and immunity measuring apparatus	CISPR 16-1-1	Measuring apparatus
		CISPR 16-1-2	Ancillary equipment – Conducted disturbances
		CISPR 16-1-3	Ancillary equipment – Disturbance power
		CISPR 16-1-4	Ancillary equipment – Radiated disturbances
		CISPR 16-1-5	Antenna calibration test sites for 30 to 1000 MHz
	in development	*CISPR 16-1-6	*Antenna calibration*
CISPR 16-2	Method of measurement of disturbances and immunity	CISPR 16-2-1	Conducted disturbance measurements
		CISPR 16-2-2	Measurement of disturbance power
		CISPR 16-2-3	Radiated disturbance measurements
		CISPR 16-2-4	Immunity measurements
		CISPR 16-2-5	In situ measurements of disturbing emissions produced by physically large equipment
CISPR 16-3			CISPR technical reports
CISPR 16-4	Uncertainties, statistics and limit modelling	CISPR 16-4-1	Uncertainties in standardized EMC tests
		CISPR 16-4-2	Measurement instrumentation uncertainty
		CISPR 16-4-3	Statistical considerations in the determination of EMC compliance of mass-produced products
		CISPR 16-4-4	Statistics of complaints and a model for the calculation of limits for the protection of radio services
		CISPR 16-4-5	Conditions for the use of alternative test methods

FFT Type Receivers- Can You Use Them?

- **Amendment 1 to CISPR 16-1-1 (3rd Ed.)**
  - Use of FFT-based measurement instruments for compliance measurements
  - Specific requirements for FFT-based measuring instruments
  - The standard was published on 21 June 2010

- **Applicability**

CISPR 13:2001 (Radio + TV)	Applicable since 21.06.2010
CISPR 32:2012 (Multimedia)	Applicable since 30.01.2012
CISPR 15:201x (Lighting)	Publication of Ed. 8 expected in 2012
CISPR 12:201x (Automotive)	Publication of Ed. 7 expected in 2013
CISPR 25:201x (Automotive)	Publication of Ed. 4 expected in 2013

  - Not applicable (not referenced) for CISPR 11:2009, CISPR 12:2007, CISPR13:2009 (5th Ed.), CISPR 14-1:2005, CISPR 15:2005, CISPR 22:2005 (5th Ed.), CISPR 22:2008 (6th Ed.) and CISPR 25:2008

FFT Type Receivers- Can You Use Them?

- **Real Answer is yes, use the FFT mode if you have it**
- Verify results FFT vs Swept on golden device
- Know the time domain characteristics of the DUT
- At least use it during initial scan for time savings
- Can always use classic method for QP / Final meas

CISPR 16-1-1 A1 (3rd Ed.)

- Definition of “measuring receiver” added:

  “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”

- Specific requirement for FFT-based measuring instruments

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

Amendments to CISPR 16-2-x

- Amendments to CISPR 16-2-1, 16-2-2 and 16-2-3 include measurement methods for FFT-based receivers (6/7/2010)

- The duration of a disturbance must be known
- Can be measured using time domain outputs
  - Zero span
  - Oscilloscope on IF output
  - Time Domain output of FFT

- Minimum measurement times
  → Table for **CW** signals has been added
  → Same requirements as for scanning receivers

Frequency band		Minimum measurement time T_m
A	9 kHz – 150 kHz	10,00 ms
B	0,15 MHz - 30 MHz	0,50 ms
C and D	30 MHz – 1 000 MHz	0,06 ms
E	1 GHz – 18 GHz	0,01 ms

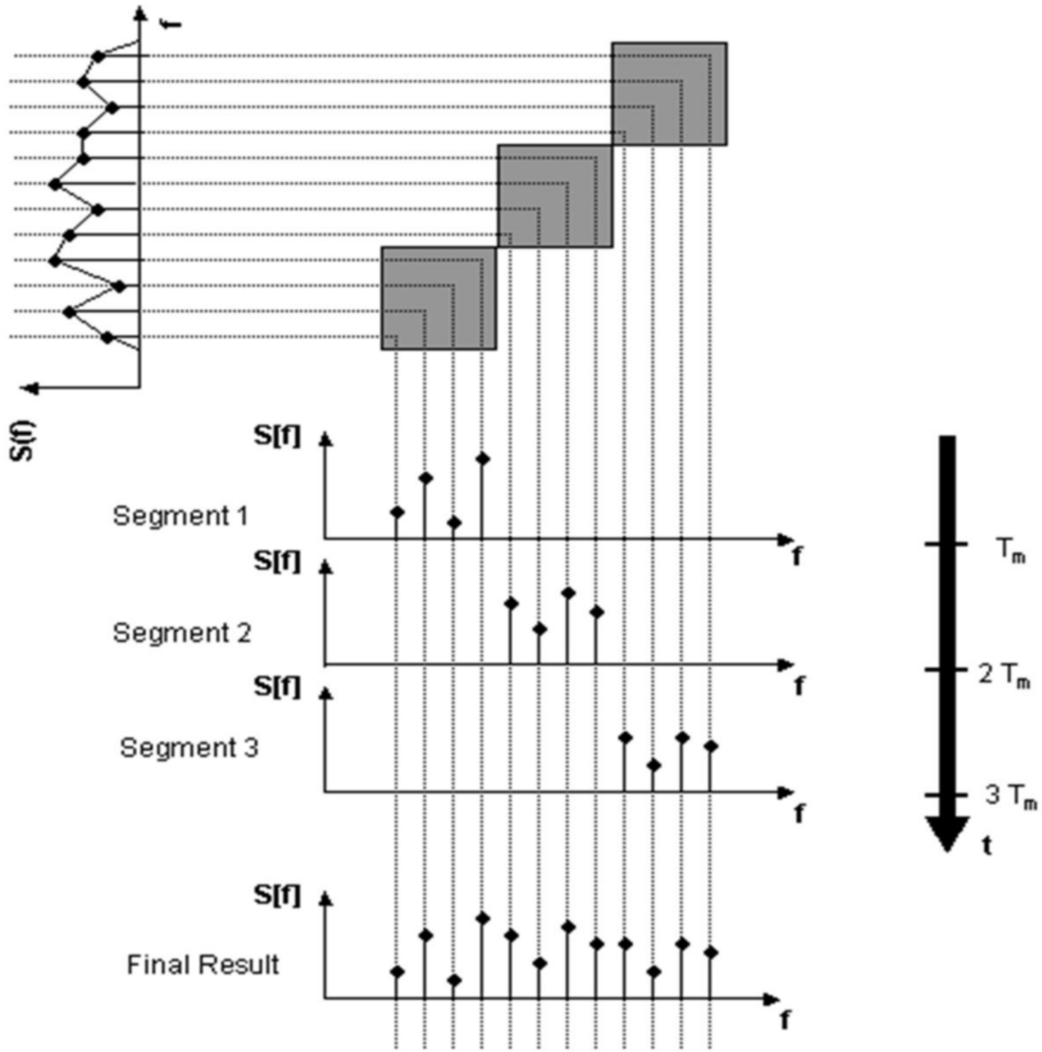
CISPR 16 – FFT-based measuring receivers

Amendments to CISPR 16-2-x

- FFT-based instruments (may) combine the parallel calculation at N frequencies and a stepped scan
- frequency range of interest is subdivided into several segments, which are measured sequentially
- The scan time $\mathbf{T_{scan}}$ is

$$T_{\text{scan}} = T_{\text{m}} \times N_{\text{seg}}$$

- $\mathbf{T_m}$ is to be selected longer than the pulse repetition interval T_p



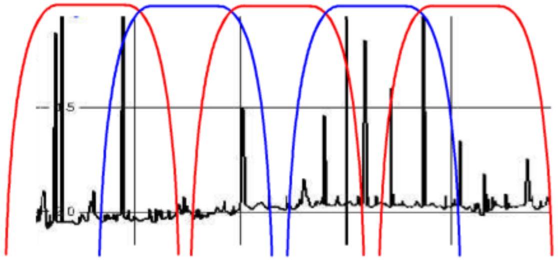
Fourier Transforms – Frequency ‹› Time Domain

- The **discrete Fourier transform** (DFT) is a numerical mathematical method that calculates the spectrum for a periodic signal
- 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

- **EMI signals include both periodic and transient signals and noise**
  - Single FFT calculation will not be sufficient to model the EMI receiver
- **Short-time FFT (STFFT) with a Gaussian window function is used**
  - Shows a discretization in both the frequency and time domains
  - IF bandwidth requirements in the frequency domain are ideally met (Fourier transform of a Gauss function in the time domain is a Gauss function in the frequency domain)
  - Gaussian window in time domain minimizes the leakage effects

CISPR 16 – FFT-based measuring receivers

FFT-based receivers – digital signal processing



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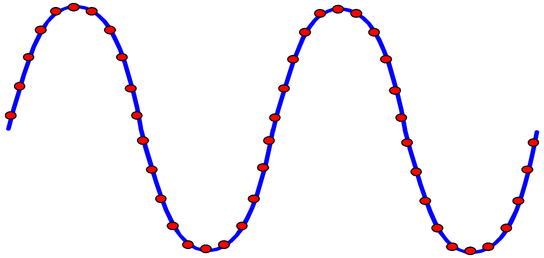

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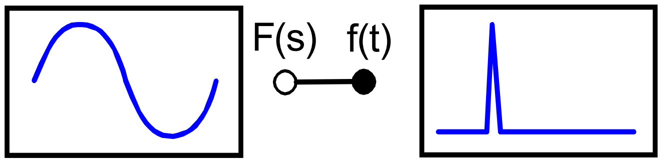
Frequency domain
Frequency range to be measured is sub-divided in consecutive frequency segments and filtering

Time domain
Temporal sampling of the filtered signals with high sampling rate/resolution



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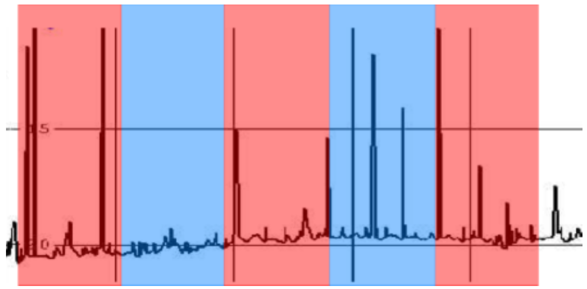

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Discrete Fourier transform (DFT)
Signal transformation of the filtered signals from time domain to frequency domain

Frequency domain
Merging the spectral distributions of all partial frequency ranges

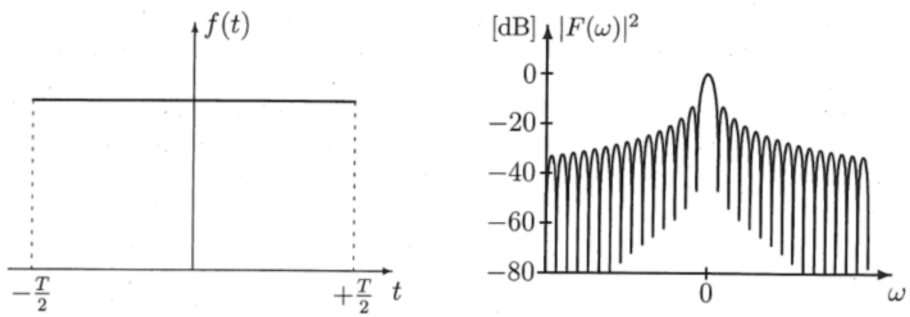
FFT Calculations Not Perfect

- **Exact calculation of the frequency spectrum would require**
  - Periodic / Repeating signals
  - Measurement time equal to integer multiple of the signal period
- **Disturbance characteristic of the signal is unknown**
  - The frequency of the signal is not known
  - The signal might not be periodic
  - The measurement time cannot be set as integer multiple of the signal period
  - Spectral lines can exist between two discrete DFT frequency bins
- **Signal distortions appear**
  - leakage effect (signal spectrum becomes more wider),
  - picket fence effect (amplitude error sine wave signals)
  - Amplitude error for isolated pulse and a sequence of pulses

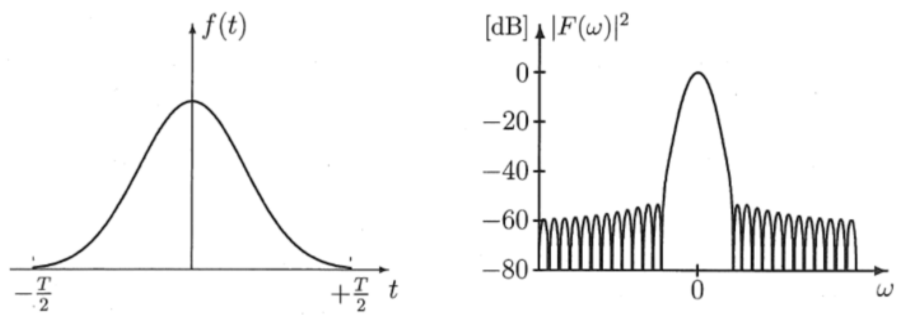
FFT Errors – Leakage Effect

- **Convolution with window function yields wider spectrum**

  i.e. shows additional spectral components
- **Sidelobes (referred to as leakage effect)**
  - These sidelobes should be suppressed by at least 40 dB
- **A suitable windowing reduces the leakage effect (Gauss, Kaiser-Bessel)**



Rectangular window and magnitude of the Fourier transform [1)]



Gaussian window and magnitude of the Fourier transform, σ=2 [1)]

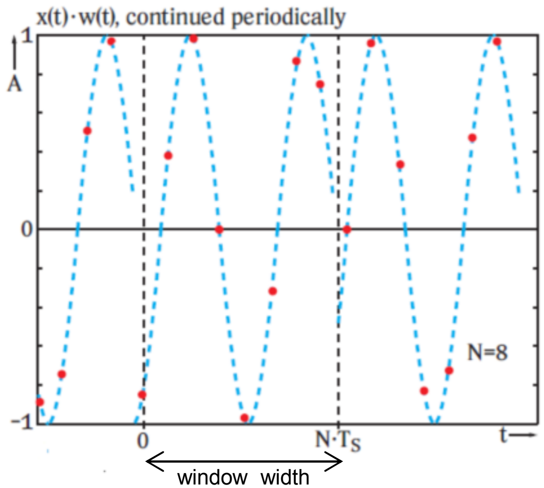
Sidelobes when using rectangular window or Gaussian window

1) Tilman Butz, Fouriertransformation fuer Fußgaenger, ISBN 978-3-8351-0135-7

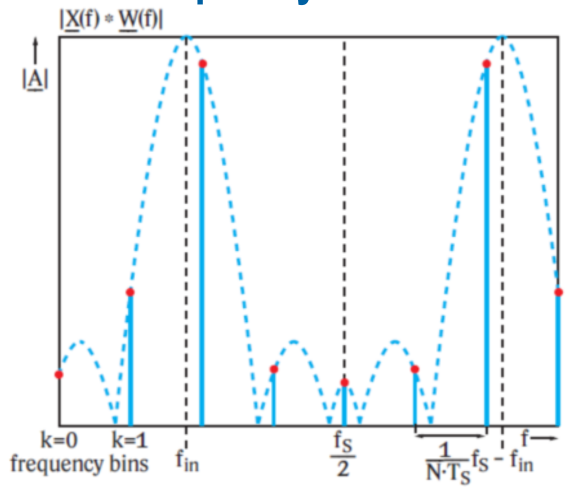
FFT Errors – Picket Fence Effect

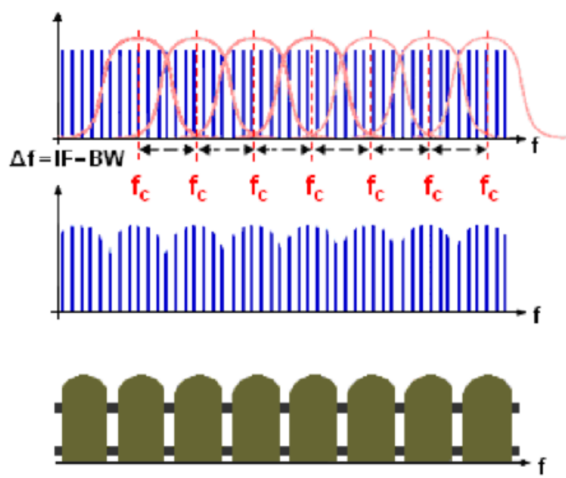
- The FFT calculates a discrete line spectrum at the frequency bins
- If the sampled sine wave signal is at a frequency that doesn't align with a calculated frequency point an amplitude error appears
- The amplitude error is known as "picket fence effect"
- Like stepped-frequency scan with wide IF bandwidth vs step size

time domain



frequency domain



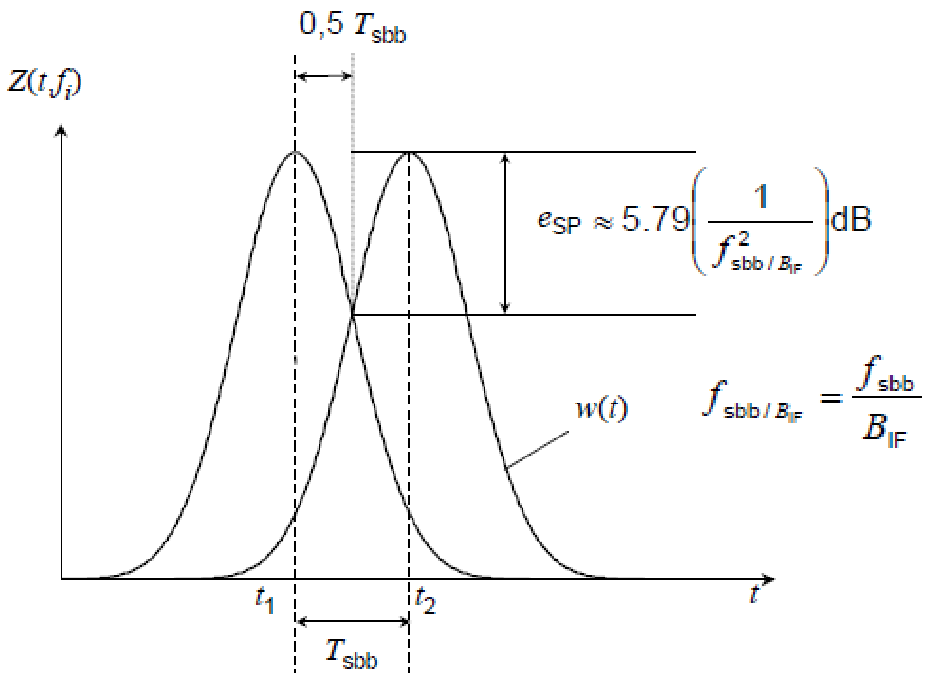


FFT Errors – Single Pulse Errors

- Measurement must be long enough to capture single pulses
- Sample/calculate process must be gapless during the meas time

- Without time domain overlap amplitude / detection problems

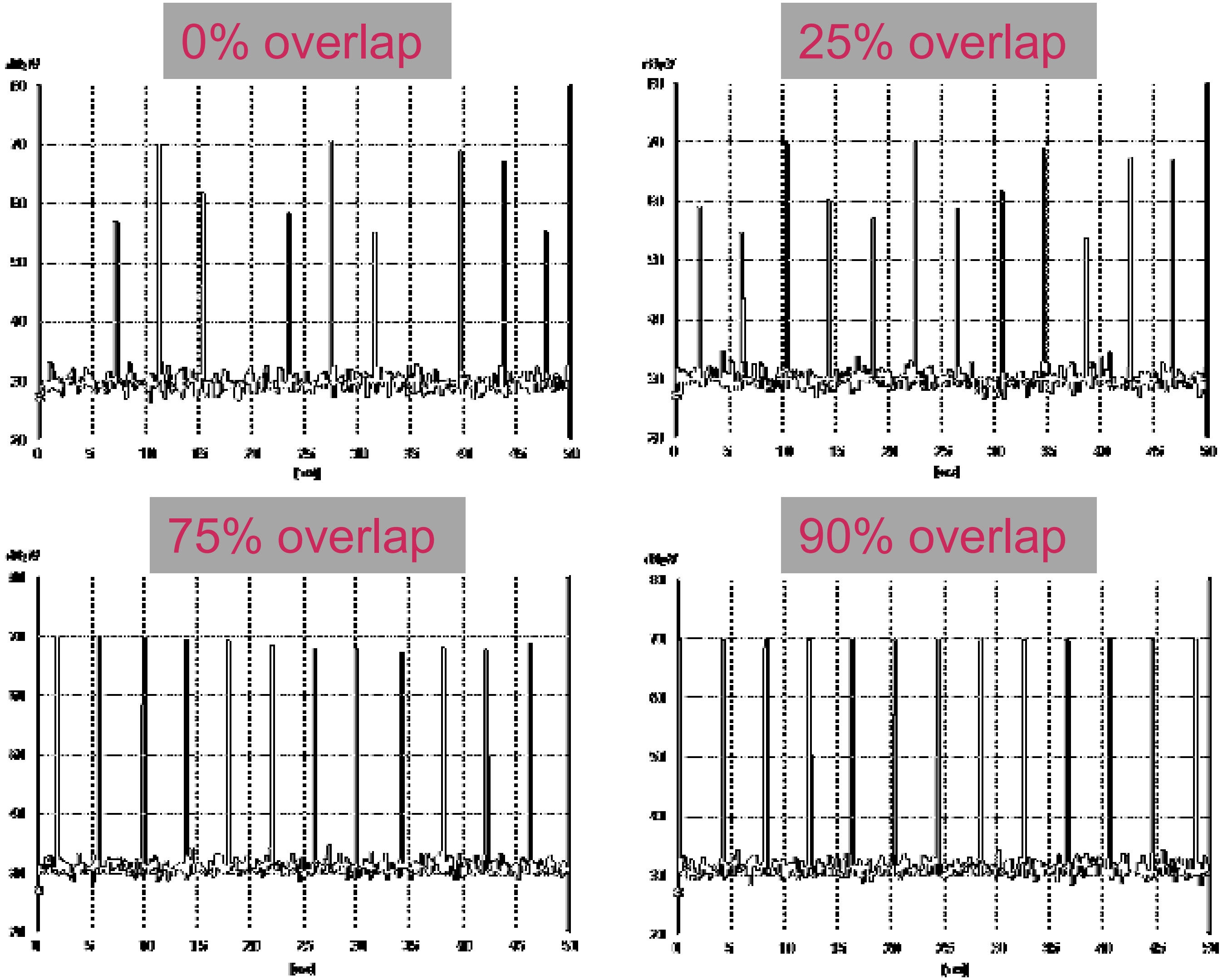
- **An overlapping factor of >75% in the time domain is necessary** to meet the pulse amplitude specification of CISPR 16-1-1



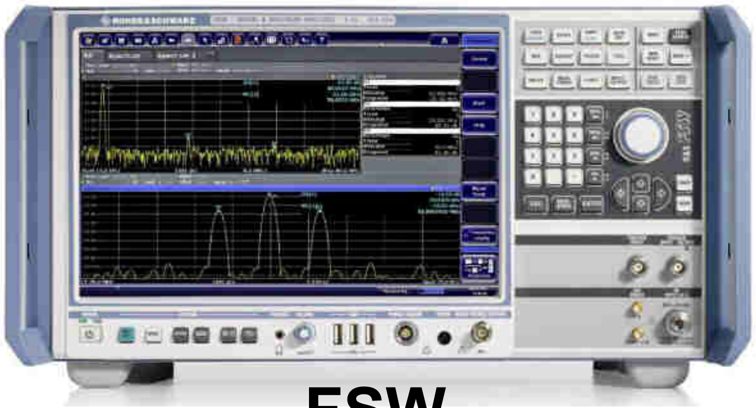
FFT Errors – Pulse Sequences

- Overlapping also fixes pulse sequence amplitude errors

- Example shows the recalculated IF signal for different over-lapping factors

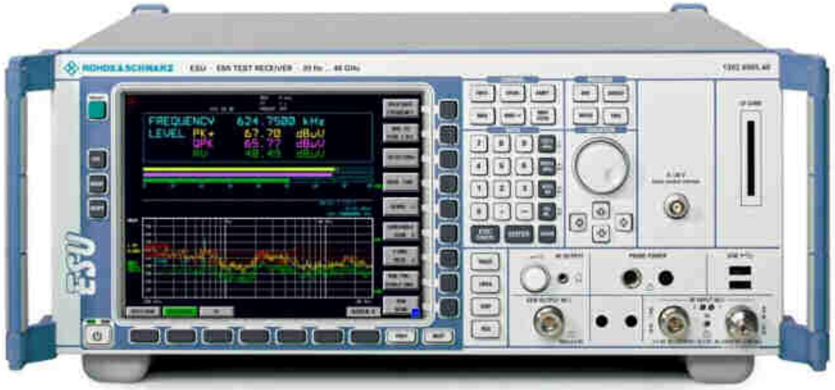


R&S EMI Instruments with FFT Functions

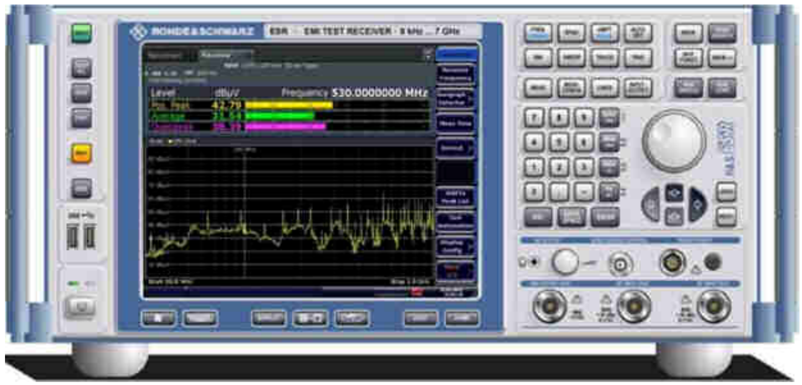


FSW

FSV / FSVR



ESU



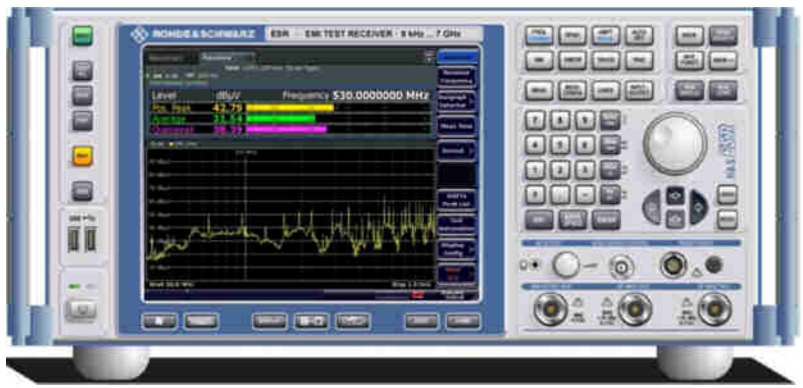
ESR

EMI Receivers with FFTs

Heterodyne EMI receivers with FFT applied to the wideband IF signal offer the following advantages:

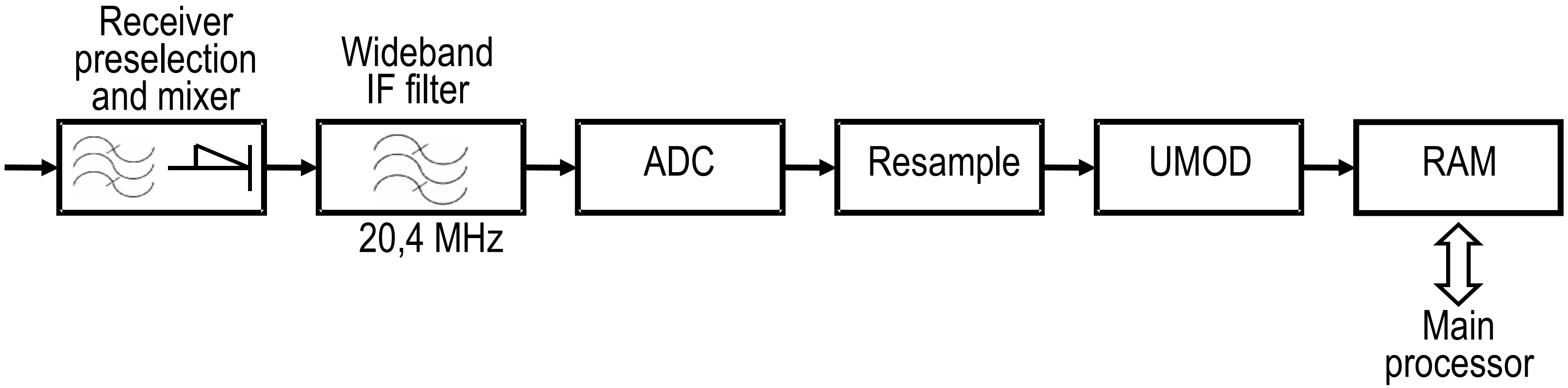
- High dynamic from 16-bit A/D converter
- Frequency range not limited by the Nyquist criterion (Mixers + FFT)
- Long maximum dwell time and high resolution (16k FFT length)
- Use of receiver preselection, preamplifier, RF-attenuation and detectors

- Use the best mode for test:
  - standard receiver
  - spectrum analyzer
  - IF – Receiver + Analyzer
  - FFT scan
  - Real-Time
  - Power meter



EMI Receiver R&S®ESR

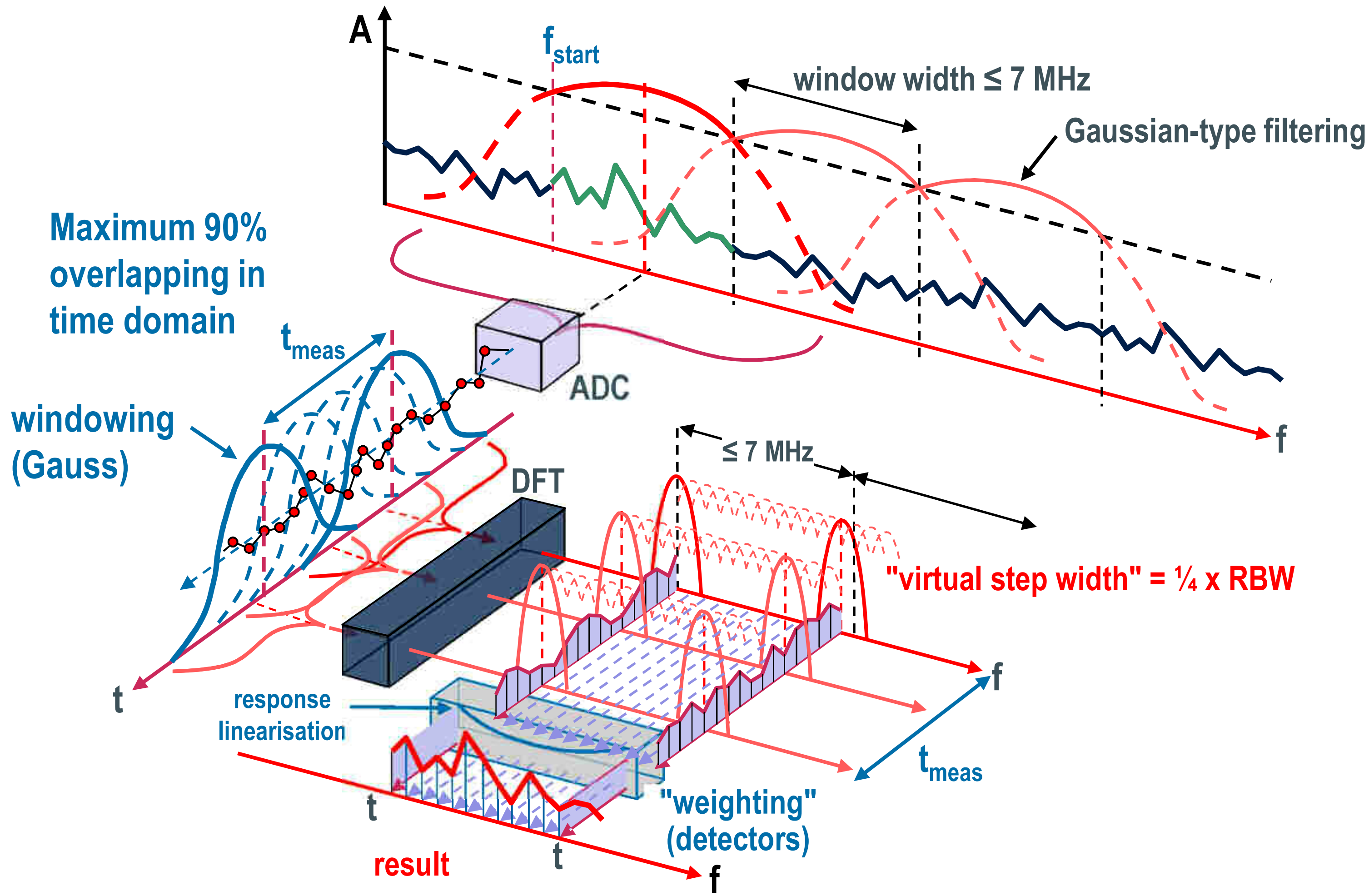
Block Diagram (ESR)



- Wideband switchable IF bandwidth preceding the A/D converter (ADC)
- 16-bit / 128 MHz sampling ADC in combination with the preselector yields high dynamic range to fulfil CISPR 16-1-1
- Resampler for data reduction where needed (at narrower RBW)
- Universal digital module (UMOD) saves the data in the 32 M-words RAM for measurement times up to **100 s without any gap** (depending on RBW)
- Main processor accesses the RAM, applies a **Gaussian window** to the time domain signal (to avoid leakage effects) and calculates the FFT

EMI receiver with FFT applied to the wideband IF

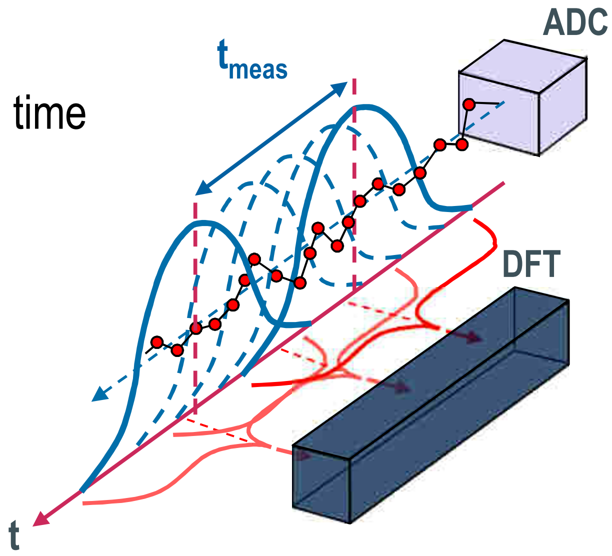
EMI Test Receiver R&S®ESU



Minimizing the FFT Errors – Leakage Effect

- Capturing an impulse-type disturbance signal by an Gaussian-type FFT window reduces the signal amplitude at the window edges
- **Overlap of the window function in the time domain minimizes this error and ensures that no impulse-type disturbance signal is missed**

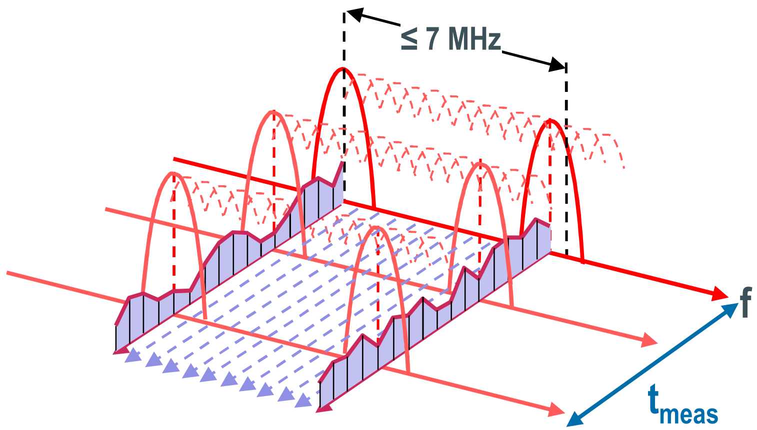
- R&S®ESU offers two different settings for time-domain scan
  - **"Auto CW" mode**
    20% overlap in the time domain
    narrowband signals are analyzed in the shortest possible time
  - **"Auto Pulse" mode**
    approx. 90% overlap in the time domain
    for broadband-impulsive and mixed signals
    ensures that even very short impulse signals at the edge of the Gaussian-type time-domain window are calculated without significant amplitude error



Minimizing the FFT Errors – Pickett Fence

- The FFT algorithm includes
  - Calculations using IF bandwidths for commercial and military standards
  - A “virtual” step size that considers the spacing between two adjacent frequency bins

- The step size is 25% of the selected IF bandwidth
  - Optimum value in terms of the amount of sampled data
  - Optimum compromise between reduction of amplitude and measurement speed
  - Lower picket fence error than conventional stepped scan

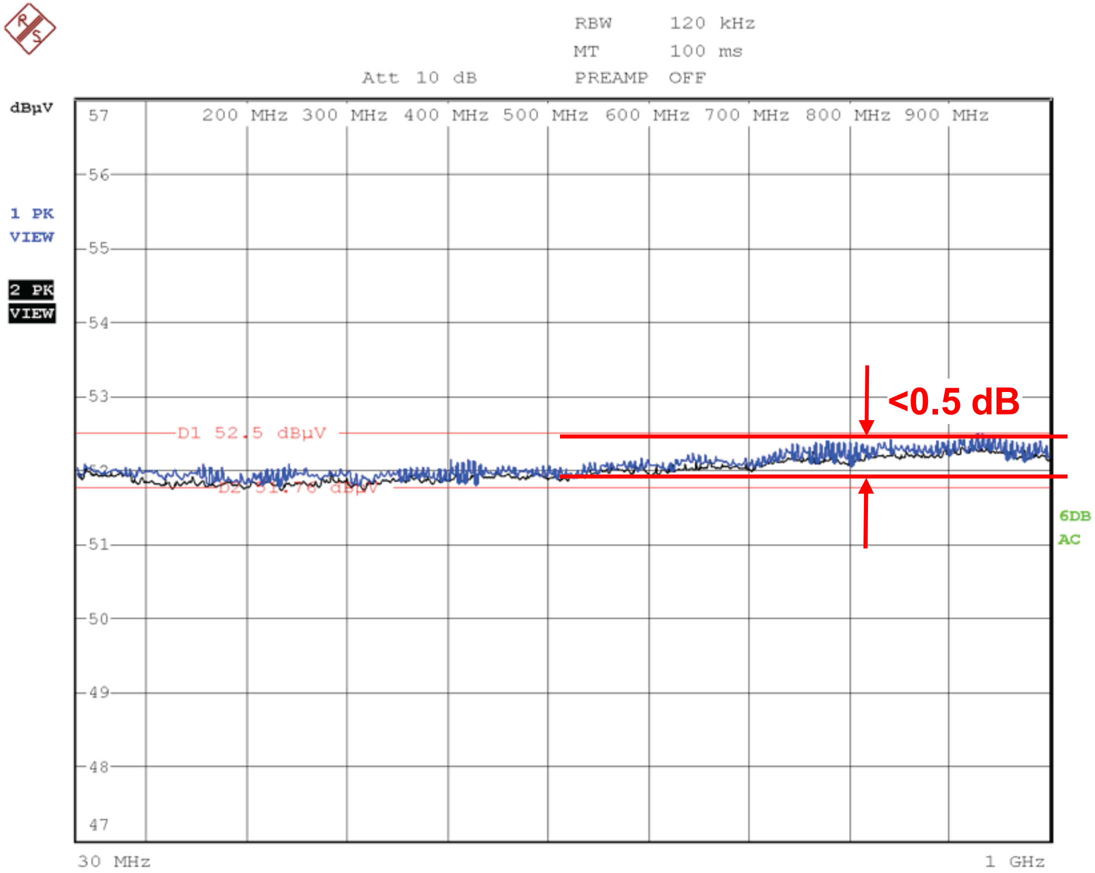


"virtual step width" = ¼ x RBW

Minimizing the FFT Errors

Time-Domain Scan versus Stepped Scan

- R&S instruments provide both scan methods using the same hardware and firmware
- Measurement was done using a pulse generator for CISPR bands C and D
- **Overall frequency response (Detector = Max.Peak) shows that the differences between the two scan modes are negligible**



Trace 1: Time-domain scan (blue)
Trace 2: Stepped frequency scan (black)

Why Bother with FFT Scans?

Measurement Times (peak detector) FFT vs stepped scan

Frequency range	Weighting detector, measurement time, IF bandwidth (no. of measurement points)	R&S ESR	
		Stepped frequency scan	Time domain scan (option)
CISPR Band B 150 k to 30 MHz	Pk, 100 ms, 9 kHz (13 267)	1 326 s	0.11 s
CISPR Band B 150 k to 30 MHz	QP, 1 s, 9 kHz (13 267)	3.6 h	2 s
Band C/D 30 to 1000 MHz	Pk, 10 ms, 120 kHz (32 334)	323 s	0.52 s
Band C/D 30 to 1000 MHz	Pk, 10 ms, 9 kHz (431 000)	4 310 s	0.82 s
Band C/D 30 to 1000 MHz	QP, 1 s, 120 kHz (32 334)	approx. 9 h	80 s

Why Bother with FFT Scans?

Comparison of typical Measurement Times (peak detector)

- R&S®ESU (Stepped Scan)
  - 9 to 150 kHz; RBW 200 Hz; Δf= 80 Hz; T_m = 20 ms: 74 s
  - 150 kHz to 30 MHz; RBW 9 kHz; Δf= 4 kHz; T_m = 20 ms: 155 s
  - 30 to 1000 MHz; RBW 120 kHz; Δf= 40 kHz; T_m = 10 ms: 247 s
  - 30 to 1000 MHz; RBW 9 kHz; Δf= 4 kHz; T_m = 10 ms: 2 573 s

- R&S®ESU (Time-domain Scan)
  - 9 to 150 kHz; RBW 200 Hz; Δf= 50 Hz; T_m = 20 ms: <1 s
  - 150 kHz to 30 MHz; RBW 9 kHz; Δf= 2,25 kHz; T_m = 20 ms: 3 s
  - 30 to 1000 MHz; RBW 120 kHz; Δf= 30 kHz; T_m = 10 ms: 13 s
  - 30 to 1000 MHz; RBW 9 kHz; Δf= 2,25 kHz; T_m = 10 ms: 20 s

Note: The frequency step of the FFT is RBW/4 to reduce the picket fence effect.
Step mode = “Auto Pulse” with an overlap of >90% of the FFT window in the time domain.

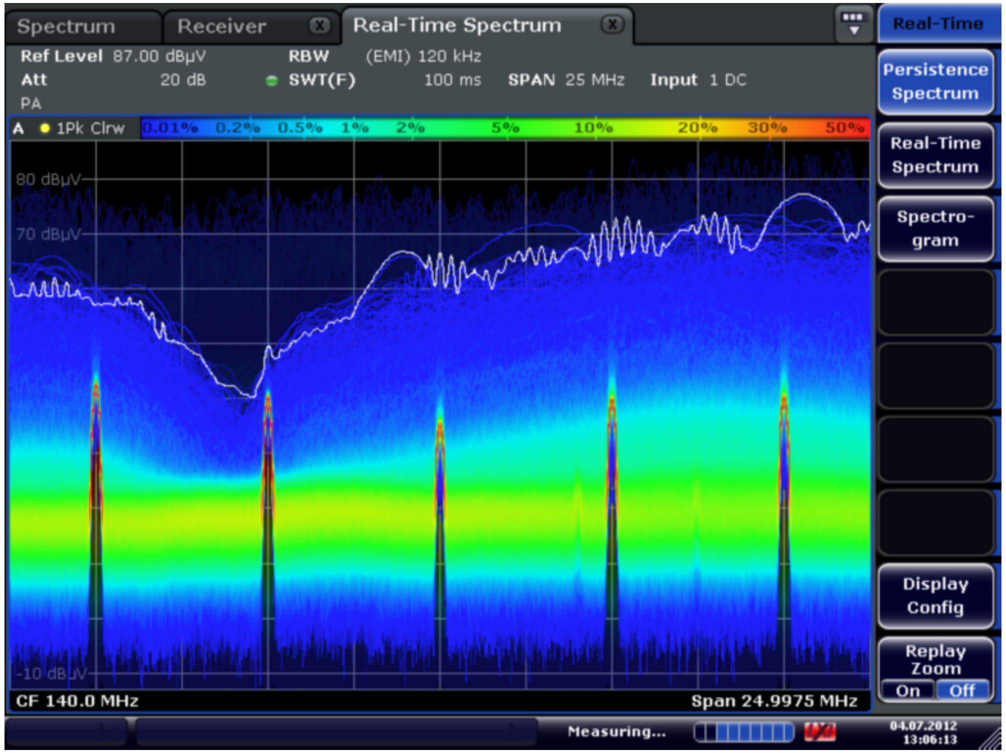
Summary: Benefits of FFT / Time Domain Scans

- Huge time savings vs conventional frequency (stepped) scans
  - 80 seconds vs. 9 hours for 30-1000 MHz / 120kHz IF / QP scan
  - .82 s vs. 4310 s for 30-1000 MHz / 9kHz IF / peak detector
- QP, CISPR-AV, RMS-AV are applicable in time-domain scan modes
  - Plus still have classic modes to compare if in doubt
- Preselection preserves the full dynamic range for band of interest
- Measurement time up to 100 s without any gaps
  - UMOD chip still allows zoom on any time window inside the capture
- Measurement of **pulses** without significant error
  - 90% overlap (Auto Pulse) of the window function and gapless sampling

Realtime analysis (option on ESR)

Provides new insights for EMC diagnostics

- **Spectrogram** for seamless spectrum display in the time domain
- **Persistance mode**
  Valuable aid for examining signals that change over time. Impulsive interferers are clearly distinguished from continuous interferers (see screen shot)
- **Frequency mask trigger**
  Responds to events in the spectrum. Comparison with a predefined frequency mask.
  Violation of the frequency mask activates the trigger event



Thank you for your interest !