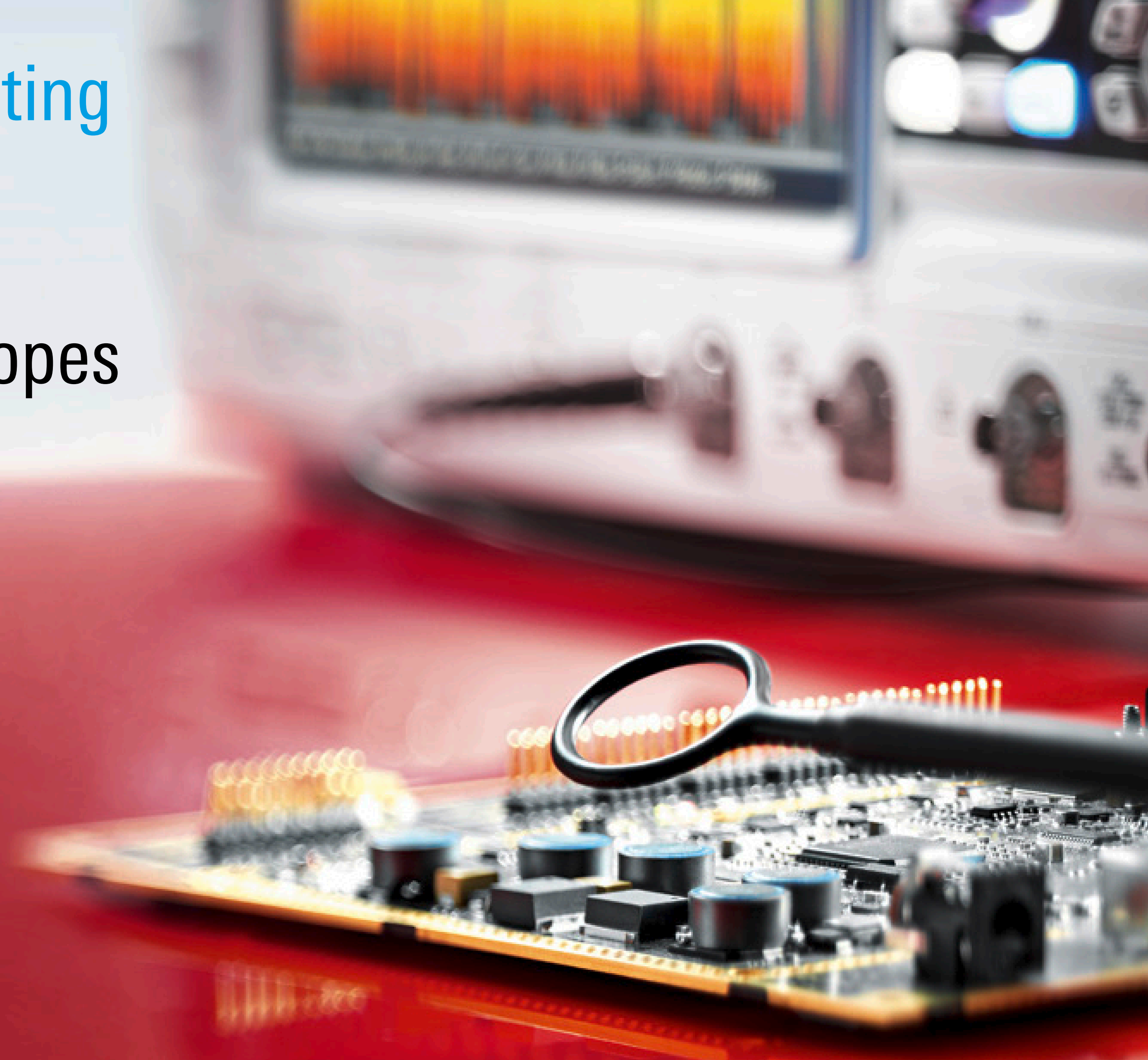
Designing for EMI testing (step-by-step guide)

Improve your time to market with oscilloscopes



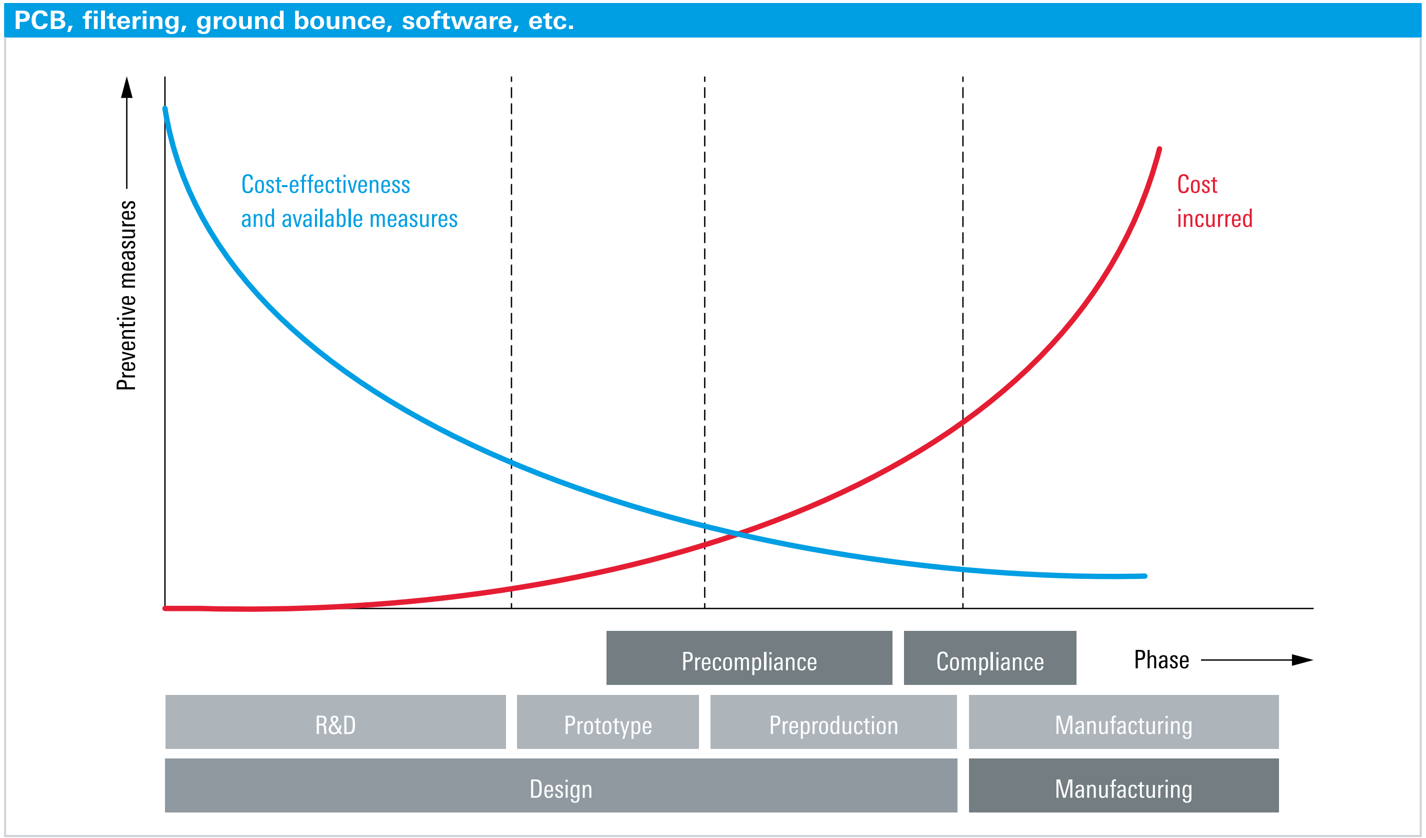
ROHDE&SCHWARZ

Today, R&D engineers face challenging time-to-market goals. Extending the product development schedule and delaying the product launch can prove to be extremely costly in terms of opportunity cost and lost market share. Nearly 50 % of products fail EMC compliance the first time. Every day spent on debugging, isolating and correcting the EMI problem increases the time to market. The time lost could have been used to work on another project or on improving the design instead.

To address these challenges, it makes sense to perform EMI tests during the product design cycle in order to reduce the possibility of failing EMC compliance, which typically comes at the end of the development cycle of a product.

As illustrated, the cost of fixing EMI problems too late in the development cycle can prove to be expensive. Preventive measures integrated into design cycle checkpoints can help avoid costly project delays.

This step-by-step guide leads you through three important steps to take advantage of the unique features of the R&S®RTO/RTE digital oscilloscopes and perform EMI testing in the product design cycle: locating, capturing and analyzing emissions with different correlations and tactics.



Basic EMI testing approach with an oscilloscope

Most, if not all, R&D engineers use oscilloscopes throughout their product design cycle to capture waveforms, verify serial buses and debug unwanted signals. Adding the capability of using the oscilloscope to perform EMI testing would eliminate the need to purchase other equipment.

In the past, oscilloscopes were not commonly associated with EMI testing due to FFT limitations. However, that changed with the R&S®RTO/RTE digital oscilloscopes which come with the industry-leading implementation of FFT digital downconversion and overlapping FFT.

Overview of EMI testing steps

Settings

- Frequency band and RBW
- Oscilloscope parameters

Locate

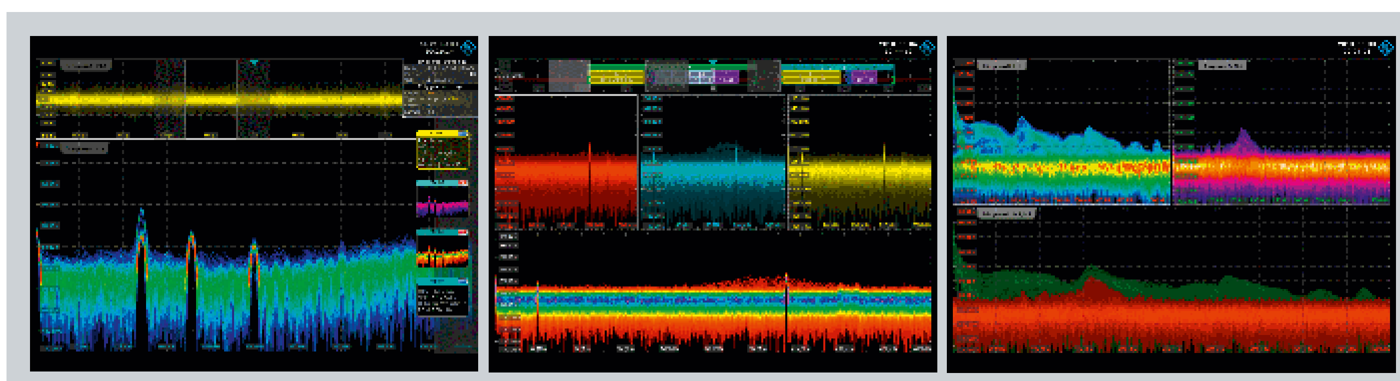
- Visualize with intensity grading
- Locate with near-field probe

Capture

- Time domain trigger
- Zone trigger
- Mask violation
- Serial, parallel and protocol trigger

Analyze

- Identify narrowband and broadband signal
- Analyze with FFT gating
- Analyze correlated signal sources
- Analyze with history function



Set the frequency band and realtime bandwidth (RBW)

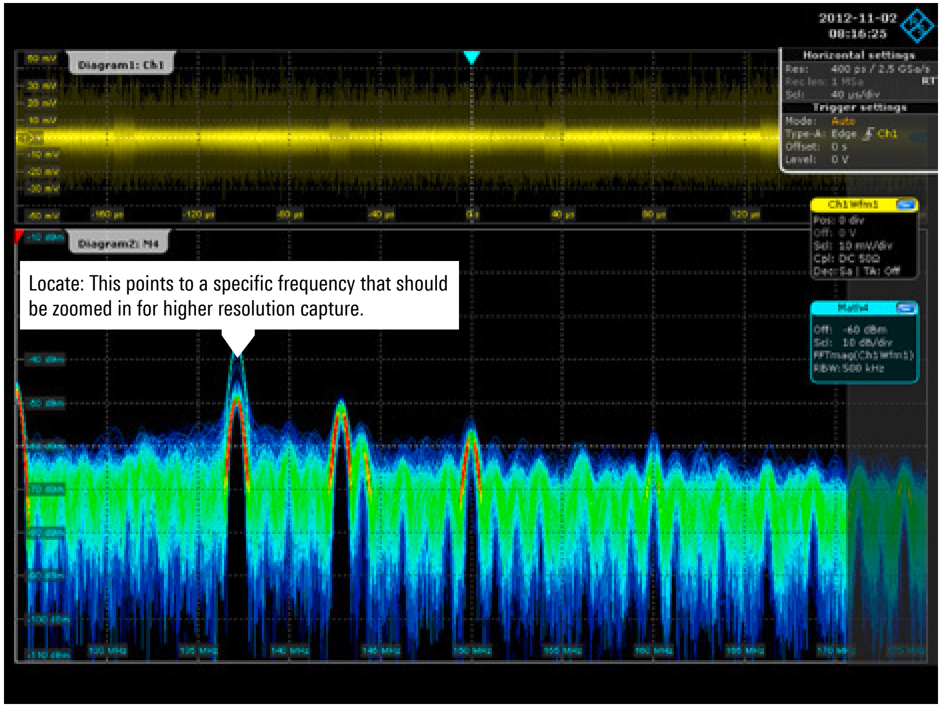
There are two ways to use an oscilloscope: set the right frequency span that you are interested in or start by setting a wide span scan as follows:

- Set full frequency span – usually 0 Hz to 1 GHz is good if your design does not involve RF modules
- Set frequency span from 0 Hz to 6 GHz and above if you are working with an RF embedded system or board

The objective is to obtain an overview of the spectrum and distinguish between narrowband and broadband signals. Afterwards, you can narrow down to the frequency span of interest for further analysis.

TIP RBW of 100 kHz to 1 MHz is typically used to measure radiated emissions having a 30 MHz span

Setting the right frequency band helps you observe the spectrum of interest. With the screen showing an irregular emission around 137 MHz, you can then define the problematic frequency span and increase the RBW to investigate the cause of the emission.



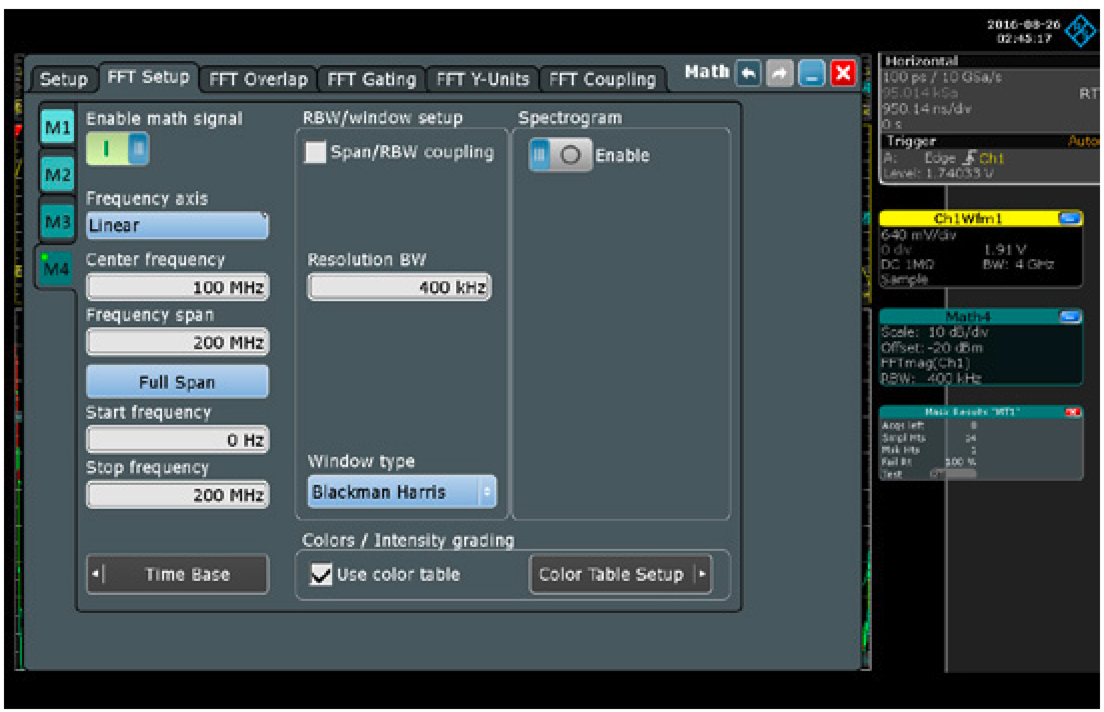
Set the oscilloscope parameters

Recommended setting parameters	Description
Record length	Ensure that you capture enough memory (≥ 500 ksample)
Vertical settings	500 µV/div to 5 mV/div for high sensitivity
Input impedance	50 Ω (1 MΩ introduces attenuation to your original signals)
Display	Envelope mode (similar to max. hold on a spectrum analyzer)

TIP Avoid overloading

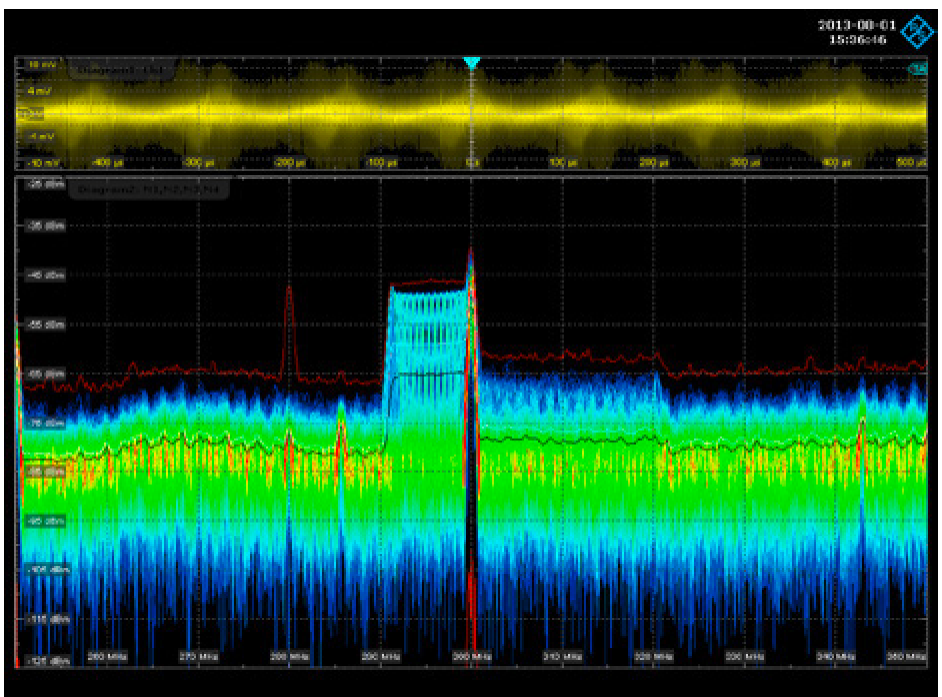
In order to obtain correct results with the spectral analysis function, it is important to make sure the oscilloscope is not overloaded, i.e. when the measured signal can no longer be fully displayed on the screen. To avoid such a situation, the time domain signal should always be monitored on the screen in addition to the spectral signal. In case of overloading, the oscilloscope's vertical sensitivity should be reduced.

Set up your FFT according to the CF and span of interest. Additionally, you can set the span/RBW ratio or decouple both of them.



Step 1:
Locate the culprit

EMI observation with four detections overlaid – envelope (red trace), average (black trace), RMS (white trace) and sample acquisitions with intensity grading.



Visualizing the spectrum with intensity grading

Intensity grading reveals signal details such as the frequency of the occurrence signal. It can easily detect and distinguish continuous wave signals, random emissions, bursts and pulses.

Commonly occurring frequency components are displayed in a different color to distinguish them from rarer frequency components. This allows you to tell at a glance whether a given emission originates in a clock line with constant frequency or if it is associated with sporadic disturbances:

- Display ▷ Turn on color table

TIP On the actual realtime capture below, in one screen and view, an R&D engineer can immediately ascertain key characteristics such as, but not limited to:

- Average noise floor shown as the intense yellow
- Amplitude of the peaks on both sides of the floor
- Any harmonics in the span
- Signal to noise ratio (SNR)
- Any correlation with time domain signals such as clock and buses

Locate with near-field probe/antenna

Generally, in this particular context, EMI/EMC emissions can be categorized as either current-dominant or voltage-dominant. Current-dominant emissions are usually associated with differential mode conditions and radiate primarily in the magnetic field (H-field). Voltage-dominant emissions are normally associated with common-mode conditions and are detected most strongly in the electro field (E-field). A dominant H-field emission indicates a lower source impedance, whereas a predominantly E-field radiation indicates that the impedance is high.

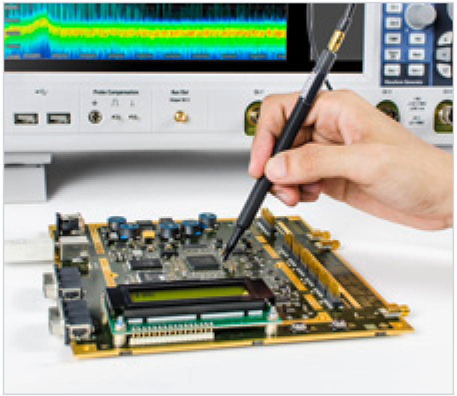
Since the H-field dominant emission fades quicker with distance from the source and would be much more difficult to detect in far-field tests, it is important at this stage to locate these unwanted emissions in the near-field using H-field probes. Despite the fact that the H-field dissipates quicker with distance, it does not eliminate its significant contribution to far-field performance when combined with other emission sources.

Naturally, with the oscilloscope's advantage of the time and frequency realtime single view, the near-field probe should also be used in combination with voltage/current/digital probes on other channels to provide further clarification.

For best results, both H-field and E-field probes can be purchased as a complete set from your local electronics supplier:

- To better locate the emission area, you can start by using a larger loop probe (which has a higher sensitivity over an area)
- Change to a smaller loop probe (which has a higher resolution) to zoom in on the probable interfering culprit(s)
- Rotate the probe to locate the maximum power
- Switch over to an E-field probe to observe voltage-dominant emissions in that area, paying particular attention to traces, IC pins, cables and metal shields

TIP You can easily build your own H-field probe by looping the ground clip to the probe tip.



H-field.

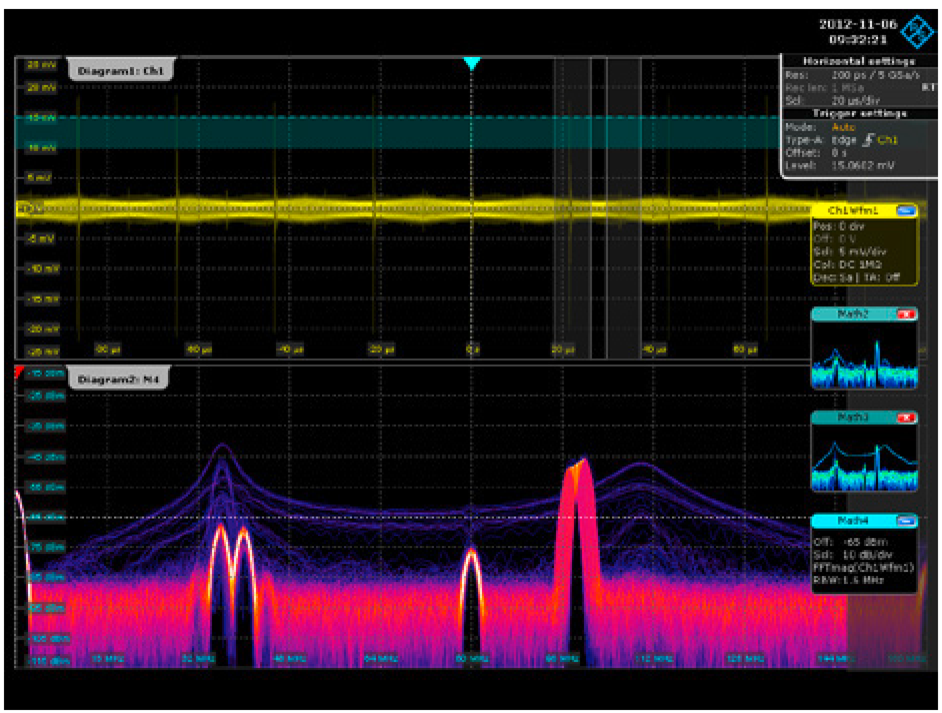
E-field.

Step 2:
Capture the emissions

After determining the physical location of the emissions with the near-field probe, you have to capture the relevant signals. It may be imperative to capture as many signals as possible in a time triggered event such as a specific CAN bus message. Having the ability to define multiple and different types of trigger for time, frequency and digital signals can prove to be extremely useful in determining the cause and effect relationships of all the captured signals.

This section explores some of the key trigger tools of the R&S®RTO/RTE digital oscilloscopes.

Time domain trigger: simple edge trigger setup on the time domain signal such that the related interference from the signal can be captured for later analysis (blue dotted line).



Time domain trigger

This is an important concept that is often neglected since the emissions are usually very weak signals of less than 5 mV/div. An oscilloscope with high sensitivity and ENOB (more than 7 bits) that detects 1 mV/div at full bandwidth must be able to accurately trigger on weak signals. Using a time domain event is the easiest way to correlate with an FFT event:

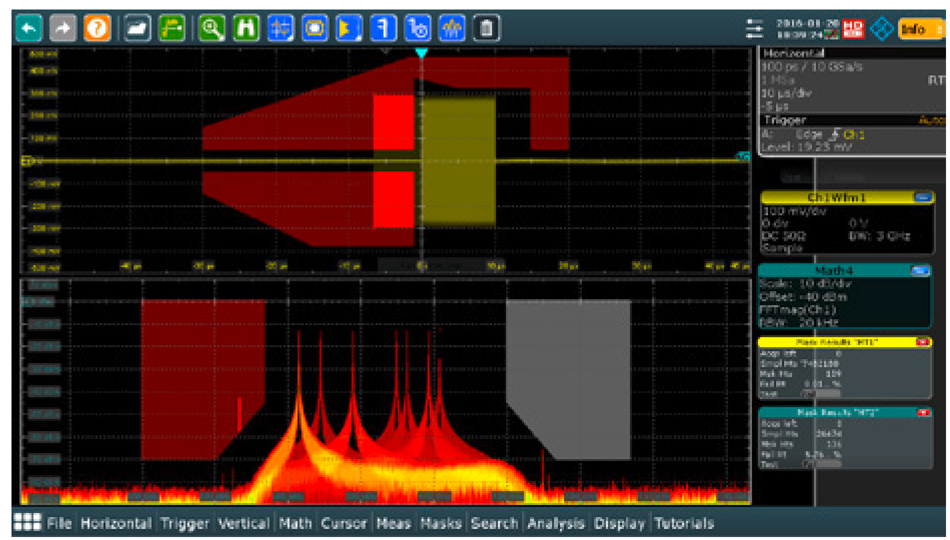
- Observe and see if the time domain signals are strong
- Set a simple edge trigger to trigger the signal whenever it rises above a certain level

Zone trigger

The zone trigger is activated when a signal either intersects or does not intersect the zone – which can be defined by the engineer. This is very useful as you can define areas or zones where you do not expect any signal (in the time domain) or interference (in the frequency domain).

TIP Apply a zone trigger in both the time domain and frequency domain to avoid missing any event regardless of the domain.

Two zone trigger violations: in the time domain (top) and in the frequency domain (bottom), so that we can trigger on the signals whenever they pass the zones.



Mask violation

Similar to the zone trigger, albeit with a slight tweak – the main objective this time is to stop the acquisition upon violation of the mask – it works similarly to the time domain trigger mode in oscilloscopes.

Whenever a portion of the signals crosses into the user-defined mask area, the oscilloscope could either stop acquiring or alert the user with beeps while continuing to acquire.

- Set up zones similar to the zone trigger
- Select event/action ▷ Stop acquisition on violation
- Review and analyze in history mode where you can play back the waveform captured before the signals violated the mask

Serial, parallel and protocol trigger

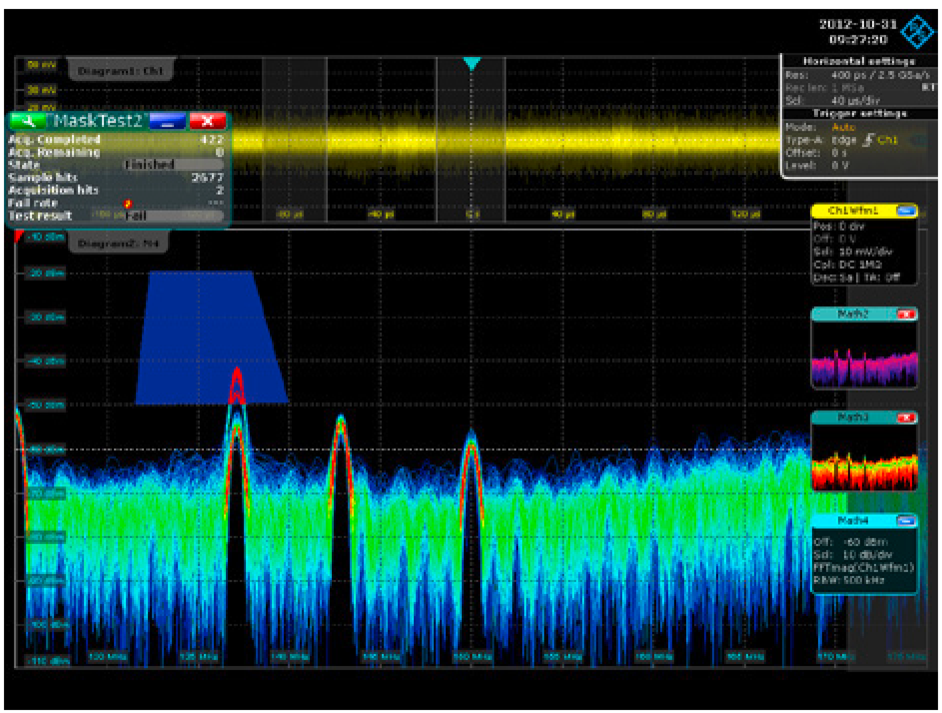
Electromagnetic interference can be introduced by digital data communications signals such as SPI, I²C, CAN or LIN. The repetitive serial data patterns at such TTL levels can easily cause EMI to propagate across the PCB.

In addition, and no less critical, certain specific commands may change the DUT's operating conditions, which could induce undesired interference. Without the ability to trigger on these commands, the engineer would be unable to determine the exact time and nature of the interference.

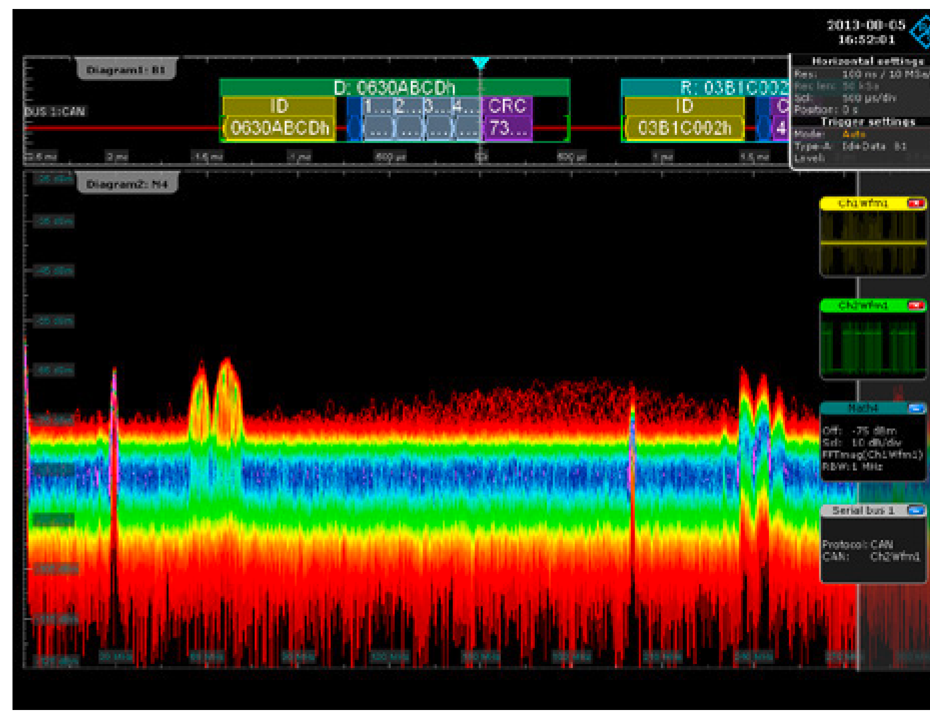
With the R&S®RTO/RTE digital oscilloscopes, the engineer triggers on the particular bus signal's states and logic to observe repeatable emissions on the FFT:

- Set up second channel for triggering and decoding the communications signals (first channel remains connected to near-field probe)
- Apply FFT gating on the near-field signals to observe emissions during communications and without

Failed signals that are violating the mask (blue). You can then go into the history mode to analyze what happened before.



Shows EMI emissions on channel 1, which is connected to near-field probe next to nearby traces, whenever decoded CAN bus (channel 2 on top of the display) is triggered.



Step 3:
Analyze the behavior of the interference

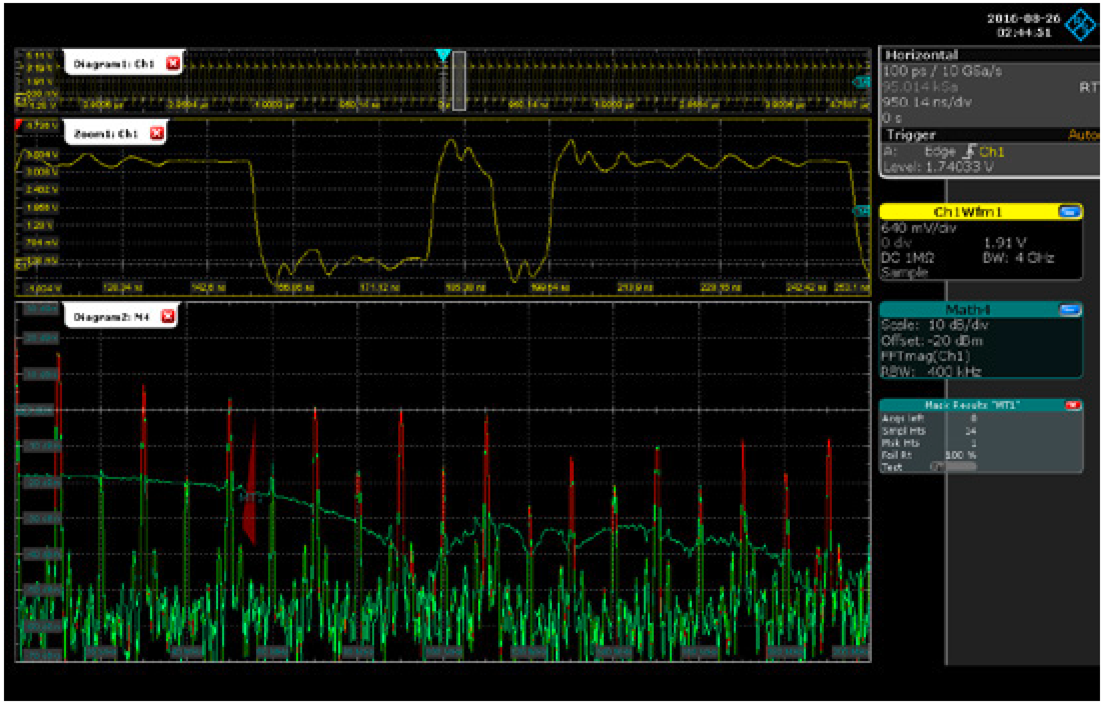
Isolating the exact and actionable source of undesired emission can be the most challenging part of EMI testing. As mentioned previously, one particularly useful feature for EMI testing is the correlated time-frequency analysis which reveals how the signal spectrum evolves over time. This method is often used in complex systems where multiple broadband sources exist, such as switched power supplies with DC/DC converters. In these cases, simply pinpointing the source location is insufficient if it is a periodic signal or harmonics induced by other sources.

Fortunately, the R&S®RTO/RTE digital oscilloscopes offer multiple analysis tools that allow the user to determine the exact behavior of the emissions.

Analyzing narrowband and broadband signals

- Narrowband signals: Check for sidebands using kHz span to identify possible modulations that will help to correlate far-field sources to many possible near-field sources. Determine if sidebands are from AM or FM modulation
- Broadband signals: Using the oscilloscope with FFT gating as discussed previously. Individual switching events can be correlated with the emissions as shown in the screenshot

Analyzing broadband signals in the spectrum provides incredible insights into possible root causes of an emission – in this case a glitch happening between the transitions of the analog signals.



Analyzing emissions with FFT gating

By applying FFT gating, you can reveal how the spectra changes over time. This is useful, for example, when identifying switching events in switched power supplies. FFT gating also helps you easily isolate spurious spectral components in the time domain.

TIP Power sources are some of the larger noise sources, thus the oscilloscope's power harmonic analysis is extremely useful here.

Analyzing correlated interference signal sources

Understanding the complex behavior in embedded RF designs often requires complex test setups and careful calibration. That is where the oscilloscope comes in handy with time-correlated measurements across multiple domains.

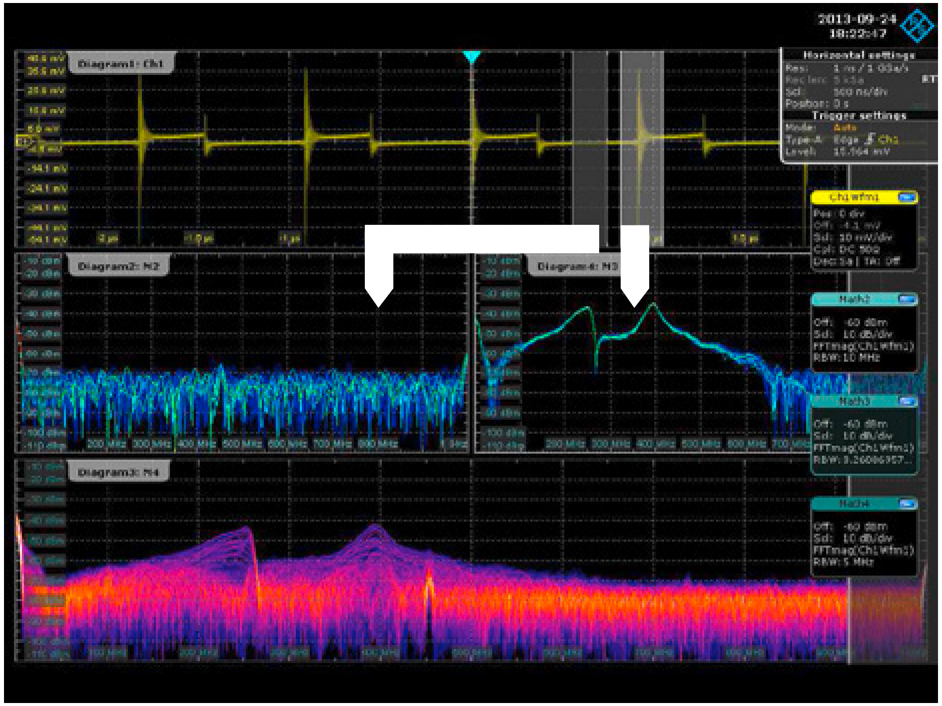
The R&S®RTO/RTE digital oscilloscopes provide realtime mixed signal analysis – analog, digital and RF – without the need for additional dedicated RF channels (e.g. the same channels can be used for both time and RF signals).

Analyzing emissions with the history function

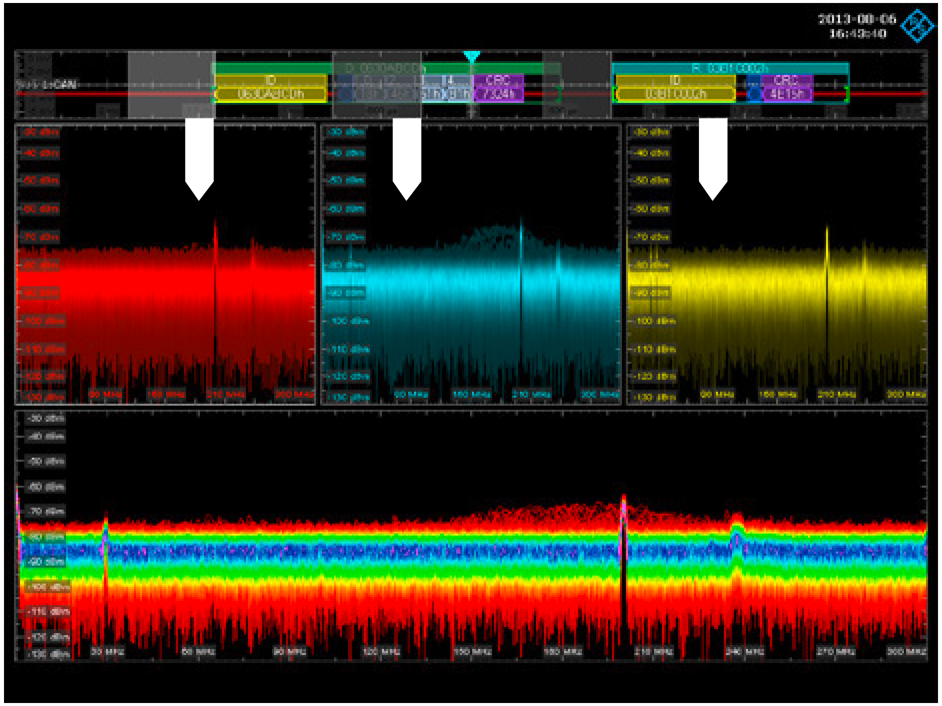
The history function ensures that previous waveforms stored in memory can be accessed. A trigger timestamp allows time correlation. You can view all saved signals and analyze them with tools such as zoom, measurement, math and spectrum analysis functions.

TIP The R&S®RTO/RTE digital oscilloscope stores the interfering time domain signals in memory, which can be used for postprocessing. The acquisitions are stored in memory, and with the history mode you can review and compare signals with earlier acquired waveforms.

Two FFT gating windows: to observe the FFT when there is no switching event resulting in the spike and when there is a switching event. The switching event causes interference to the DUT.



Setup of three different FFT gatings at different time points of the CAN bus on the top display. Blue trace: interference is happening only when communications signals are transmitted.



Conclusion

Designing a product is already a daunting task without increasing the time-to-market pressure. Testing EMI can and should done as early as possible in the product development cycle to avoid large costs and lost market share due to delayed product launches.

Testing EMI requires a different approach than the usual time domain related measurements and other types of general RF tests. Due to the unpredictable interactions of interference sources that may come from one or multiple components on the DUT, it is imperative for R&D engineers to choose the best tools for locating, capturing and analyzing those signals.

Oscilloscopes, spectrum analyzers and test receivers tackle EMI problems from different perspectives and angles. Each offers a different approach and diagnostic techniques that can certainly complement each other at different stages of the product development cycle.

By integrating the use of the ubiquitous oscilloscope at multiple stages throughout the product development cycle with the techniques shown here, engineers can get to market on time without having to invest in additional purpose-specific tools. In this case, using the R&S®RTO/RTE digital oscilloscopes and near-field probes can open up unlimited analysis and testing possibilities.

Instruments for EMI testing, precompliance and compliance

Concept → Design → Prototype → Verify → Preproduction

Design for test | Precompliance | Compliance

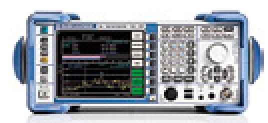
R&S®RTE

R&S®RTO2000

R&S®FPH

Oscilloscopes
- Near-field
- Multichannel FFT and gating
- Time/frequency correlation
- Serial/parallel/protocol correlation

Spectrum analyzer
- Near-field
- Quasi-peak detector
- Interference analysis
- Excellent sensitivity



R&S®ESL

R&S®ESRP

R&S®ESW

R&S®ESR

EMI test receiver
- Conducted and radiated measurements
- Precompliance and compliance in line with CISPR/EN/MIL standards
- High measurement speed
- Highly accurate results

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Sustainable product design
- Environmental compatibility and eco-footprint
- Energy efficiency and low emissions
- Longevity and optimized total cost of ownership

Certified Quality Management
ISO 9001

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Rohde & Schwarz GmbH & Co. KG
www.rohde-schwarz.com

Regional contact
- Europe, Africa, Middle East | +49 89 4129 12345
  customersupport@rohde-schwarz.com
- North America | 1 888 TEST RSA (1 888 837 87 72)
  customer.support@rsa.rohde-schwarz.com
- Latin America | +1 410 910 79 88
  customersupport.la@rohde-schwarz.com
- Asia Pacific | +65 65 13 04 88
  customersupport.asia@rohde-schwarz.com
- China | +86 800 810 82 28 | +86 400 650 58 96
  customersupport.china@rohde-schwarz.com

PD 3607.5348.92 | Version 01.01 | October 2017 (sk)

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3607.5348.92 01.01 PDP 1 en