Debugging EMI Using a Digital Oscilloscope

ROHDE&SCHWARZ

Debugging EMI Using a Digital Oscilloscope

- **Background – radiated emissions**
- **Basics of near field probing**
- **EMI debugging process**
- **Frequency domain analysis using an oscilloscope**
  - FFT computation
  - Dynamic range and sensitivity
  - Time gating
  - Frequency domain triggering
- **Measurement example**

The Problem: isolating sources of EMI

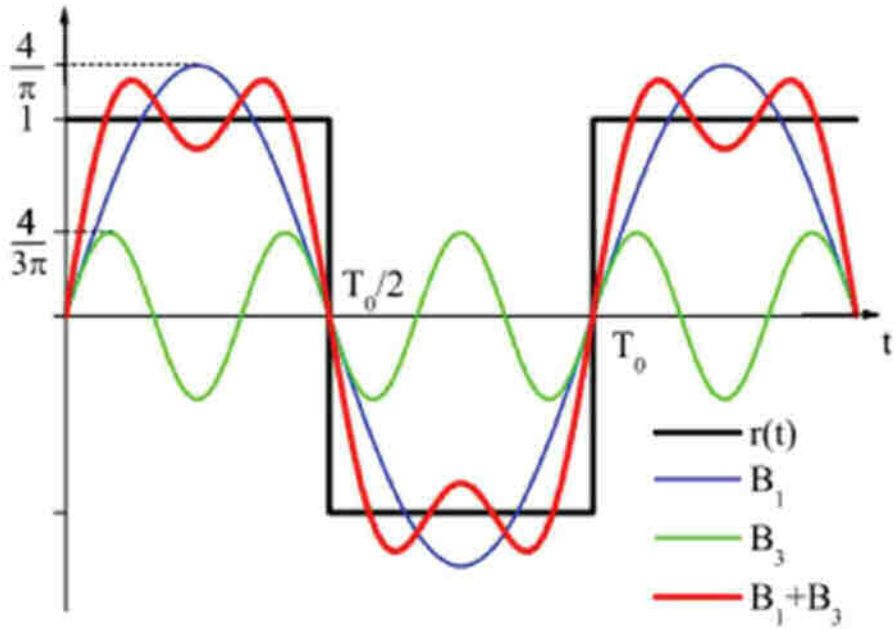
- **EMI compliance is tested in the RF far field**
  - Compliance is based on specific allowable power levels as a function of frequency using a specific antenna, resolution bandwidth and distance from the DUT
  - No localization of specific emitters within the DUT
- **What happens when compliance fails?**
  - Need to locate where the offending emitter is within the DUT
  - Local probing in the near field (close to the DUT) can help physically locate the problem
  - Remediate using shielding or by reducing the EM radiation
- **How do we find the source?**
  - Frequency domain measurement
  - Time/frequency domain measurement
  - Localizing in space

Basic Principles: Radiated Emissions
The following conditions must exist

- An interference source exists that generates a sufficiently high disturbance level in a frequency range that is relevant for RF emissions (e.g. fast switching edges)
- There is a coupling mechanism that transmits the generated disturbance signals from the interference source to the emitting element
- There is some emitting element that is capable of radiating the energy produced by the source into the far field (e.g. a connected cable, slots in the enclosure or a printed circuit board that acts as an antenna)

Interference sources

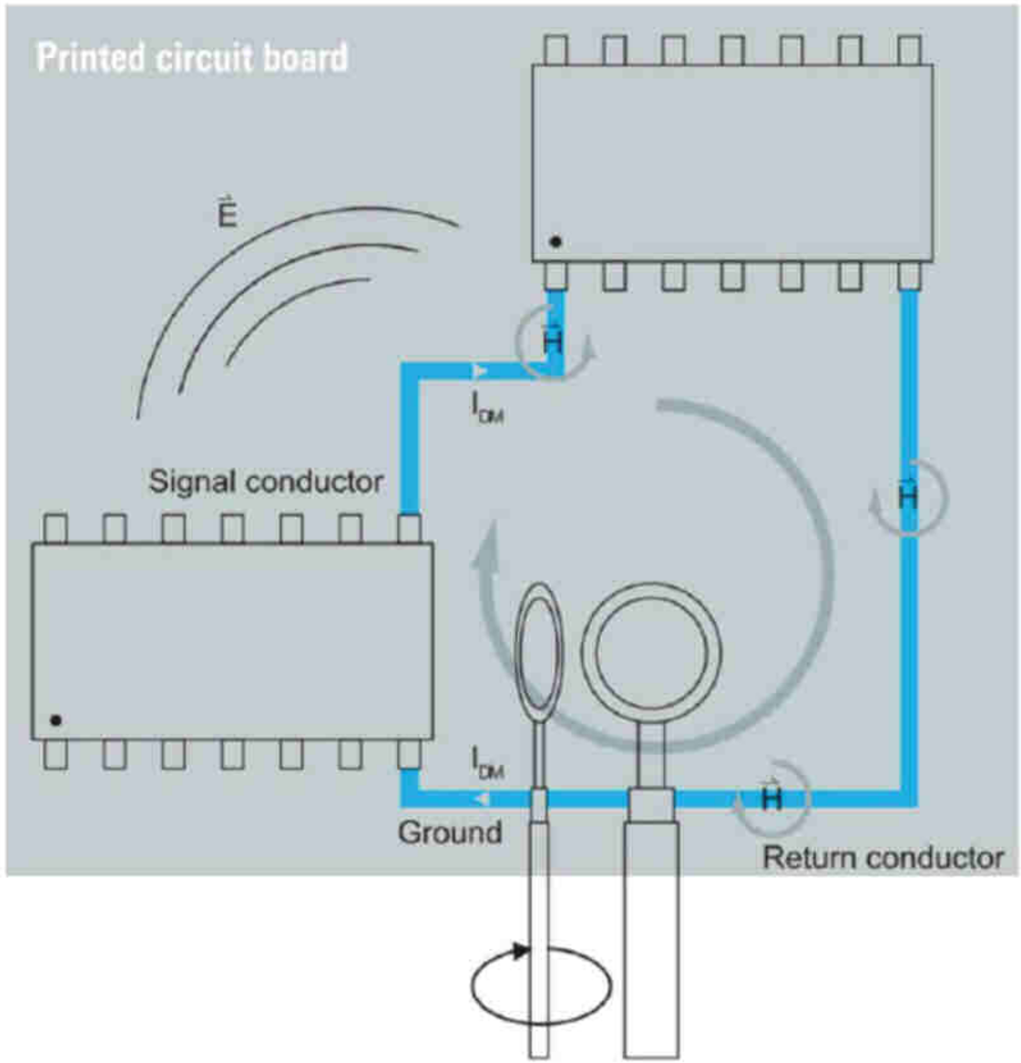
- Fast switching signals within digital circuits
  - Single-ended (asymmetrical) data signals
  - Switched mode power supplies - harmonics
  - Differential data signals with significant common mode component
- Relatively low voltage swing of signals makes them sensitive to external EMI (e.g. SMPS)



high-order harmonics decrease at 20 to 40 db/decade
Structures on the PC board can begin to resonate at harmonic frequency

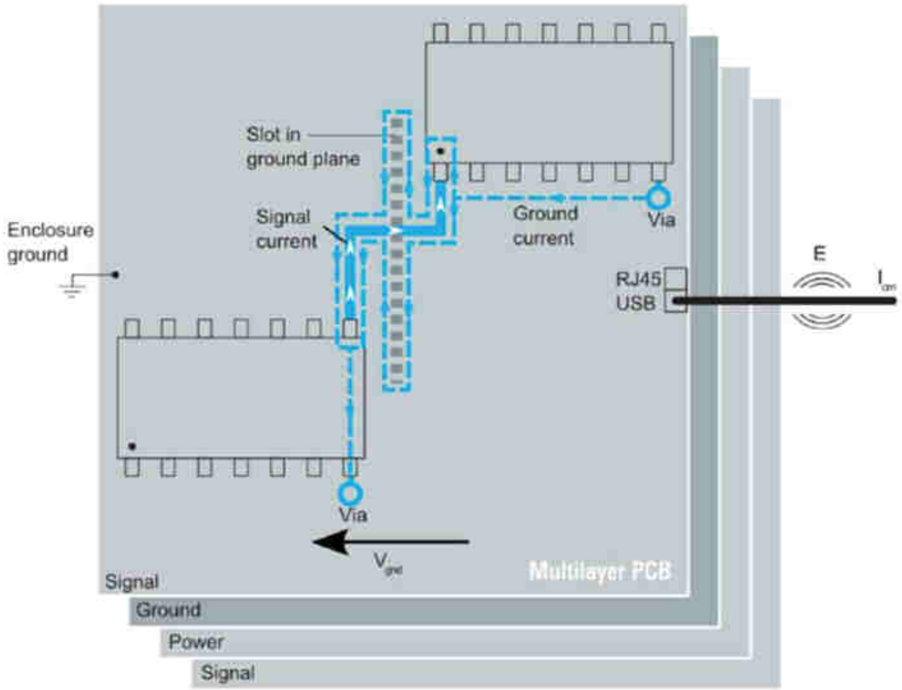
Differential Mode RF Emissions

- Emission results when signal and return are not routed together
- Near field probe can detect this by positioning within the loop – position of probe is critical
- Mitigate by routing signal and ground closer, reducing signal current or decreasing slew rate



Common Mode RF Emissions

- Common problem in multi-layer PC boards
- Caused by parasitic inductance in return path or asymmetrical transmission
- External cable acts as an antenna
- Rule of thumb for line length as an antenna: $\lambda/10$ not critical $\lambda/6$ critical



Common Mode RF Emissions

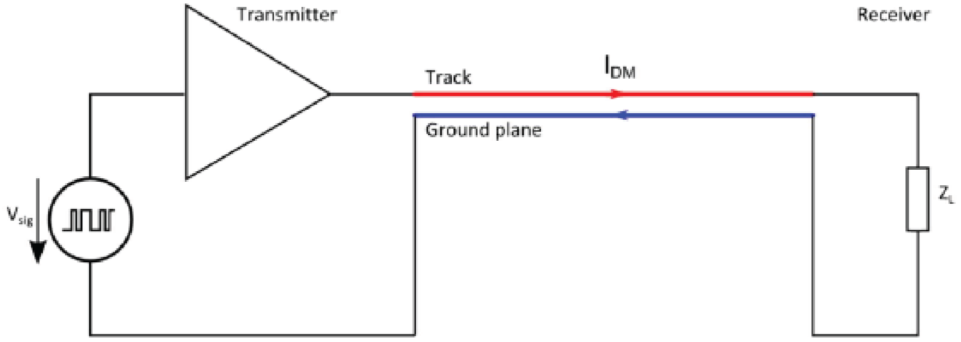


Fig. 2-4: Ideal differential-mode transmission: The forward and return conductors are arranged close to one another while the generated magnetic field is almost entirely canceled out in the far field.

Common mode emissions are more frequent and can be measured using H-field probes

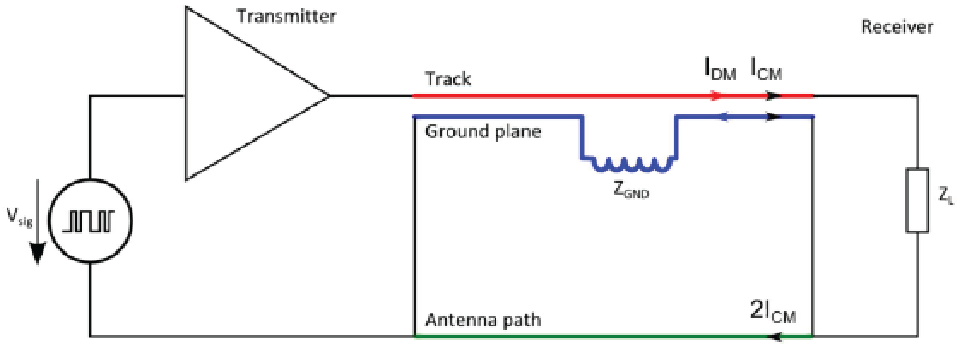


Fig. 2-5: Formation of a common-mode return current via the antenna path due to undesired parasitic inductance in the ground plane. Here, the "antenna path" is typically an external line that functions as an antenna, e.g. a power supply cable.

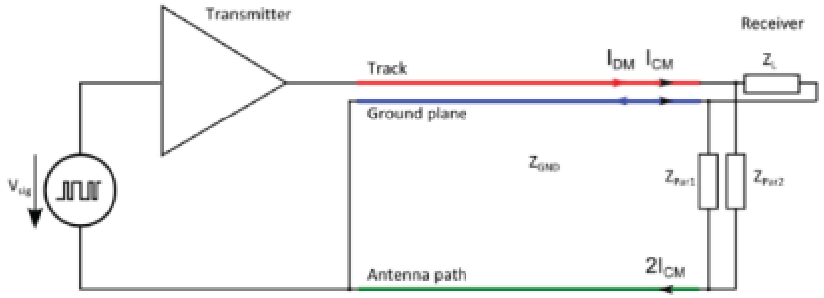


Fig. 2-6: Unbalanced (parasitic) terminating impedances of a differential-mode signal line that causes an unwanted common-mode current I_{CM}. A line connected to the ground plane can thus function as an antenna if it is capable of carrying a part of the common-mode current I_{CM}.

General steps to help reduce common-mode RF emissions

- Reduce the RFI current ICM by optimizing the layout, reducing the ground plane impedances or rearranging components
- Reduce higher-frequency signal components through filtering or by reducing the rise and fall times of digital signals
- Use shielding (lines, enclosures, etc.)
- Optimize the signal integrity to reduce unwanted overshoots (ringing)

Coupling Mechanisms

- Three coupling paths:
  - Direct RF emissions from the source, e.g. from a trace or an individual component
  - RF emissions via connected power supply, data or signal lines
  - Conducted emission via connected power supply, data or signal lines
- Coupling Mechanisms
  - Coupling via a common impedance
  - Electric field coupling – parasitic capacitance between source and antenna
  - Magnetic field coupling – parasitic inductance between source and antenna
  - Electromagnetic coupling – far field coupling (greater than 1 wavelength)

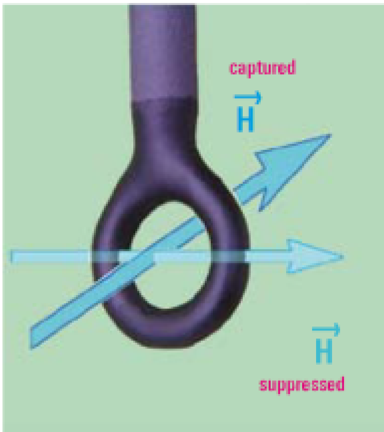
Emitting Elements (Antennas)

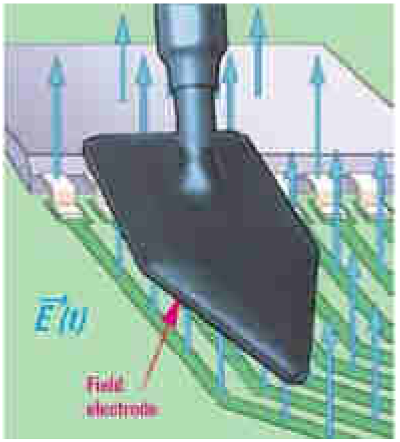
- Main types of unintentional antennas in electronic equipment

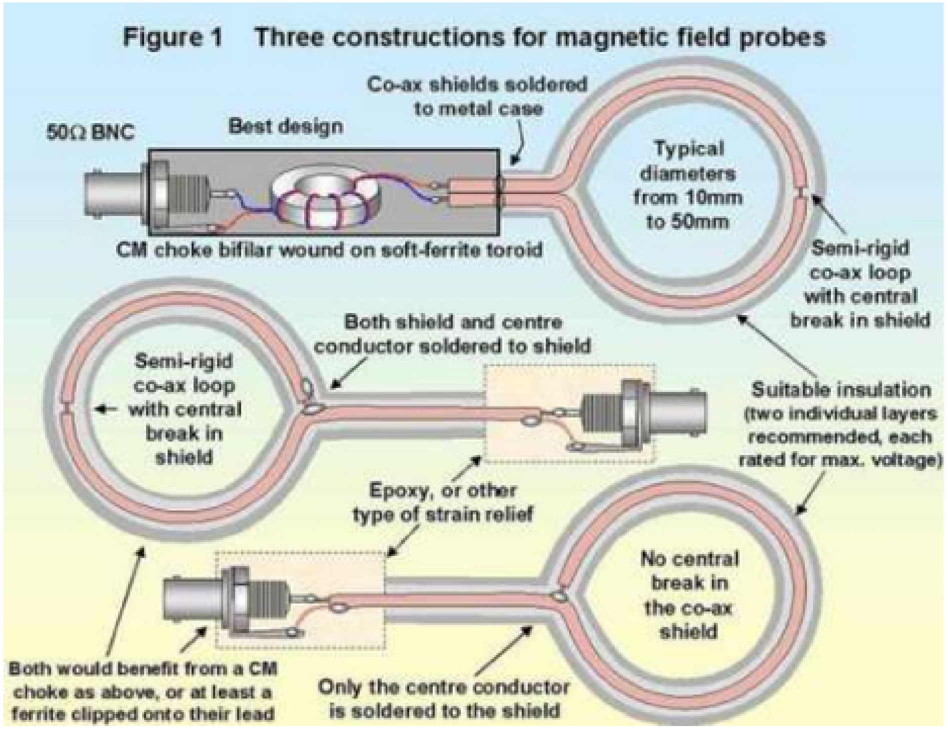
- Connected lines (power supply, data/signal/control lines)
- Printed circuit board tracks and planes
- Internal cables between system components
- Components and heat sinks
- Slots and openings in enclosures

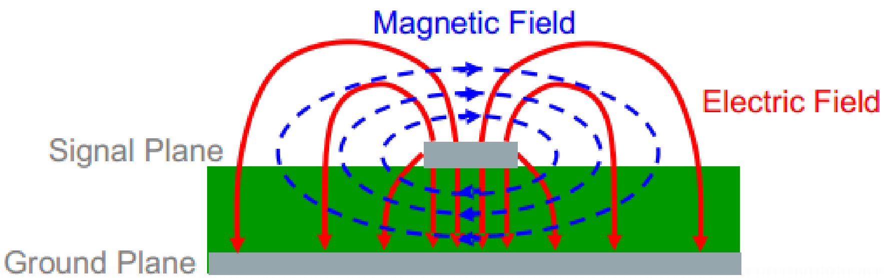
Magnetic and Electrical Near-Field Probes

- Basically the probes are antennas that pickup the magnetic & electric field variation
- The output Depends on the position & orientation of the probe

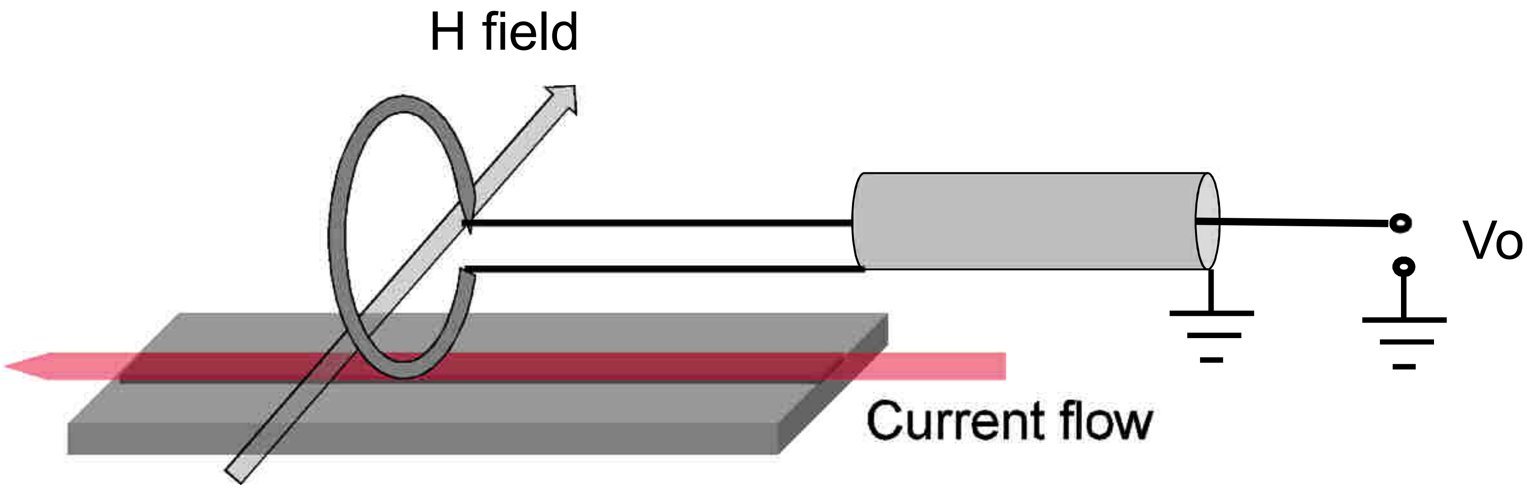






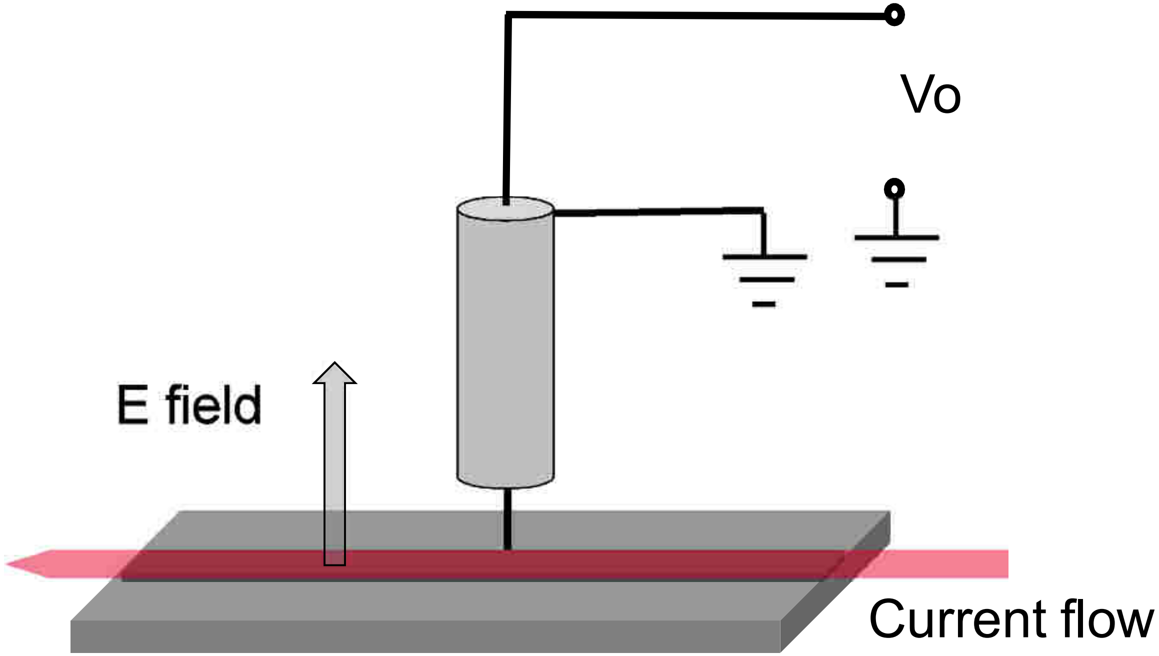


H-Field Probe



- **Maximum response with probe parallel with current and closest to the current carrying conductor**
- **Traces with relatively high current, terminated wires and cables**

E-Field Probe



- Maximum response with probe perpendicular with current and closest to the current carrying conductor
- Traces with relatively high voltage: unterminated Cables, PCB traces to high impedance logic (tri-state outputs of logic IC's)

Basic EMI Debug Process

Far-field measurement provides standard-compliant summary of critical frequencies — EMC test lab

↓

Reference measurement with DUT switched off to identify extraneous radiated emissions — Development lab

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RFI current measurement for analysis of the emission mechanism

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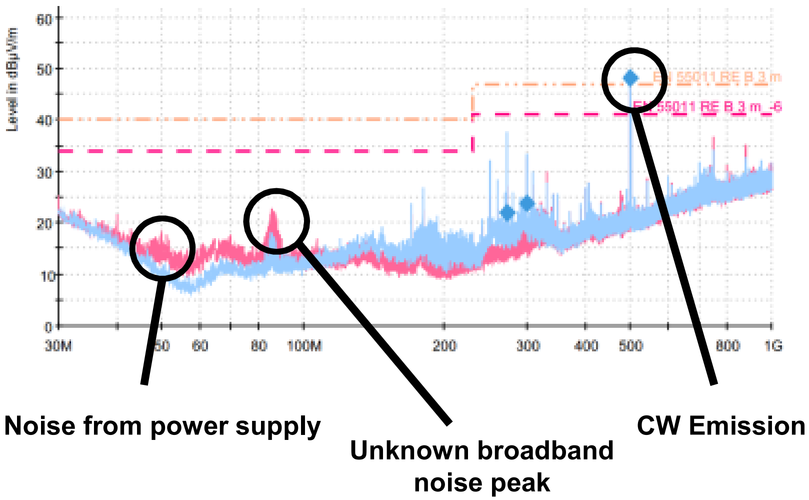
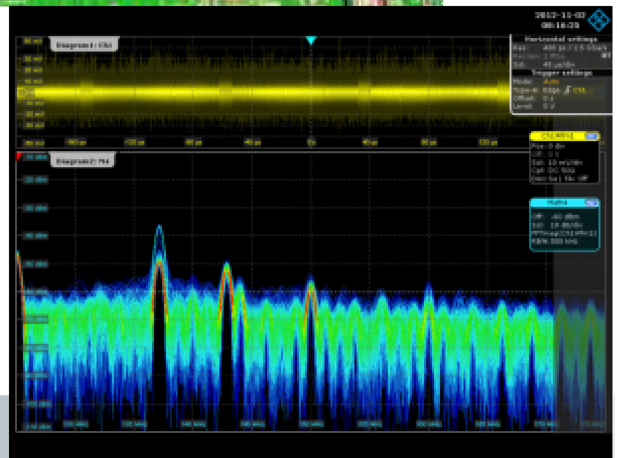
Localization of the interference source in the near field and analysis of the coupling mechanism

↓

Evaluation of possible corrective action





Using an Oscilloscope for EMI Debugging

- Benefits

- Wide instantaneous frequency coverage
- Overlapping FFT computation with color grading
- Gates FFT analysis for correlated time-frequency analysis
- Frequency masks for triggering on intermittent events
- Deep memory for capture of long signal sequences

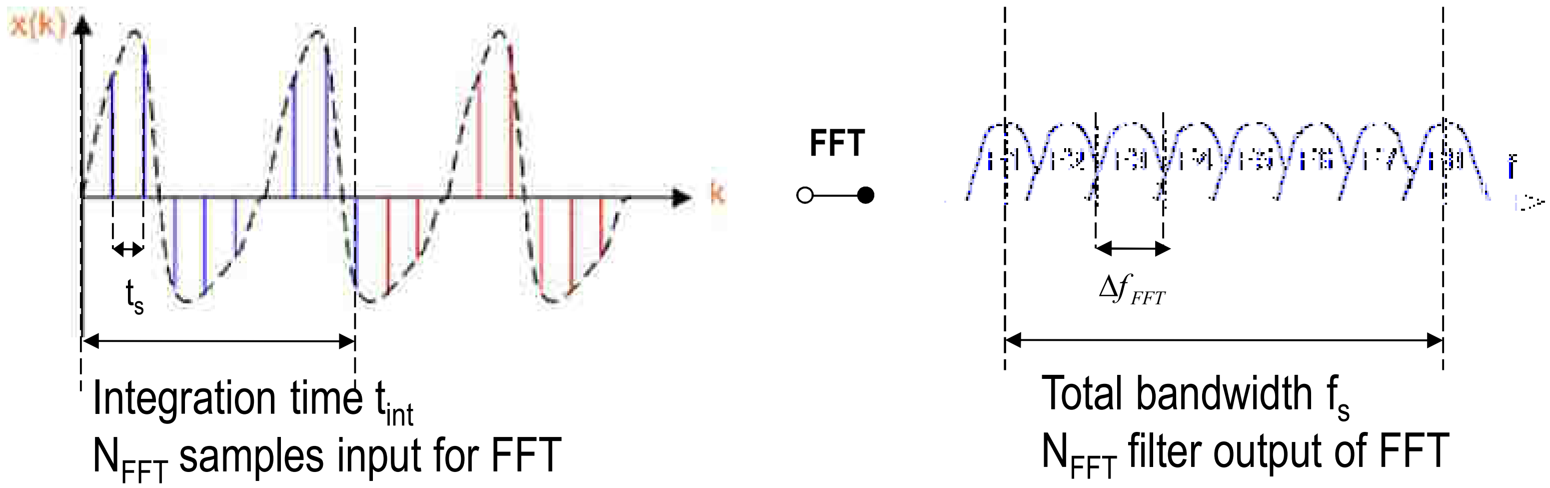
- Limitations

- Dynamic range
- No preselection
- No standard-compliant detectors (i.e CISPR)

Important Scope-Parameters for EMI Debugging

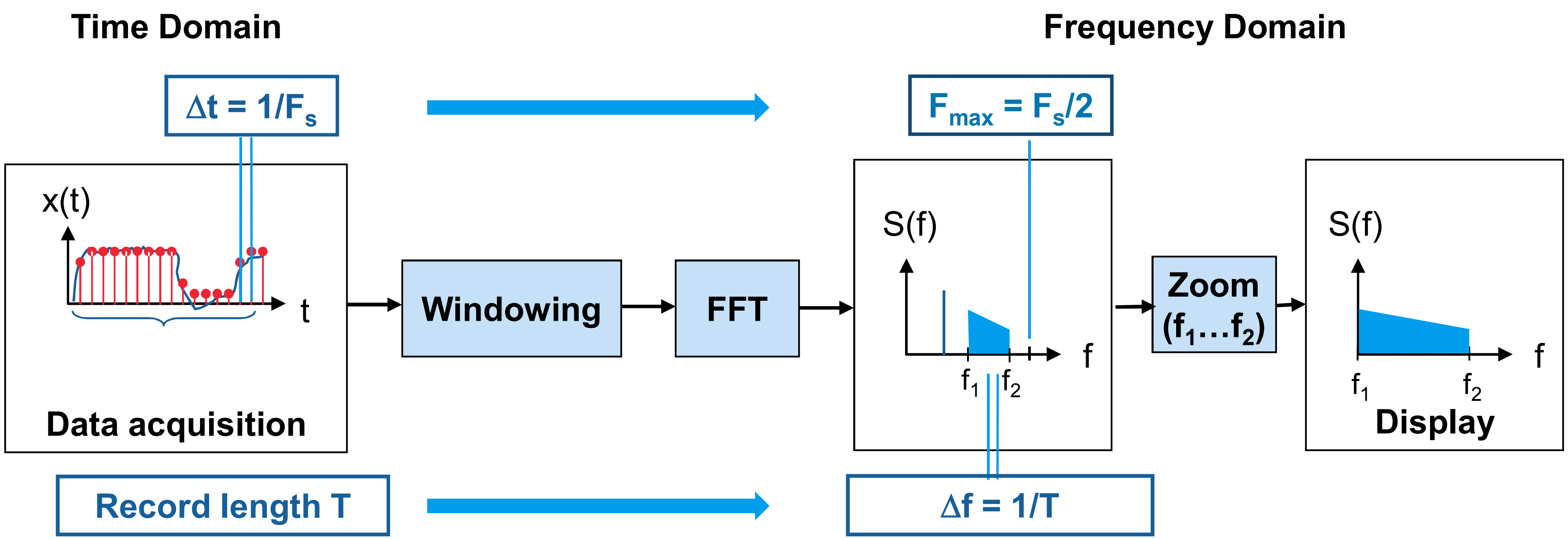
Parameter	Description
Record length	Ensure that you capture enough
Sample rate	>2x max frequency, start with 2.5 GS/s for 0 – 1 GHz frequency range
Coupling	50 Ω for near-field probes (important for bandwidth)
Vertical sensitivity	1 – 5 mV/div is usually a good setting across full BW
Color table & persistence	Easily detect and distinguish CW signals and burst
FFT – Span / RBW	Easy to use “familiar” interface, Lively Update
Signal zoom & FFT gating	Easily isolate spurious spectral components in time domain

Frequency Domain Analysis
FFT Basics



- **N_{FFT}** — **Number of consecutive samples (acquired in time domain), power of 2 (e.g. 1024)**
- **Δf_{FFT}** — **Frequency resolution (RBW)** $$\Delta f_{FFT} = \frac{1}{t_{int}} = \frac{f_S}{N_{FFT}}$$
- **t_{int}** — **integration time**
- **f_s** — **sample rate**

FFT as Basis for EMI Debugging with Oscilloscopes
Conventional FFT Implementation on a Scope

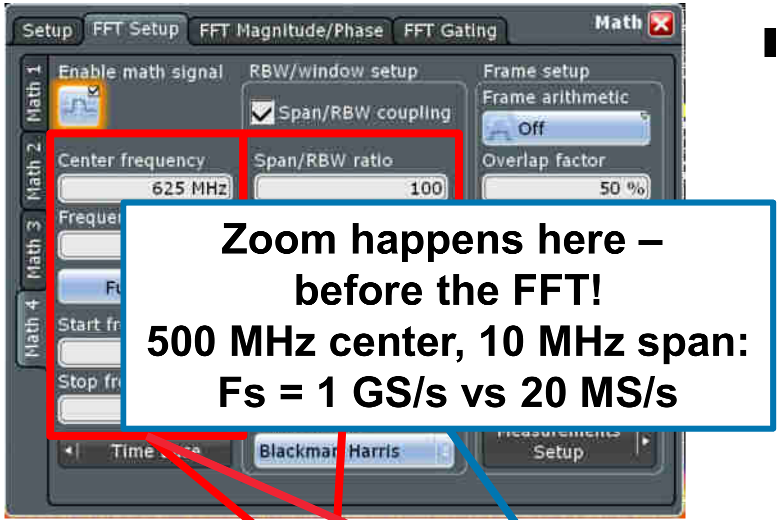


Disadvantages:

- Time domain settings define frequency domain
- Zoom in frequency domain does not give more details
- Correlated Time-Frequency Analysis not possible

FFT on the RTO

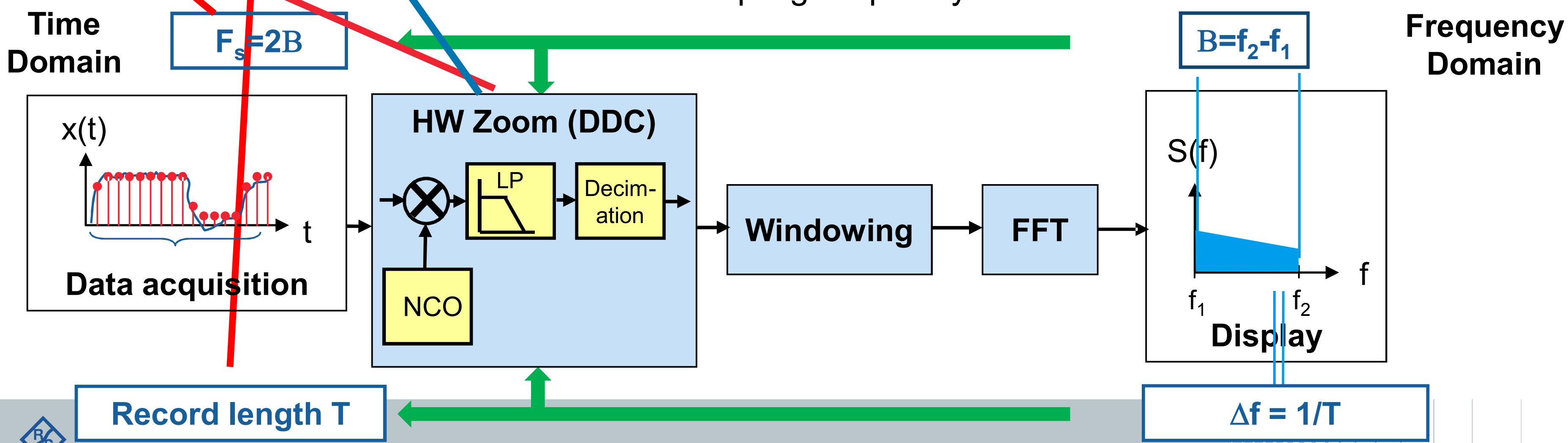
Spectrum Analyzer Use Model



- **Use model: Frequency domain controls time domain**
  - Time domain parameters (record-length / sampling rate) automatically changed as necessary

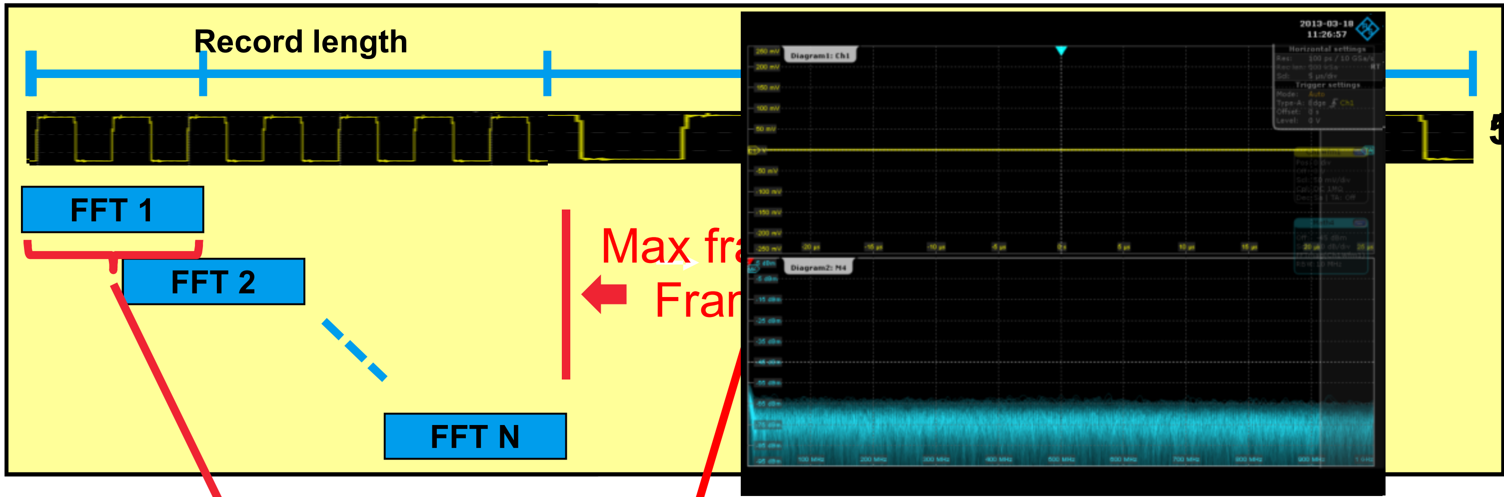
Downconversion FFT (DDC) zooms into frequency range *before* FFT

- Largely reduced record length, much faster FFT 500 MHz center, 10 MHz span: 1 GHz vs 20 MHz sampling frequency



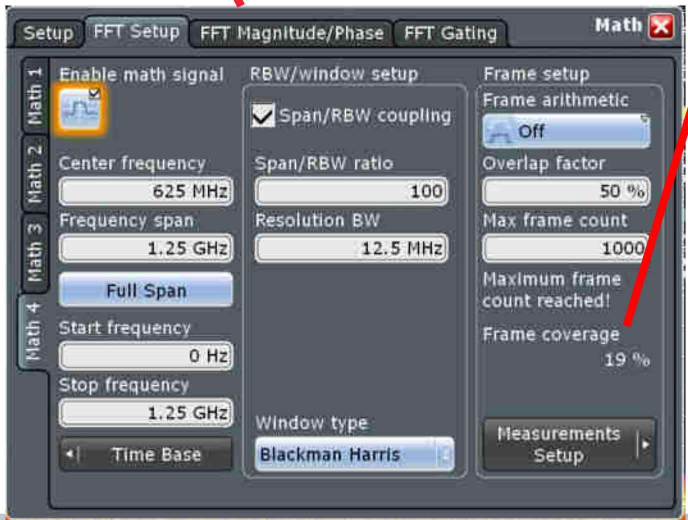
What if we combine time and frequency domain?

Overlap FFT comes into play



10GS/s
18596s/div
5608kSamples

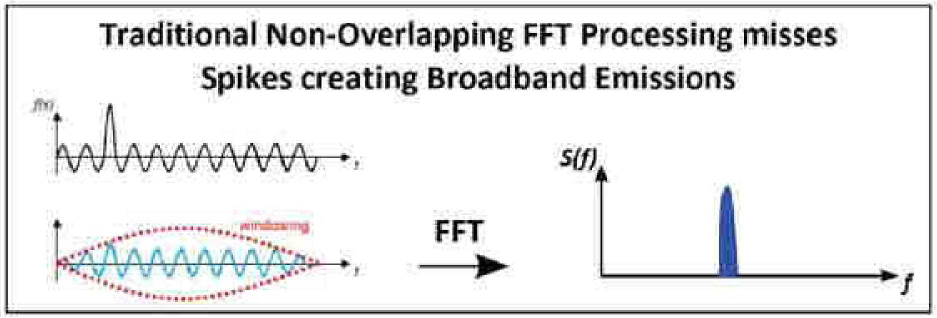
~440FFFTs
(persistance disabled)

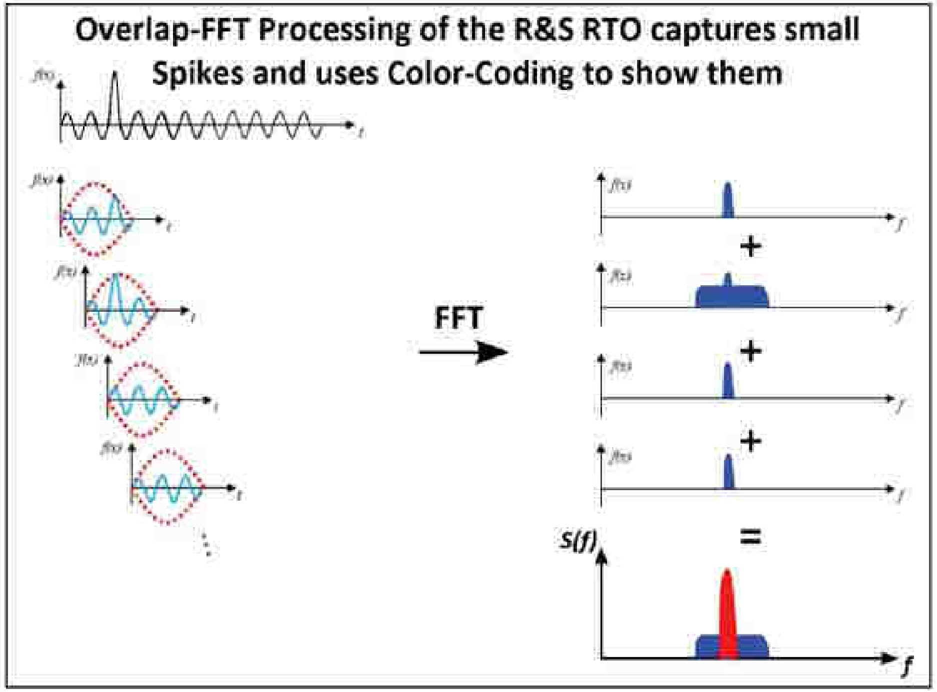


Advantages:

- Analyze time-dependent spectrum
- Conventional (non-overlapping) FFT loses information due to windowing → overlapping allows to capture everything
- Limit No of frames to ensure fast FFT processing
  - **Note:** FFT processing starts from the left!

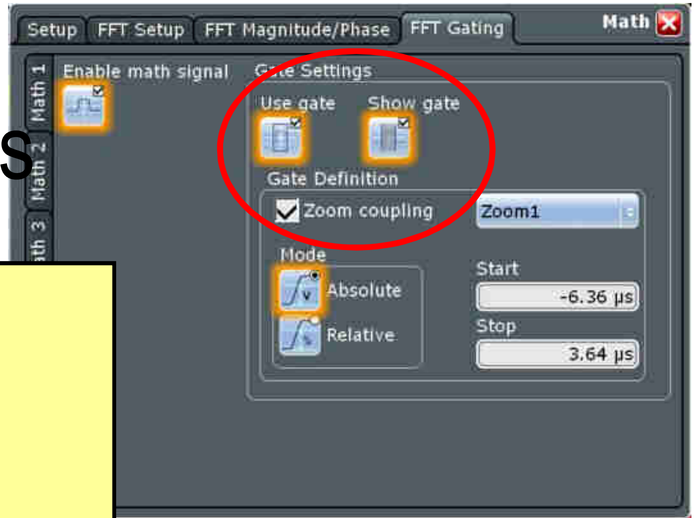
Overlapping FFT Computation





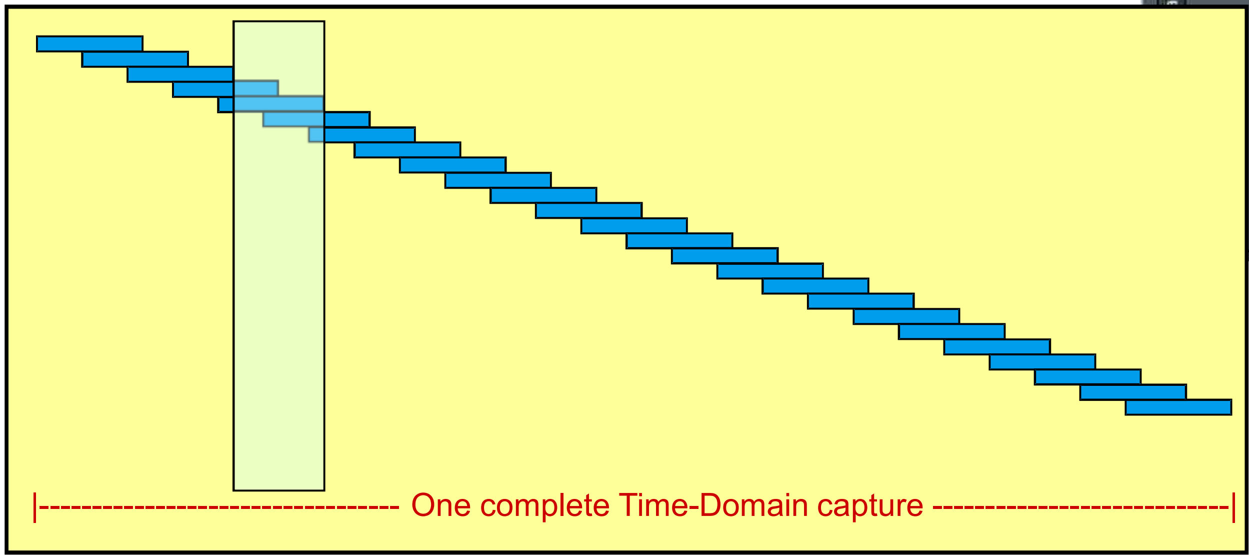
Gated FFT in the RTO

Practical Time-Frequency Analysis



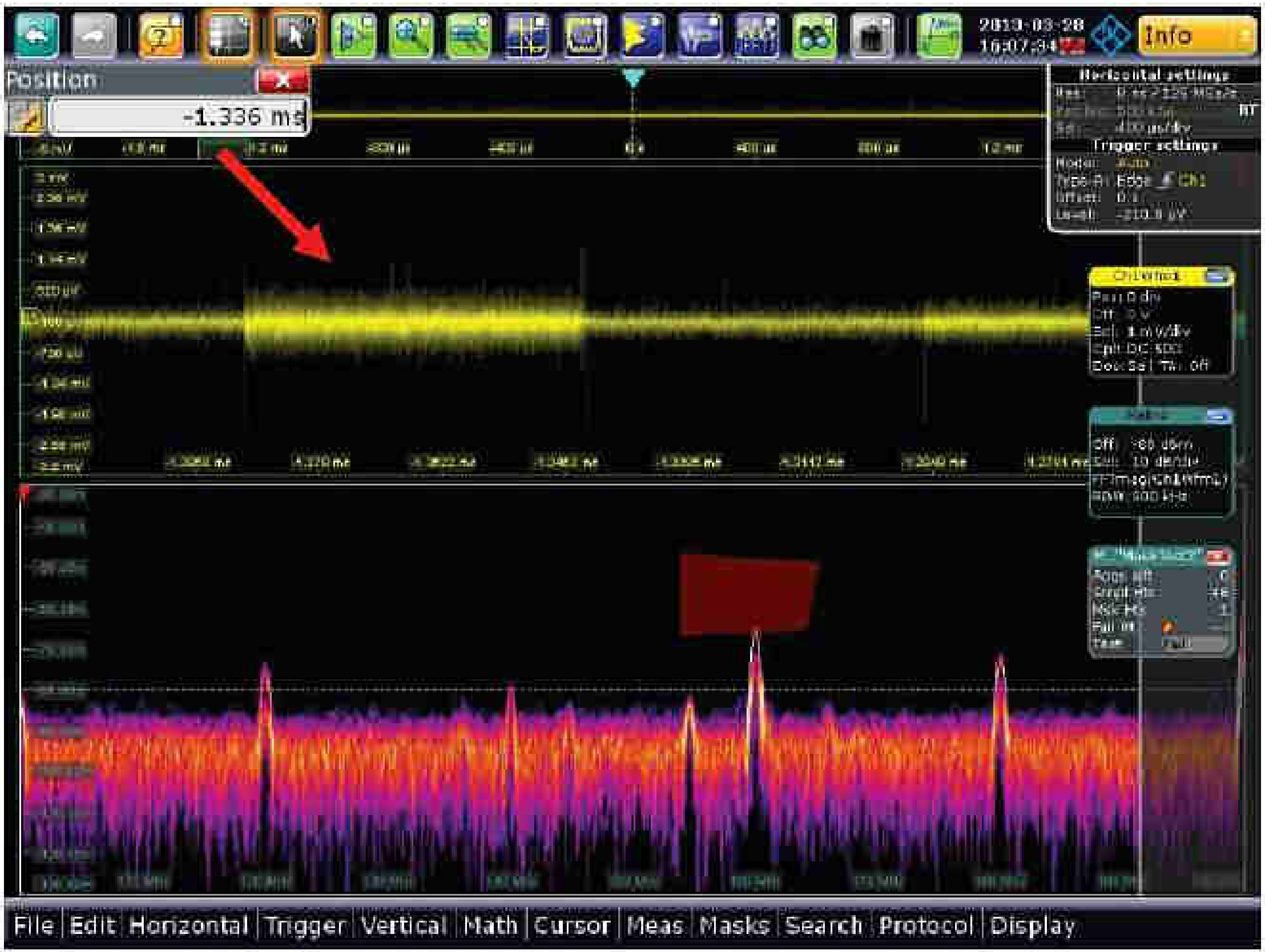
Gated FFT:

50% overlap (default setting)



Key Feature for EMI Debug!

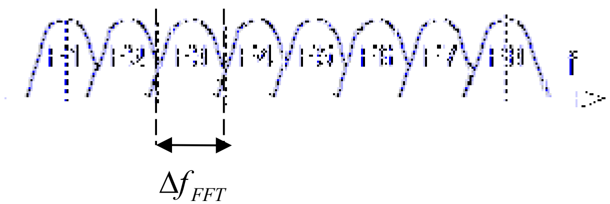
FFT Gating


Info
Position
-1.336 ms
Horizontal settings
Trigger settings
File
Edit
Horizontal
Trigger
Vertical
Math
Cursor
Meas
Masks
Search
Protocol
Display

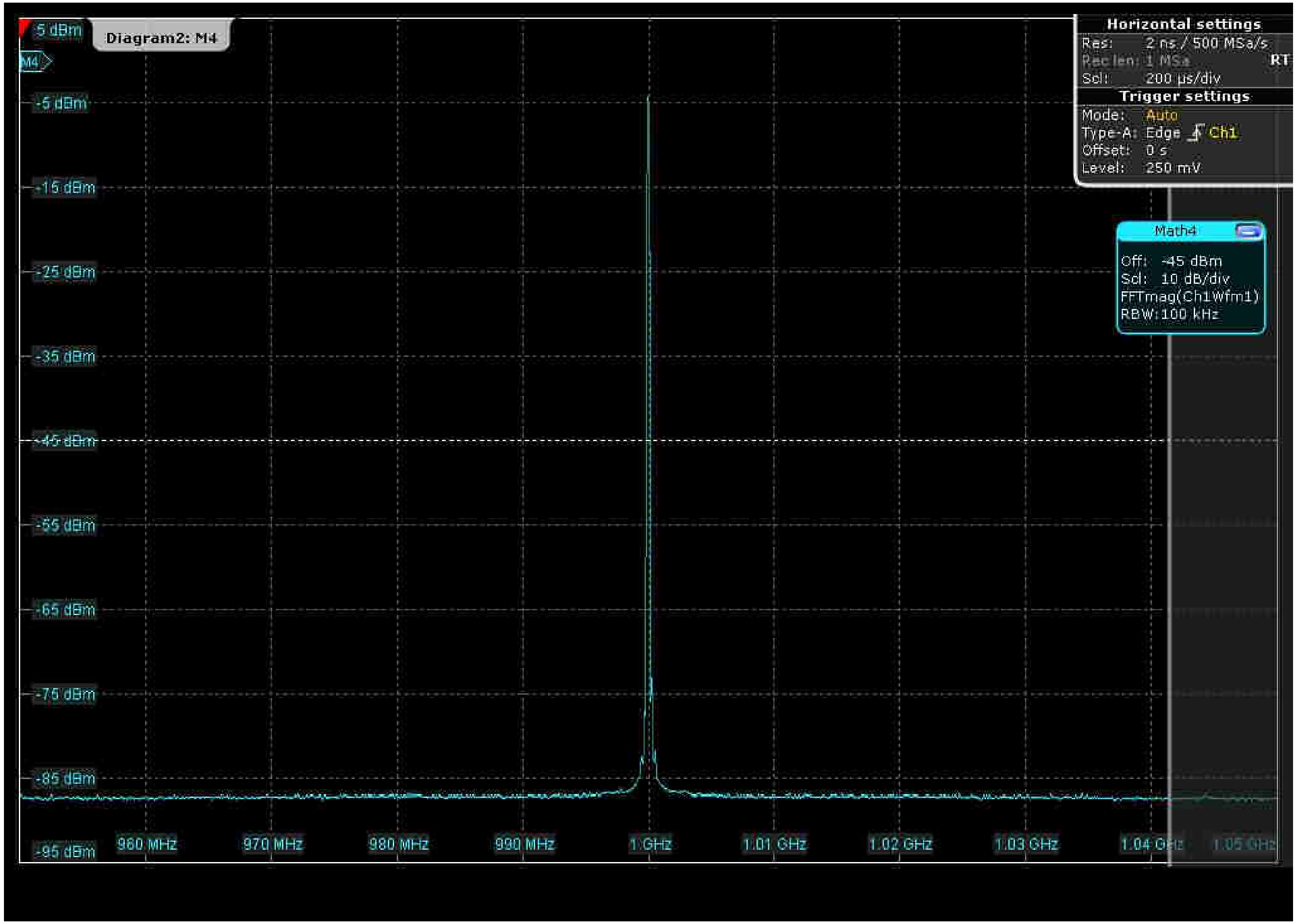
Signal to Noise and ENOB

Higher ENOB => lower quantization error and higher SNR => Better accuracy

- Thermal noise is proportion to BW.
- An FFT bin is captures a narrow BW proportional to 1/ N_{FFT}
- Noise is reduced in each bin by a factor of $10 * \log_{10}\left(\frac{1}{N_{FFT}}\right)$
- The limit approaches sum of all non-random errors. (Measurement induced errors are still present)



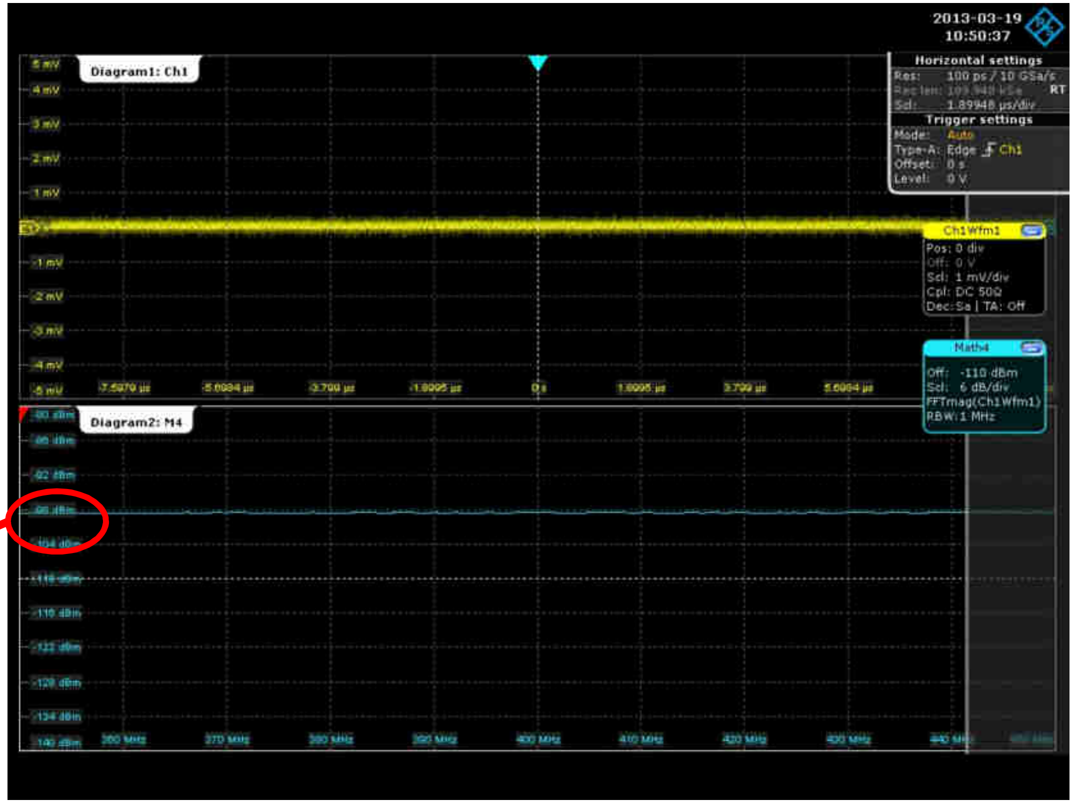
Signal to Noise



>80 dB

Noise Figure

- **RTO Noise Figure**
  - Vertical Settings
    - **1mV/div, 50 Ω**
  - Enable **FFT**
  - Use **RMS** detector
  - Set center frequency
  - Set **RBW** to e.g. **1 MHz**
  - Set unit to **dBm**



NF = Output noise – Input noise ≈

≈ RMS Power$_{dBm/RBW}$ - (-174 dBm/Hz + 10xlog10 (RBW/Hz)) =

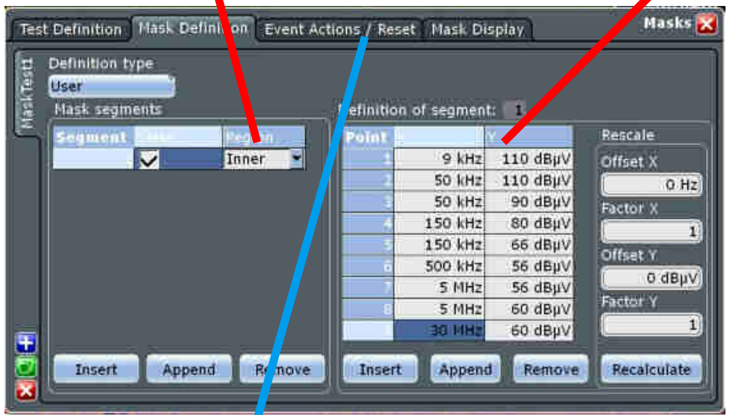
= -98 dBm – 60 dB + 174 dBm = **16 dB**

Limit Lines

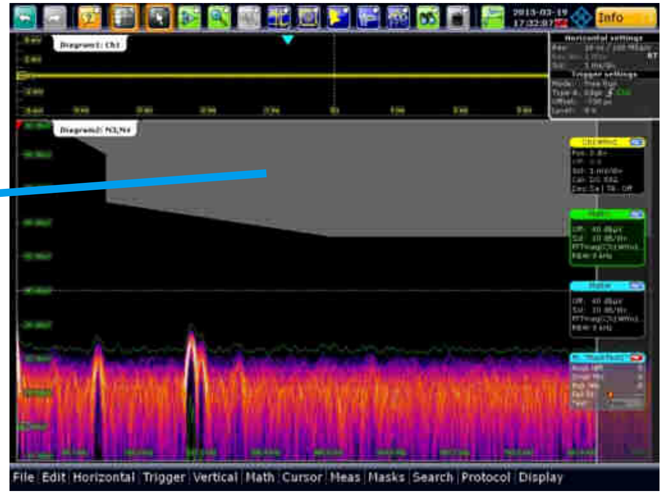
▮ Mask Tool

Upper for limit line usage

Mask definition in units of FFT



Upper region mask acting as limit line

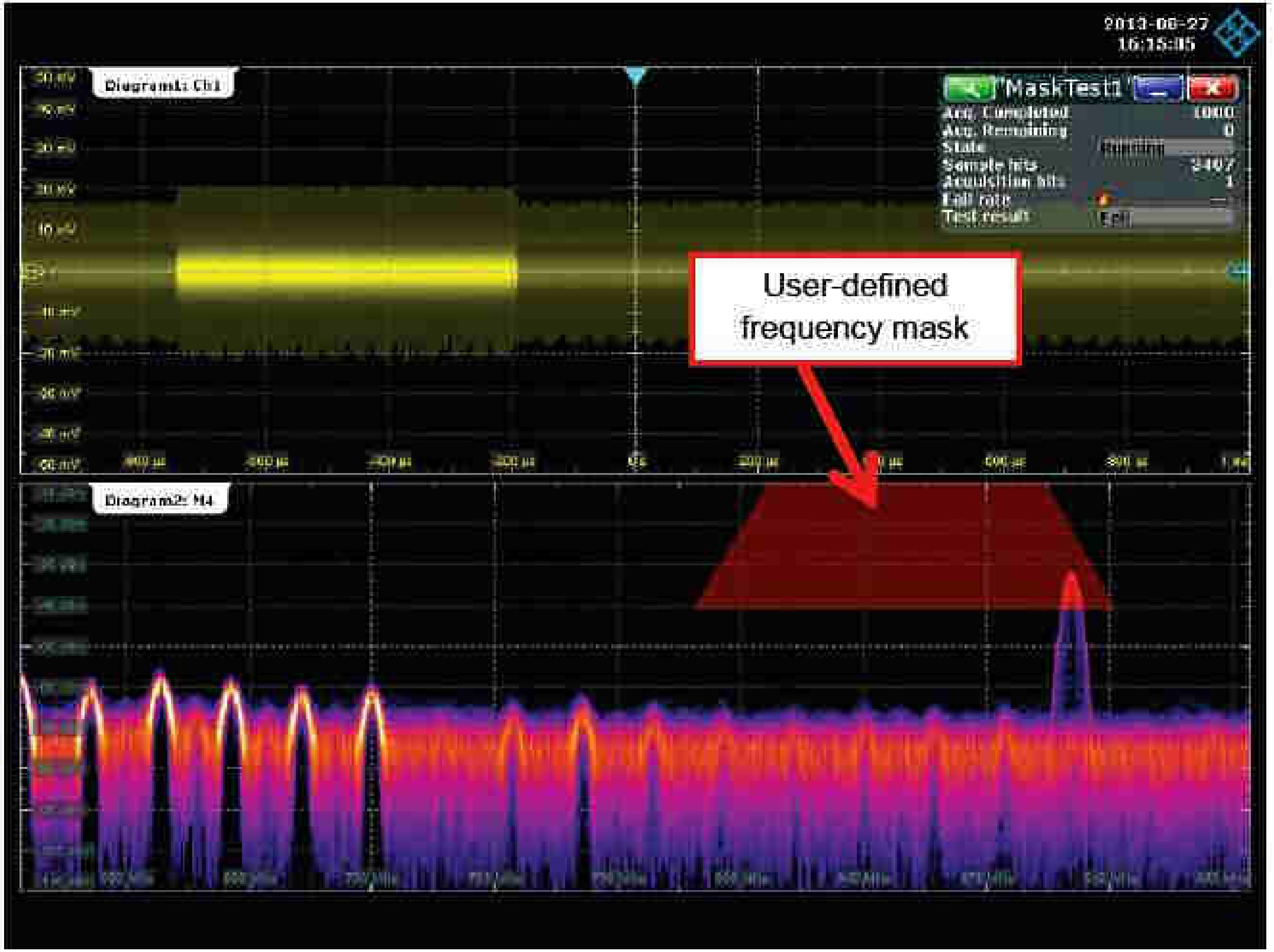


Stop-on mask violation setting is very useful!

▮ 6 dB EMI filter?

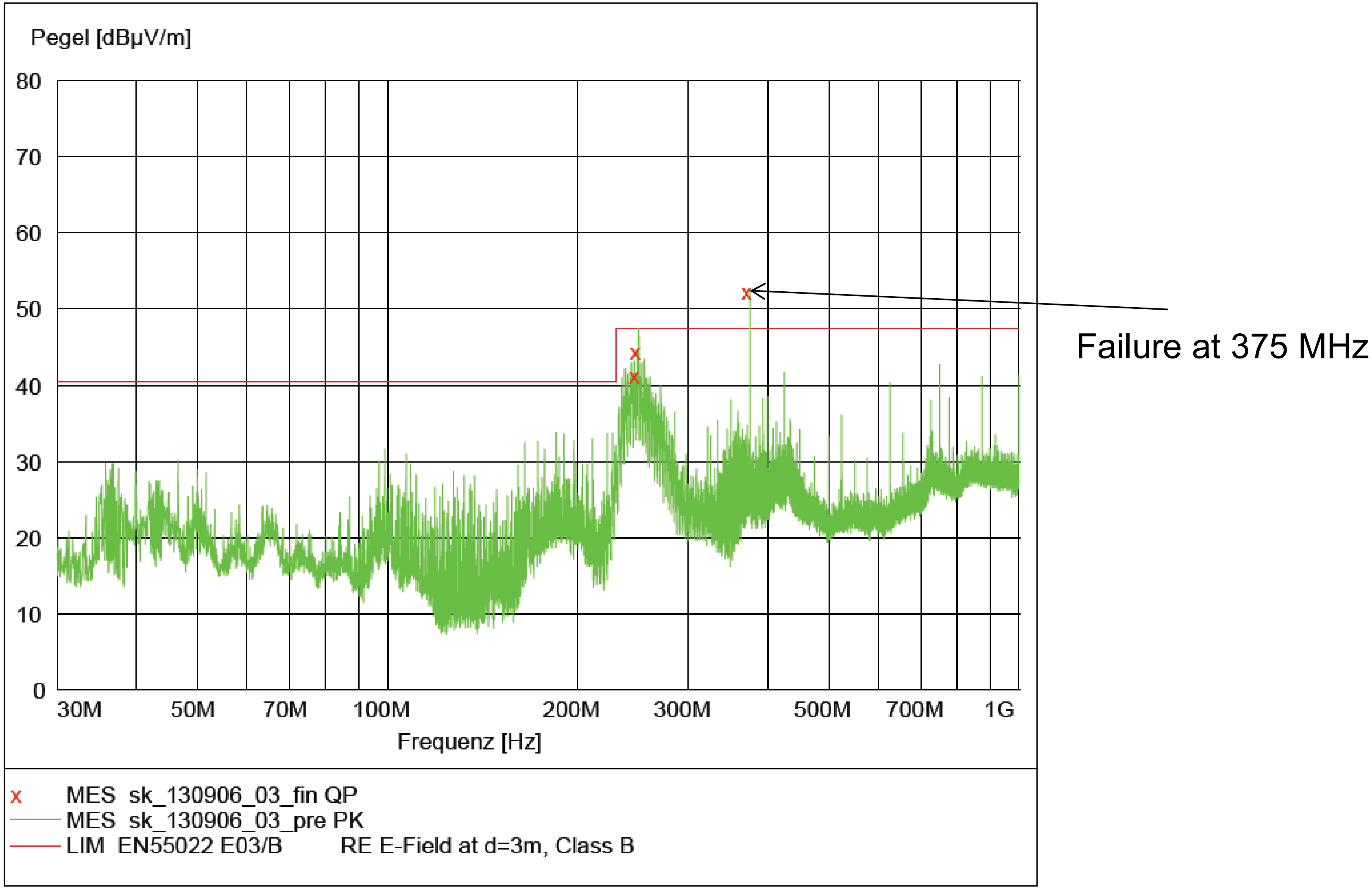
- Not critical for precompliance, will change results only slightly.

Frequency Mask Triggering



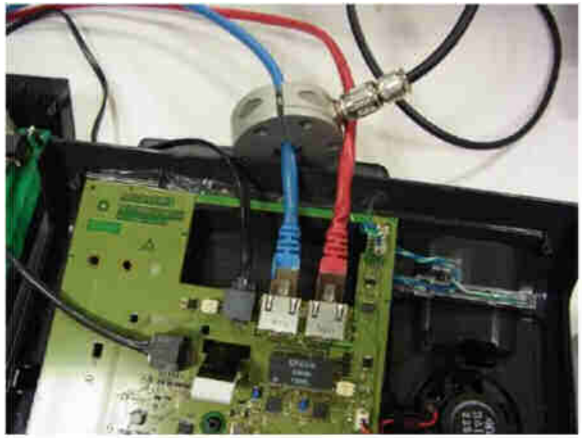
Measurement Example – IP Phone

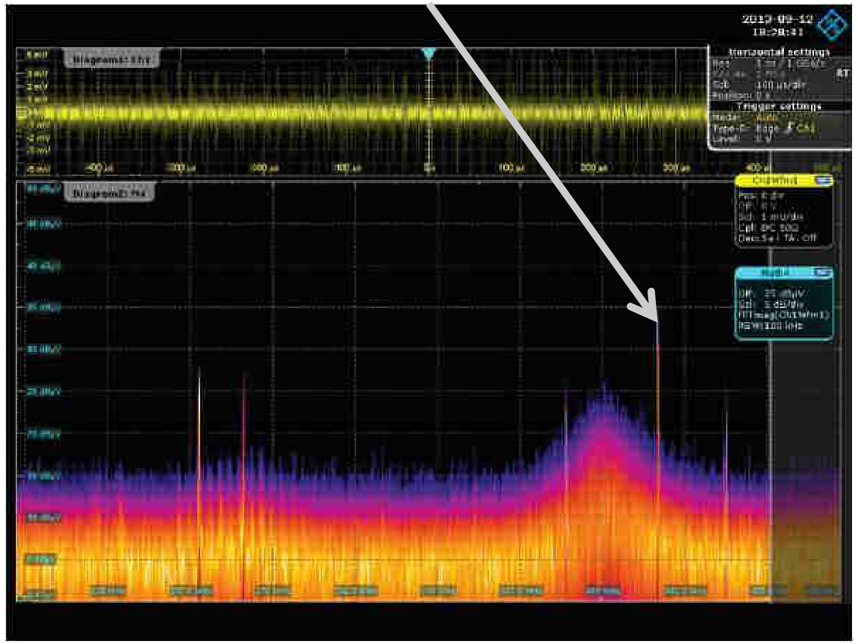
Far Field Measurement

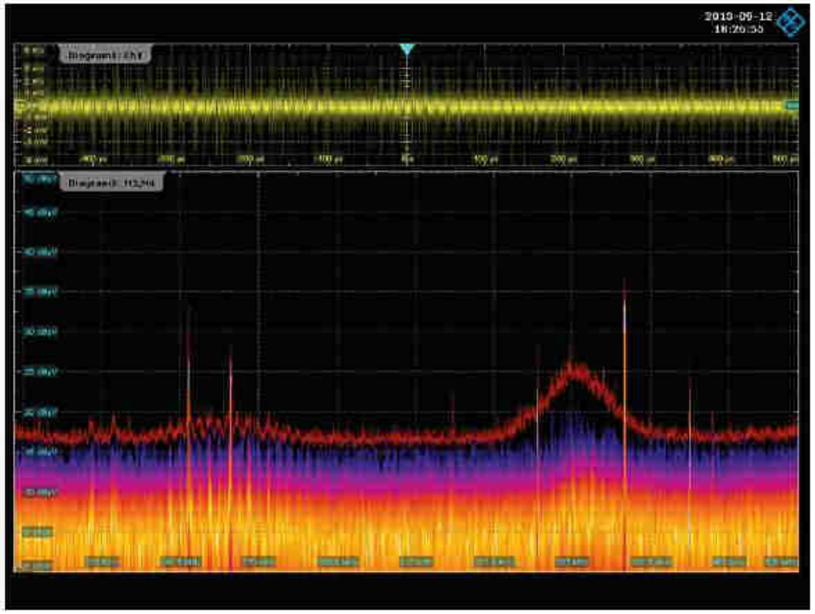


RFI Current Measurement

375 MHz Spur

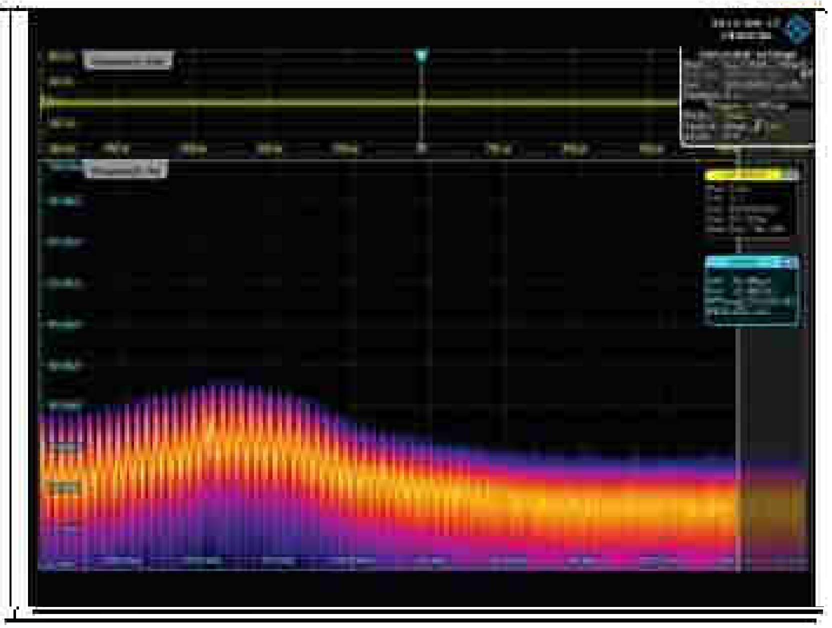




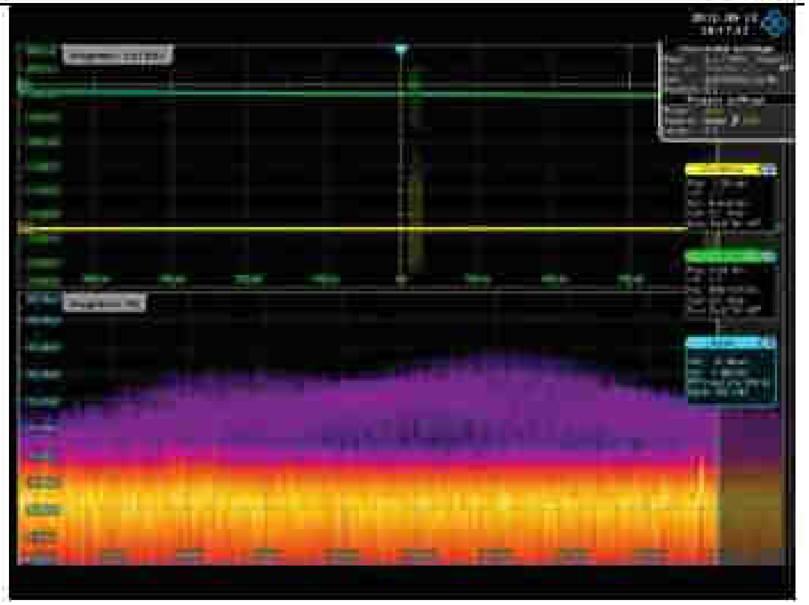


Peak detect separates intermittent interference

Identifying Coupling Using Near Field Probes



Correlating Time and Frequency Domains



Debugging EMI Using a Digital Oscilloscope
Summary

- The modern oscilloscope with hardware DDC and overlapping FFT is capable of far more than a traditional oscilloscope

- EMI Debugging with an Oscilloscope enables correlation of interfering signals with time domain while maintaining very fast and lively update rate.

- The combination of synchronized time and frequency domain analysis with advanced triggers allows engineers to gain insight on EMI problems to isolate and converge the solution quickly.

- Power Supply design choices have a large impact on EMI emissions, frequency and time techniques can help unravel the mystery.