Application Note

PRECOMPLIANCE EMI DEBUG

Accelerating time-to-market with EMI Debugging & Troubleshooting Simplified

Products:

- R&S®ESRP
- R&S®FSW
- R&S®FSV and FSVA
- R&S®RSVR
- R&S®RTE1000 Series
- R&S®RTO2000 Series
- R&S®ELEKTRA software

Rohde & Schwarz | Version 1.00 | 08.2020

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1 Overview

When it comes to passing the final EMI Compliance test for a new design, the sooner testing begins, the more likely you can address potential issues. The cost to address a problem exponentially rises as the project nears completion. So, designing with EMI in mind can help prevent the first-time EMI compliance test failure rate of 50 to 80%. Save both time and money by learning how to discover & address potential issues early in the design cycle in this webinar.

This paper discusses how to use instruments like a spectrum analyzer and an oscilloscope to help locate, diagnose, and fix EMI or EMC issues with a design. These proactive measurements can result in a more predictable product release schedule, enabling the success critical to today’s competitive market.

2 Introduction

Testing for electromagnetic compliance (EMC) is an essential activity in the development of any electrical or electronic product. Unfortunately, data from leading test labs suggest that half of all products fail formal compliance testing on the first try. Failure to pass at the pre-production stage can lead to cost overruns, launch delays, and revenue shortfalls.

Traditionally, compliance testing has been done using a specialized instrument called an EMI receiver. Testing is performed by qualified test labs, many of which are independent service providers; however, some technology companies maintain in-house labs. Whether external or internal, these labs have finite daily capacity and tend to be heavily booked.

Today, product developers can perform “precompliance” testing on their own using a spectrum analyzer or oscilloscope along with appropriate test accessories and test software programmed with standard-specific procedures and limit lines.

Performing EMI testing during the development process can reveal problems early enough to provide greater flexibility in assessing and applying cost-effective remedies (Figure 1). As a further best practice, occasionally pausing to check for EMI issues during prototyping gives developers multiple opportunities to fine-tune their designs, apply needed fixes, and check the results. This helps avoid the pitfalls of last-minute revisions that tend to be overdesigned and therefore detrimental to project schedule and product cost.

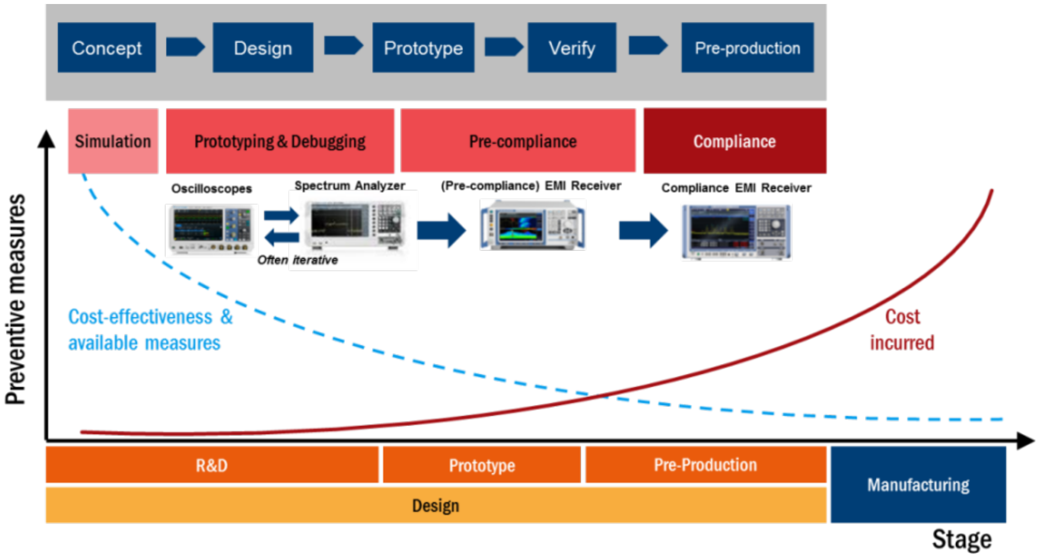


Figure 1: The later EMI problems are found, the fewer the alternatives and the greater the cost of implementation.

To provide a foundation for EMI debugging and troubleshooting, this white paper provides overviews of measurement types and compares compliance and precompliance testing. It then outlines the use of general-purpose spectrum analyzers and oscilloscopes for EMI measurements during product development. It concludes with a brief look at suitable instruments, accessories and software from Rohde & Schwarz (R&S).

3 Standards, Instruments and Measurements

EMC is the umbrella concept. It includes electromagnetic interference (EMI) emanating from a device under test (DUT) and the electromagnetic susceptibility (EMS) of that DUT in the presence of EMI. Interference signals can be conducted through the power mains or radiated through the air (Figure 2).

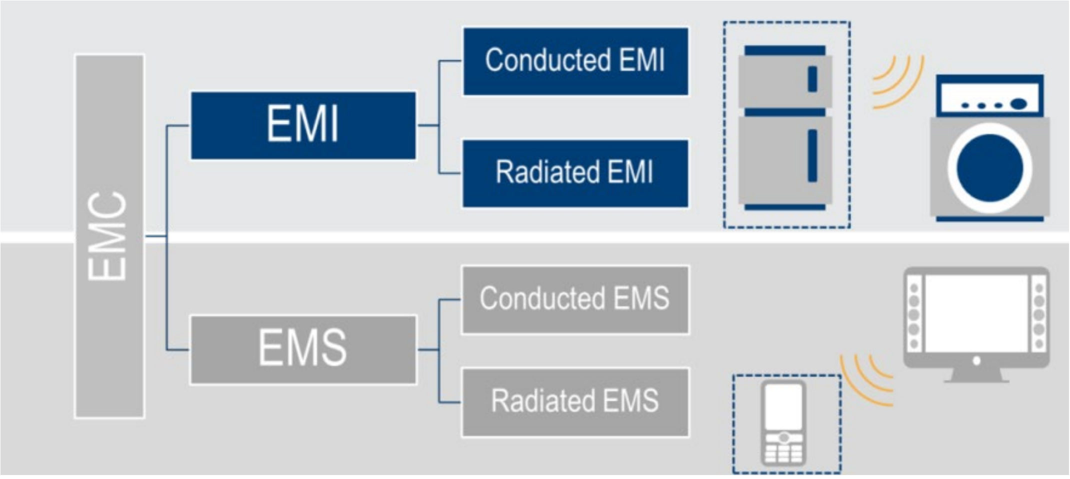


Figure 2: EMC spans EMI and EMS testing of all electrical and electronic products.

EMC applies to all types of electrical or electronic product: appliances, computers, military equipment, smartphones, tablets, and so on. For all, the goal is to pass all of the relevant standards. Certification of compliance is mandatory for every country in which a product will be sold. This adds complexity because the standards vary by country or region. A few examples of the major standards bodies may be immediately familiar:

- International Electrotechnical Commission (IEC)
- Comité International Spécial des Perturbations Radio (CISPR)
- European Committee for Electrotechnical Standardization (CENELEC; EN standards)
- U.S. Federal Communications Commission (FCC)
- United States Military Standard 461 (MIL-STD-461)
- China Compulsory Certification (Gao Biao or GB)
- Bureau of India Standards (BIS)

Around the world, the primary guide is the standard called CISPR 16-1-1, which specifies the equipment requirements for characterizing continuous wave (CW) and pulsed signals originating in a DUT. Thus, there is overlap in the standards; however, each set of regulations has its own sets of tests, procedures, limit lines, and so on. For product developers, understanding which limits apply to a specific DUT will help reveal problems areas, guide troubleshooting, and focus follow-on remediation and testing.

3.1 Analog and digital EMI receivers

An EMI measuring receiver is a calibrated, laboratory-grade instrument designed to provide stable, repeatable results over a wide frequency range. Traditionally, these receivers have been based on analog technology that provides exceptional accuracy, linearity and sensitivity.

Measurements are performed using a stepped frequency scan across the range of interest, and readings are taken with specific intermediate frequency (IF) bandwidths (e.g., 200 Hz, 9 kHz, 120 kHz, 1 MHz) and standardized detector modes (peak, quasi-peak, average, root-mean square (RMS), and more). The use of an input filter called a preselector ensures greater dynamic range by attenuating out-of-band signals.

These high quality instruments tend to produce exceptionally good results. One disadvantage: measurements can be quite time consuming given the wide frequency ranges to be covered and the long settling times of narrow analog filters.

More recently, the governing bodies have ratified the use of digital technologies such as analog-to-digital conversion (ADC), digital filtering, and the fast Fourier transform (FFT) within EMI receivers. Collectively, these technologies can meet or exceed analog performance and, with a capability called time-domain scan, can provide significantly faster test times.

3.2 Focusing on EMI: Conducted and radiated

The block diagram in Figure 3 shows a simplified system configuration for the testing of conducted and radiated EMI (upper and lower paths, respectively). Radiated testing requires specialized antennas or probes to detect signals emanating over the air. Conducted testing requires at least two special transducers. One is a line impedance stabilization network (LISN) that stabilizes AC power to the DUT, filters out unwanted RF signals, and provides a test port for the EMI receiver. The other is an absorbing clamp (or ferrite clamp) that detects interference carried on power cables.

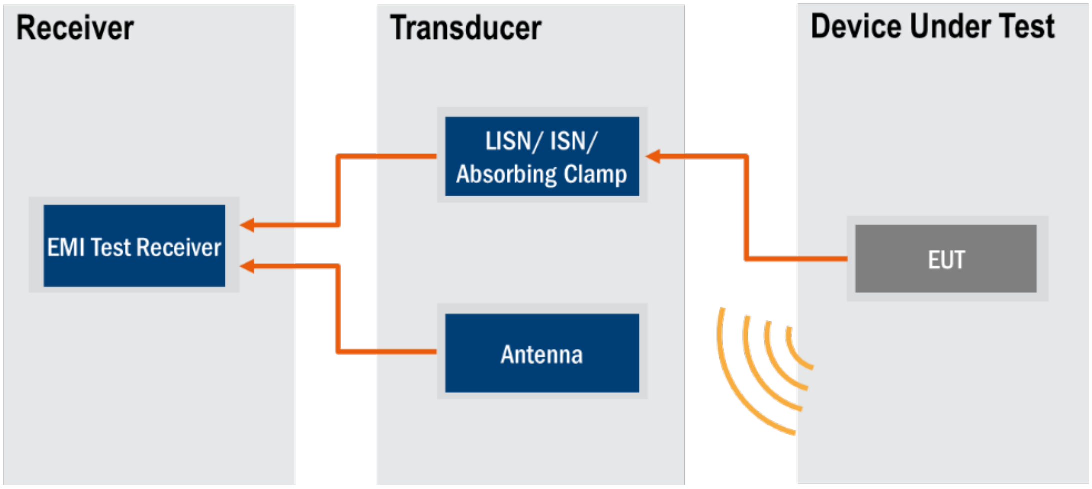


Figure 3: Conducted (upper path) and radiated (lower) EMI testing relies on transducers to provide signals to the EMI test receiver.

Figures 4 and 5 illustrate typical configurations used to perform conducted and radiated testing, respectively. In both cases, a PC running specialized software automates the test procedures, captures test data, and provides reports in the required formats.

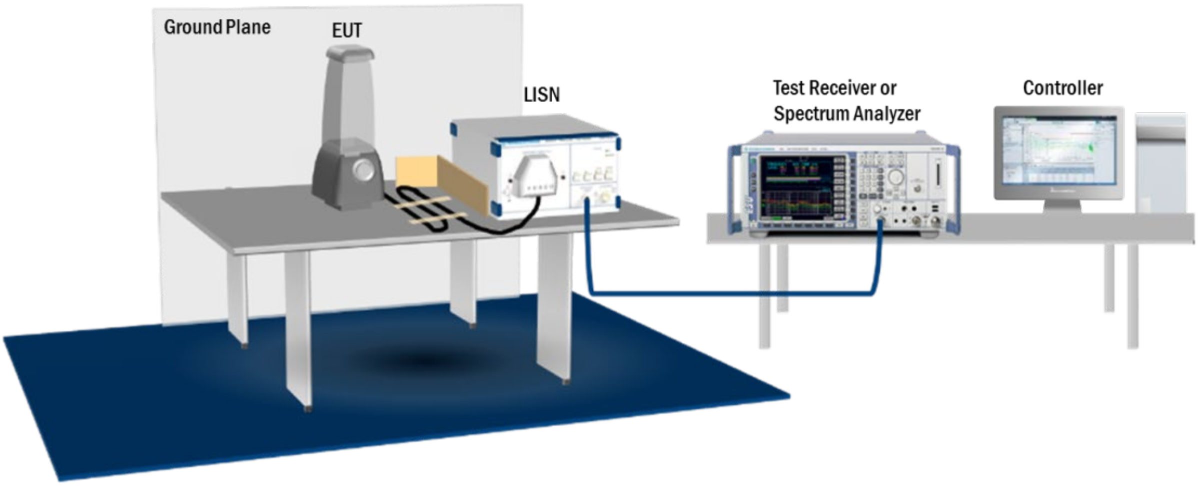


Figure 4: Conducted testing requires an LISN to filter the incoming AC mains, stabilize the line impedance, and provide a measurement port for the EMI test receiver.

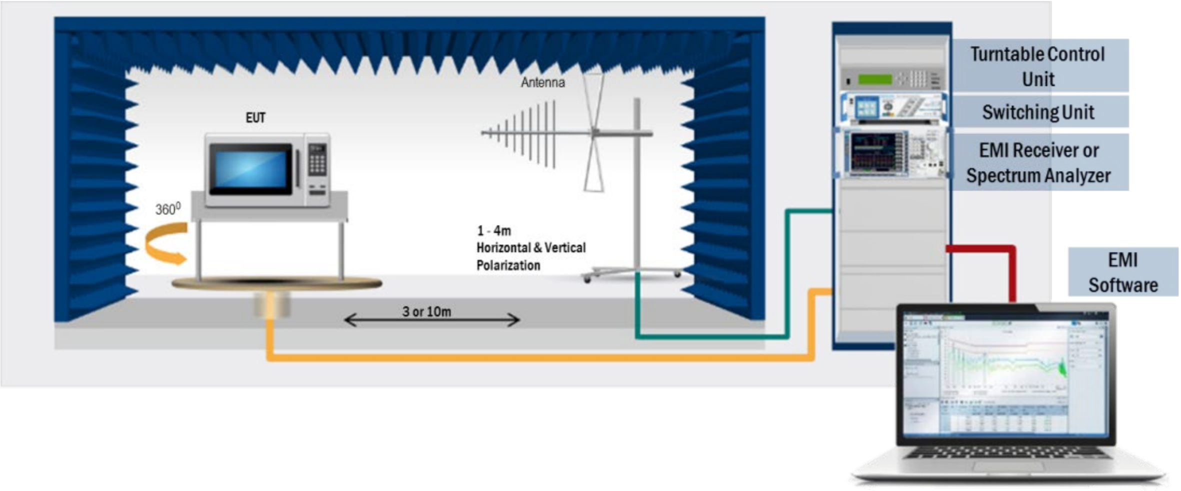


Figure 5: Far-field radiated testing utilizes complex antennas, automated switching and a remotely controlled turntable to perform detailed testing of the DUT.

Referring back to Figure 5, note the RF anechoic chamber used for far-field (1 to 10 m) testing of radiated emissions. These chambers are a major investment that helps ensure valid test results by blocking extraneous RF energy. In contrast, near-field testing can be done with handheld probes, making it easier and more cost-effective for benchtop measurements in the R&D lab.

3.3 Compliance versus precompliance

Compliance testing is a formal certification process carried out by qualified test labs. Some large companies have in-house testing groups that maintain the certification needed to perform standard-compliant testing. Other manufacturers rely on independent service providers that charge as much as $2,500 per day for testing and certification. If the DUT fails, many of these labs also offer for-fee consulting services to help pinpoint EMI sources and suggest possible solutions.

To improve the likelihood of passing compliance testing on the first try, many manufacturers are adding precompliance testing to their product-development process. This type of testing can be performed on the test bench using readily available oscilloscopes or spectrum analyzers. The only additional items needed to produce usable test results are near-field probes (essentially handheld antennas) and purpose-built software that includes the test procedures and limit lines specified by the various standards.

4 Precompliance Testing: Tools & Process

Product developers can perform useful and instructive precompliance testing on their own. Of course, it can be difficult to test with confidence given the large number of emitters that are now commonplace in the workplace: Wi-Fi, Bluetooth, mobile phones and cordless phones as well as radio and TV signals from the surrounding environment. Thus, the most desirable locations are a test chamber or a shielded RF/EMI quiet area.

4.1 The essential tools

As mentioned earlier, a designer can perform these tests using readily available instrumentation along with specialized accessories and software. The preferred instrument is either a digital oscilloscope or a spectrum analyzer (SA).

One key advantage of the digital oscilloscope is its presence on many if not most test benches. Other pluses include multiple measurement channels, time correlation between those channels, and the ability to observe small signals with 1 millivolt/division resolution. Newer-model oscilloscopes also provide versatile display capabilities and an FFT function for analysis in the frequency domain.

An SA offers advantages in dynamic range, input sensitivity and frequency coverage. The key attributes of a suitable SA start with the requisite frequency spectrum display and include the flexibility to scan wide spans to find suspect signals then use narrow spans to zoom in on signal details. Other capabilities that assist EMI debugging include the information-rich spectrogram display (frequency and amplitude versus time) and versatile trace markers. Also, the so-called zero-span mode displays amplitude versus time, enabling observation of the RF power envelope at a specific frequency.

As a detail point, an SA can provide standards-compatible results if it offers emulation of the detectors used in dedicated EMI test receivers. In this case, the so-called quasi-peak detector is especially useful. By definition, quasi-peak means “tending towards but not quite peak.” This lossy filter is believed to be a better indicator of the subjective annoyance level experienced by a listener hearing impulsive interference to an AM radio station.

With either instrument, probes are needed when performing near-field measurements. These are available in two types: E-field and H-field. An E-field probe is a monopole designed to measure electric fields. In contrast, H-field probes are loops designed to measure magnetic fields.

In general, H-field probes provide the best compromise between sensitivity, coverage area and usability. As a result, these are often used first when scanning for offending emitters. An E-field probe can then be used to isolate a specific component.

4.2 A structured process

Within this scenario, a four-step testing process can help ensure results that closely approximate those obtained with a compliant EMI receiver in a qualified test lab. The reference is the relevant test standard and its specified frequency ranges, power levels and test limits. These details are readily available online, and are built into the necessary software (or application) compatible with an advanced oscilloscope or spectrum analyzer.

4.2.1 Step 1: Understand the DUT

The designer knows the product in detail and will be able to answer the critical questions related to the potential for EMI problems:

- What are the clock rates inside the device?
- What are the operating frequencies of any switched-mode power supplies (SMPS)?
- Which harmonics might exist based on those clock rates or operating frequencies?

The second question is especially important because SMPS tend to be common sources of EMI problems.

Narrowing the range of likely offending frequencies produced by the DUT helps accelerate testing. More often than not, the designer will be able to quickly recognize a cardinal frequency or one of its harmonics. This is another argument in favor of early testing: once the design is released to production, other engineers will be responsible for the product and may be much less familiar with its inner workings.

4.2.2 Step 2: Measure the DUT in an RF-quiet location

The ideal case is to make far-field measurements in an isolated test chamber or EMI-quiet location. Another alternative: if forced to work in an RF-noisy location, make baseline measurements with the DUT turned off (and unplugged from AC power, if necessary). Next, store those measurements in SA memory or oscilloscope reference waveform so the ambient signals can be subtracted from measurements of the active DUT. This is not ideal, but can provide a close approximation of the desired far-field results.

Measured emissions are then compared to the relevant standards: Which frequencies exceed the specified power limits? By how much do they exceed the limits? The answers provide clues about the culprit radiators.

4.2.3 Step 3: Understand critical frequencies and signal behavior

In this step, the DUT is tested under a variety of operating conditions: off, power up, powered on, sleep, and so on. Culprit signals may occur at cardinal frequencies or their harmonics, and the goal is to pinpoint those operating conditions in which emissions are close to or above the limit lines.

4.2.4 Step 4: Use near-field probing

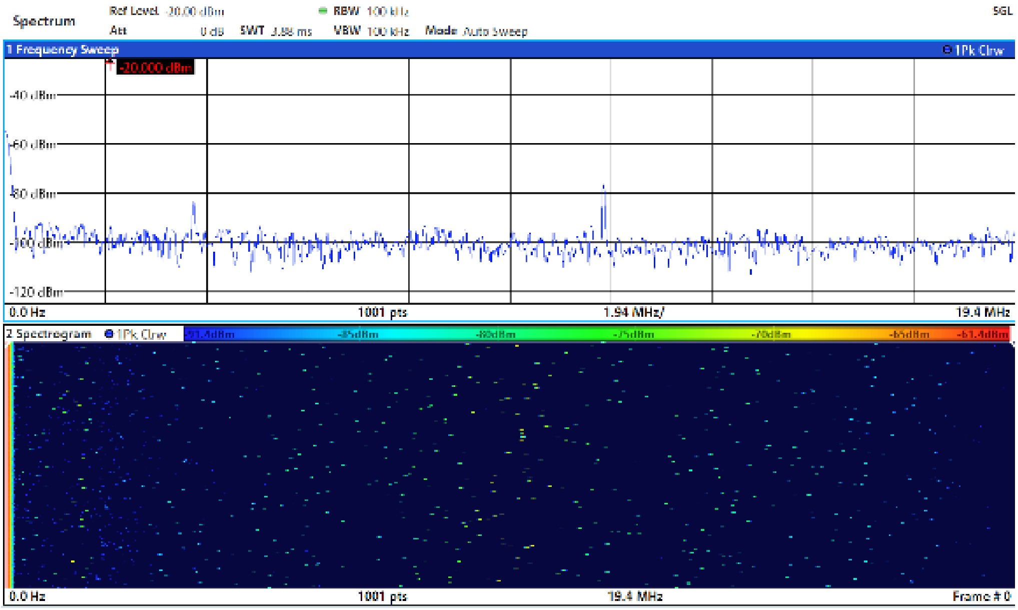
Here, the goal is to identify hotspots and identify the sources of offending EMI emanations. This will benefit from a methodical approach: locate, capture and analyze. More specifically, use a handheld probe to scan the DUT and locate the “loudest” emitters among the individual components on the printed circuit assembly (PCA). Later, periodically repeating this process, especially after any significant design changes, will surface potential issues before the DUT is released to production.

4.3 Examples: Debugging & Troubleshooting

Two examples, one each with an SA and a digital oscilloscope, will help illustrate the types of information that can be gleaned from benchtop measurements.

4.3.1 Using a spectrum analyzer

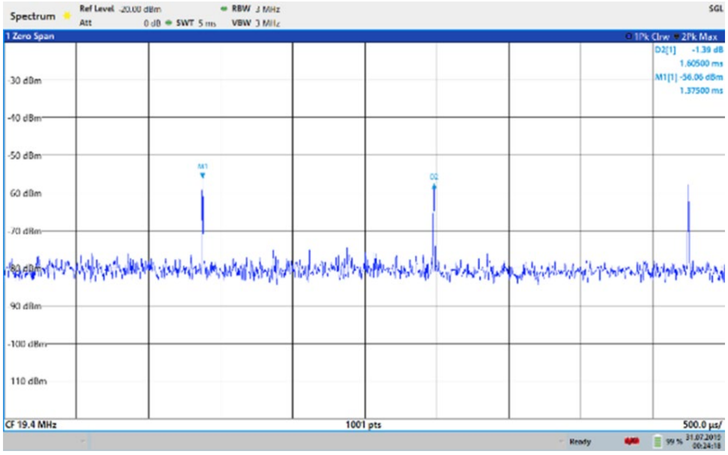
The first example is the exploration of a switching power supply. The first step is to hunt for offending signals that would exceed the limit lines for the standard of interest. While an individual spectrum measurement can be useful, the information-rich spectrogram provides an overview of frequency and power versus time (Figure 6). Observing the spectrogram, markers can be used to find yellow, orange or red peaks that indicate the highest power levels.



Spectrum
Ref Level -20.00 dBm
Att 0 dB
SWT 3.88 ms
RBW 100 kHz
VBW 100 kHz
Mode Auto Sweep

Figure 6: The spectrogram (lower trace) provides an informative view of amplitude (color) versus frequency (horizontal axis) and time (vertical axis). The upper trace is a single frequency spectrum from the spectrogram.

The next step is to use the zero span measurement at the frequency of any signal of interest. A zero span trace shows the RF envelope power versus time (Figure 7). In this case, the frequency of interest is 19.4 MHz and the markers can be used to measure the time between pulses (1.6 ms, the clock period).



Spectrum
Ref Level -20.00 dBm
Att 0 dB
SWT 5 ms
RBW 3 MHz
VBW 3 MHz

D2[1] -1.39 dB
1.60500 ms
M1[1] -56.06 dBm
1.37500 ms

Figure 7: The 1.6 ms time interval between pulses reveals the period of the DUT clock signal.

The third step is to set up a sweep time that is greater than 1,000 times that of the measured time interval (e.g., at least 1.6 seconds). This is long enough to capture enough spectrum points to reveal the pulse. Figure 8 shows the magnitude of the worst-case signal; using a quasi-peak detector would likely show a lower power level. If the peak exceeds the limits of the relevant standard, the final step is to use this information to isolate and attenuate the offending emission.

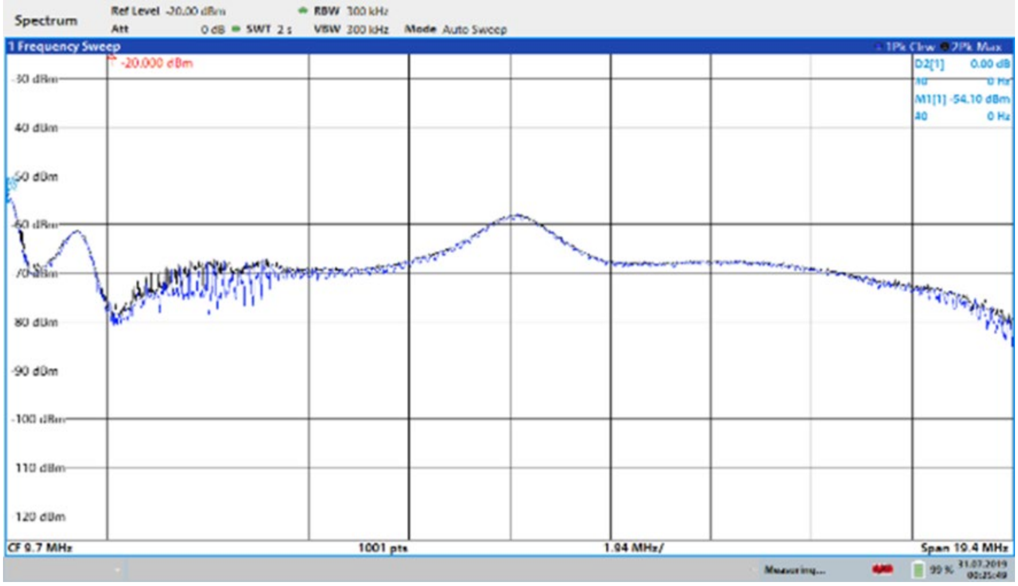

Ref Level -20.00 dBm
Att 0 dB
SWT 2 s
RBW 300 kHz
VBW 300 kHz
Mode Auto Sweep
D2[1] 0.00 dB
M1[1] -54.10 dBm
CF 9.7 MHz
1001 pts
1.94 MHz/
Span 19.4 MHz

Figure 8: Using max hold with the average detector and a two-second sweep time (>1.6 ms X 1000) enables comparisons of the magnitude of the offending signal with the test limits of the relevant EMI standard.

One note: These same measurements can also be performed using a real-time spectrum analyzer (RTSA). The choice of a conventional SA versus an RTSA often comes down to a tradeoff between time, capability and cost.

4.3.2 Using an oscilloscope

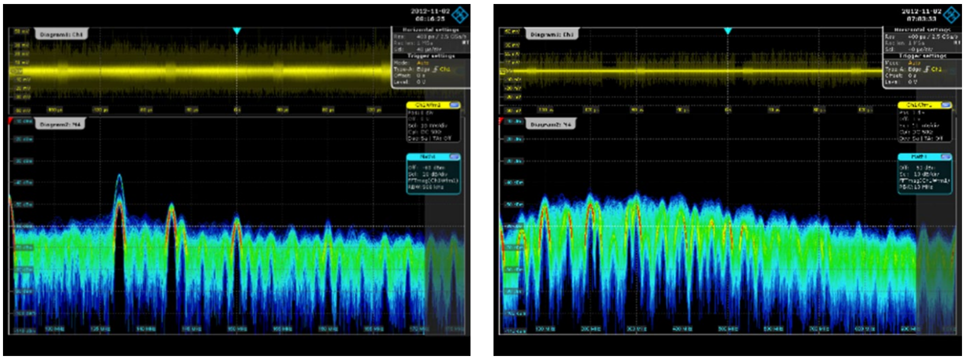
Near-field probing of a PCA is a fast and effective way to track down the source of excessive emissions. In this case, a few example traces will illustrate the differences between successive measurements performed with a digital oscilloscope.

A modern oscilloscope with FFT capabilities provides correlation between time-domain activity and the associated frequency spectra. Figure 9 is an example: the top trace shows a noise chirp (yellow) and the block of time data under analysis (between the white vertical lines); the middle trace is a spectrogram; and the bottom trace is a single frequency spectrum at a specific time within the spectrogram. Frequency-domain results can be displayed in units of dBµV, as used in EMI measurements.

Figure 9: A digital oscilloscope can be used to investigate the correlation between time- and frequency-domain activity.

With this overview of frequency versus time, the next step is to focus on the area of greatest activity. In this case, most of the frequency content occurs below 350 MHz.

Figure 10 shows a succession of measurements made by scanning an H-field probe over a PCA. For the designer, the first trace did not cause any concern because the three most prominent peaks were normal and expected within the design. Moving to a different part of the board, the second trace showed an increase in total spectral content concentrated at lower frequencies. The third trace shows even greater power and a peak at an unexpected frequency (red box). Switching to an E-field probe would help isolate the problem to a specific component, perhaps a switcher, an inductor, a capacitor, or another radiator. With the culprit isolated, possible fixes can be assessed and the best alternative implemented.



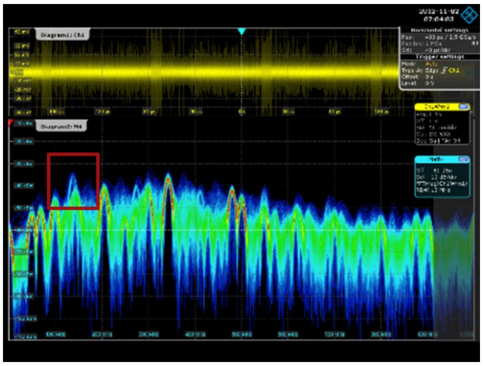


Figure 10: Scanning a PCA with an H-field probe provides informative views of time-domain activity (upper traces) and the associated frequency spectra (lower traces).

Some oscilloscopes provide two additional features that are especially useful during EMI debugging: frequency-mask triggering and FFT gating. Frequency-mask triggering lets the user define a range of thresholds (i.e., an area) that will trigger specific actions: capture a measurement, compute statistics (e.g., number of occurrences), and more (Figure 11). This is a good way to capture intermittent events and track down suspect frequencies of interest.

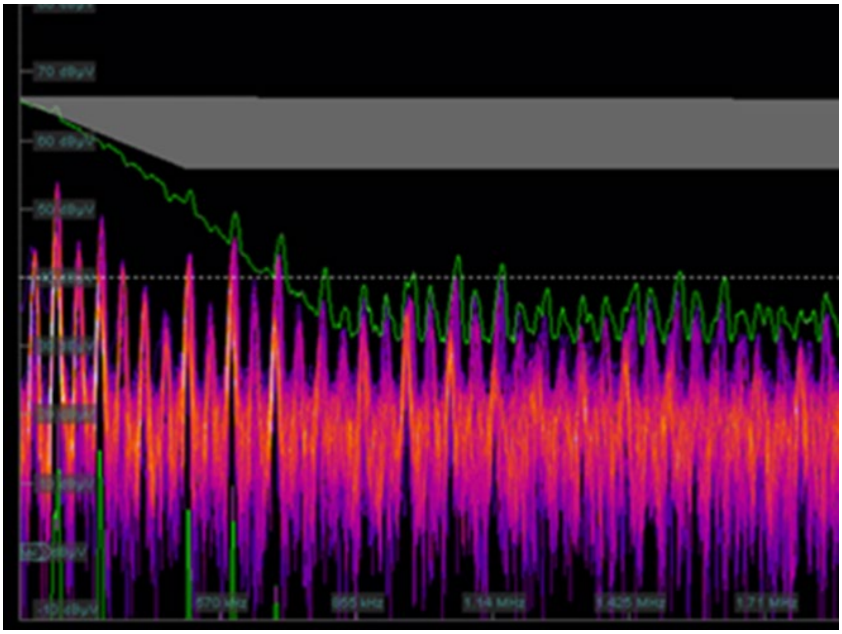


Figure 11: The gray area is a user-defined spectrum mask, and any frequency peak that breaks the threshold will trigger a specific action.

Because oscilloscopes can capture large quantities of time data to memory, the ability to gate an FFT calculation on specific time-domain activity is a powerful way to reveal frequencies of interest. In Figure 12, the upper trace shows two time-domain channels: the green waveform (A) is believed to be the culprit signal, and the yellow trace (B) is the victim. The lower-left trace is a gated FFT of just the burst portion of A; the lower-right trace is a gated FFT in the same region of B. Taking a closer look and comparing the respective FFT results, trace A has greater frequency content at the far right. This suggests the culprit is having an effect on the victim signal.

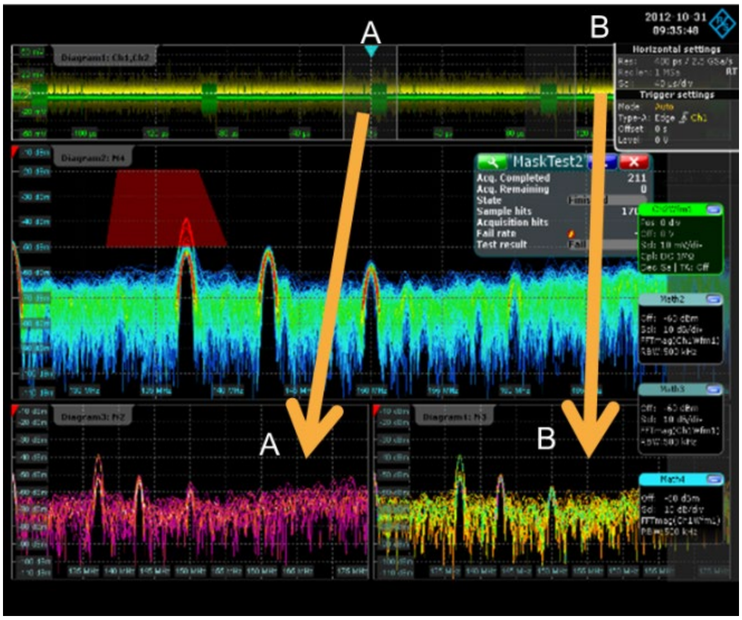


Figure 12: The ability to isolate specific sections of acquired signals and then perform an FFT enhances EMI troubleshooting.

4.3.3 Common problems and possible solutions

During debugging and troubleshooting, four commonly found problems may be the source of EMI issues. Table 1 provides short descriptions of those problems and offers possible solutions.

Problem or suspected culprit	Possible solution or revision
Routing or stacking of signal traces can cause interference between RF and IF signals, clock signals, and serial data lines	Reroute signal paths to avoid stacking or sharp corners Add shielding (expensive, not always preferred) Relocate components to different areas
Sharp corners on signal traces can cause unwanted electromagnetic emissions	Reroute signal paths to avoid stacking or sharp corners Add shielding (expensive, not always preferred)
Board components can have excessive electromagnetic emissions	Place components where EMI will not cause problems Shield components Select different components
Power supplies can emit harmonics that cause conducted emissions on the power line	Add ferrite loop to power cord Choose different power supply

Table 1: The solutions on the right can help resolve four issues commonly found in electronic assemblies.

4.4 Choosing a Solution

In all, there are three possible solutions for debugging and troubleshooting: EMI receivers, spectrum analyzers, and oscilloscopes. It is reasonable to include EMI receivers because models based on digital technologies often include the capabilities of a spectrum or signal analyzer, and these features are useful during troubleshooting. In addition, some EMI receivers are designed specifically for precompliance applications. Table 2 provides a side-by-side comparison of all three types of instruments.

Feature	EMI Receiver	Spectrum Analyzer	Oscilloscope
General purpose RF measurements	Yes, with some digital-based units	Best	Good
Wireless standards (e.g., WLAN, IoT, cellular)	Yes, with some digital-based units	Yes	Yes
Decoding of serial data bus			Best
EMI detectors & bandwidths (including quasi-peak)	Yes	Yes	
Dynamic range & sensitivity for EMI measurements	Very high / Very high	High / Very high	Medium
Log scale & limit lines	Yes	Yes	(Some)
Scan types	All: sweep, step, time-domain, zero-span	Some: sweep, zero-span	None
Correlation of time & frequency	Yes	Yes	Best
Gapless recording	Very long	Long	Medium
Auto-ranging	Yes		

Table 2: Given the capabilities of each alternative, selecting an instrument may come down to the user's preference for working in the time or frequency domain when debugging and troubleshooting.

4.4.1 Rohde & Schwarz Spectrum Analyzers

Specific to Rohde & Schwarz, a few models are especially useful in this application. Starting with R&S spectrum analyzers, the crucial characteristics are frequency coverage to 1 GHz, sufficient dynamic range to see and measure low-level signals, and versatile display capabilities such as the spectrogram.

The R&S catalog includes a full lineup of spectrum analyzers, ranging from handheld to economy class to high performance. The following models are widely used for EMI debugging and troubleshooting:

- **R&S®ESRP EMI test receiver:** Designed for lab use and precompliance testing, the ESRP measures EMI disturbances using either conventional stepped frequency scan or the much faster FFT-based time-domain scan. It also provides full-featured spectrum and signal analyzer capabilities. Covers 10 Hz to 7 GHz.
- **R&S®FSW signal and spectrum analyzers:** These high-performance instruments help engineers accomplish the most demanding tasks. The 2 GHz analysis bandwidth (internal) enables the characterization of wideband components and communications systems. Covers 2 Hz up to 67 GHz.
- **R&S®FSV and FSVA signal and spectrum analyzers:** These versatile signal and spectrum analyzers address general-purpose measurement tasks. Analysis bandwidth of up to up to 160 MHz supports measurements of components, chipsets and base stations. Covers 10 Hz up to 40 GHz.
- **R&S®FSVR real-time spectrum analyzers:** Combining conventional and real-time spectrum analysis in a single instrument, the FSVR series seamlessly captures even the briefest events for measurement and analysis. Covers 10 Hz up to 40 GHz.

The FSW, FSV, FSVA and FSVR are available with Option K54, an EMI precompliance application. This is the ideal extension for EMI analysis during product development and when preparing for product certification. Supported standards include CISPR, EN (CENELEC), FCC, MIL-STD-461, and DO-160 (avionics hardware).

4.4.2 Rohde & Schwarz Oscilloscopes

The most applicable oscilloscope models include those with versatile display capabilities and FFT functions. Two models are especially well suited to EMI precompliance applications:

- **R&S®RTE1000 Series oscilloscopes:** This fully integrated multi-domain test solution offers time, frequency, protocol, and logic analysis functions. Flexible enough for embedded design development, power electronics analysis, and general debugging, the RTE1000 handles everyday measurement challenges quickly, accurately and easily. Maximum bandwidth: 2 GHz.
- **R&S®RTO2000 Series oscilloscopes:** These instruments excel at time- and frequency-domain testing. With excellent signal fidelity, the responsiveness of 1M waveforms per second, and vertical resolution of up to 16 bits, the RTO2000 enables confidence in measurements. Maximum bandwidth: 6 GHz.

4.4.3 Rohde & Schwarz Software

R&S®ELEKTRA EMI test software combines the essential requirements for EMI disturbance measurements into an easy-to-use application (Figure 13). It supports R&S EMI measuring receivers, spectrum analyzers and oscilloscopes (requires R&S®ELEMS-SCP oscilloscope drivers). Tried-and-tested measurement procedures ensure reliable results and, to simplify configuration, the software includes test templates with relevant limit lines and transducer correction factors.

Figure 13: A simplified and dedicated version of the R&S® ELEKTRA software (R&S®ELEMI-E) addresses EMI precompliance testing, covering the most common EMI standards with predefined templates.

4.4.4 Rohde & Schwarz accessories

When making radiated EMI measurements, antennas and probes are needed for far-field and near-field tests, respectively. Here is a brief listing of those that provide the best balance of performance and cost effectiveness for EMI debugging and troubleshooting:

- **Directional antenna:** The R&S®HL223, a Yagi antenna, provides frequency coverage from 200 MHz to 1.3 GHz, sufficient for most commercial EMI applications (up to 1 GHz).
- **Biconical antenna:** To cover lower frequencies, the R&S®HK116E can handle 20 MHz to 300 MHz.
- **Probes and preamps:** R&S®HZ-15 probe set includes five passive near-field probes, two E-field and three H-field. When probing low-level signals, the R&S®HZ-16 preamplifier increases measurement sensitivity.

5 Conclusion

Informative EMI testing can be performed during the product development cycle. As a best practice, testing early and often can reveal problems when a wider range of cost-effective remedies can be considered and applied. This increases the likelihood of passing formal compliance testing on the first try, thereby avoiding launch delays, cost increases, and lost revenues.

Meaningful EMI debugging and troubleshooting can be performed with an oscilloscope, a spectrum analyzer, an EMI test receiver or, when available, a combination of all three. During precompliance testing on the lab bench, near-field probes will accelerate the process of tracking down hotspots and offending emitters.

Because R&S personnel participate in the various responsible committees, our products are always current with the latest testing requirements. R&S is also the leader in providing full compliance receivers and systems, and this expertise extends into competitively priced R&S instruments that can fit most budgets.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

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