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2020 EMC TESTING GUIDE

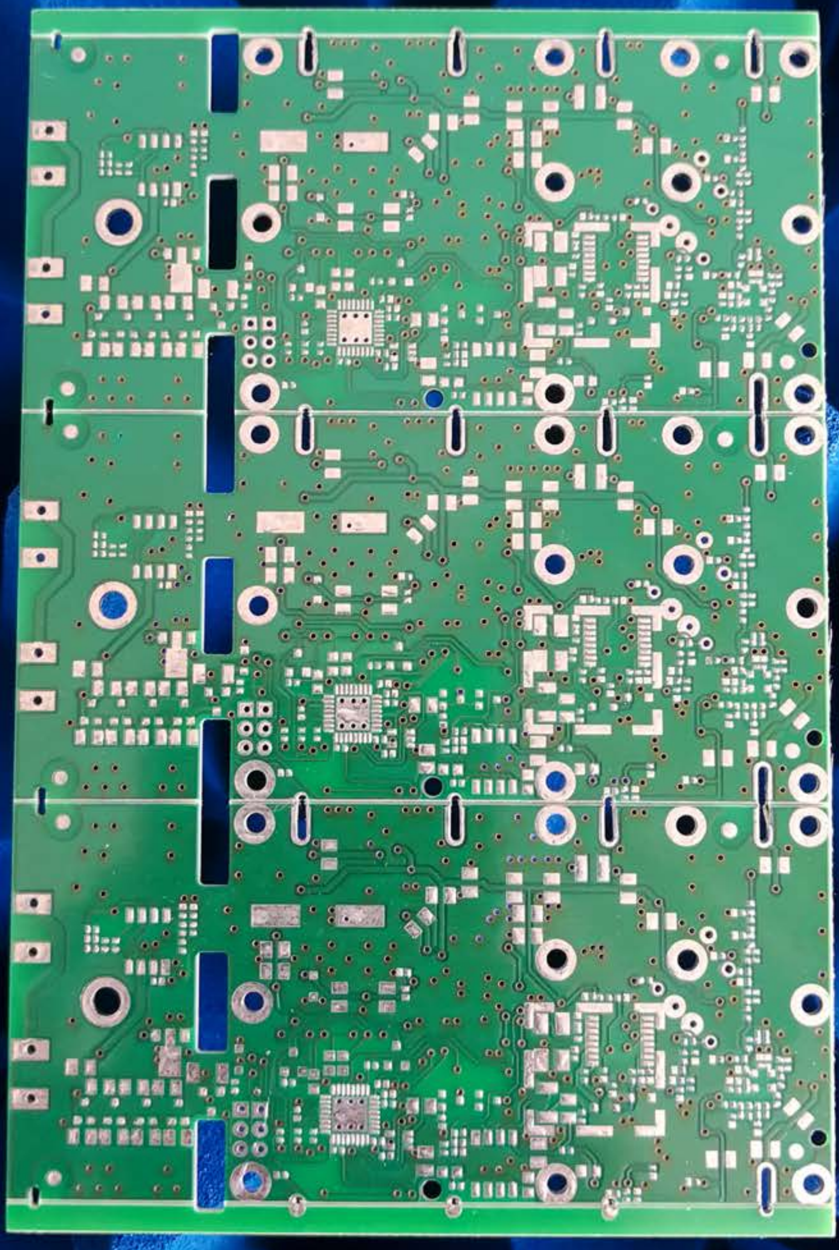

TABLE OF CONTENTS

INTRODUCTION

Jennifer Arroyo
Editorial Director, *Interference Technology*

Hello, and welcome to the 2020 edition of the EMC Testing Guide from *Interference Technology*. We hope you enjoy the informative articles and helpful resources and references we have featured in this guide.

Testing is an integral part of the engineering and manufacturing process. Electromagnetic compatibility (EMC) testing, in particular, is important as electromagnetic interference (EMI) is often overlooked during the design phase of an electronic device. This oversight will often come back to haunt engineers at the testing phase with delays and added costs.

The articles included in this year's guide speak to EMC testing and planning. "EMC Test Equipment Selection and Sizing," by Flynn Lawrence, explains the factors to consider when selecting test equipment for EMC, including the test requirements and equipment parameters.

Next up, we have "Flexibility Key to Trends in EMI Pre-Compliance Debugging," by Chris Armstrong, which centers on pre-compliance testing for electronic and wireless products.

We round out our articles with "Case Study: Poor PC Board Layout Causes Radiated Emissions," by James Pawson, which delivers an overview on the radiated emissions fault finding process.

Finally, I wanted to note the new downloadable EMC guides we've produced last year. If you visit our homepage, you'll see the list of guides. Some of the more popular ones include Military/Aerospace, Automotive, Wireless & IoT, and EMC Fundamentals.

Cheers,

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EMC EQUIPMENT MANUFACTURERS SUPPLIER MATRIX

Introduction

The following chart is a quick reference guide of test equipment and includes everything you'll need from the bare minimum required for key evaluation testing, probing, and troubleshooting, to setting up a full in-house precompliance or full compliance test lab. The list includes amplifiers, antennas, current probes, ESD simulators, LISNs, near field probes, RF signal generators, spectrum analyzers, EMI receivers, and TEM cells. Equipment rental companies are also listed. The products listed can help you evaluate radiated and conducted emissions, radiated and conducted immunity, and a host of other immunity tests, such as ESD and EFT.

EMC Equipment Manufacturers Supplier Matrix		Type of Product/Service												
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
A.H. Systems	www.ahsystems.com	X	X		X						X			
Aaronia AG	www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	www.atecorp.com/category/emc-compliance-esd-rfi-emi.aspx	X	X			X	X	X	X	X	X		X	X
AR RF/Microwave Instrumentation	www.arworld.us	X	X			X		X	X	X	X			X
Anritsu	www.anritsu.com					X					X			X
BHD Test and Measurement	www.bhdtm.com		X			X	X	X	X	X	X		X	X
Compliance Worldwide	www.complianceworldwide.com								X	X	X			
CPI	www.cpii.com	X	X			X								
Electro Rent	www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	www.emtest.com/home.php									X	X	X		
EMC Partner	www.emc-partner.com						X			X				
Empower RF Systems	www.empowerrf.com		X						X					
Exodus Advanced Communications	www.exoduscomm.com		X											
F2 Labs	www.f2labs.com								X	X	X			
Gauss Instruments	www.gauss-instruments.com/en/					X								
Haefley-Hippotronics	www.haefely-hipotronics.com						X			X				
Instruments For Industry (IFI)	www.ifi.com		X						X	X				

EMC Equipment Manufacturers Supplier Matrix		Type of Product/Service												
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
ITG Technologies, Inc.	www.itg-electronics.com		X											
Kent Electronics	www.wa5vjb.com	X												
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng			X		X		X			X			X
Microlease	www.microlease.com/us/home		X			X	X	X	X	X	X		X	X
Milmega	www.milmega.co.uk		X						X	X				
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X			X		X	X	X	X			
Noiseken	www.noiseken.com						X			X	X			
Ophir RF	www.ophirrf.com		X							X				
Pearson Electronics	www.pearsonelectronics.com				X									
PPM Test	www.ppmtest.com	X			X						X			
Rigol Technologies	www.rigolna.com			X	X	X					X			X
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	www.siglentamerica.com			X		X					X			X
Signal Hound	www.signalhound.com			X		X					X			X
Solar Electronics	www.solar-emc.com	X			X		X	X		X				
TekBox Technologies	www.tekbox.com		X	X				X			X	X		
Tektronix	www.tek.com			X		X					X			
Teseq	www.teseq.com/en/index.php		X		X		X		X	X	X	X		
Test Equity	www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thermo Keytek	www.thermofisher.com/us/en/home.html						X			X				
Thurlby Thandar (AIM-TTi)	www.aimtti.us					X					X			X
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	www.rf-consultant.com													X
Transient Specialists	www.transientspecialists.com								X	X		X		
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	www.vectawave.com		X											
Windfreak Technologies	www.windfreaktech.com													X

EMC TEST EQUIPMENT SELECTION AND SIZING

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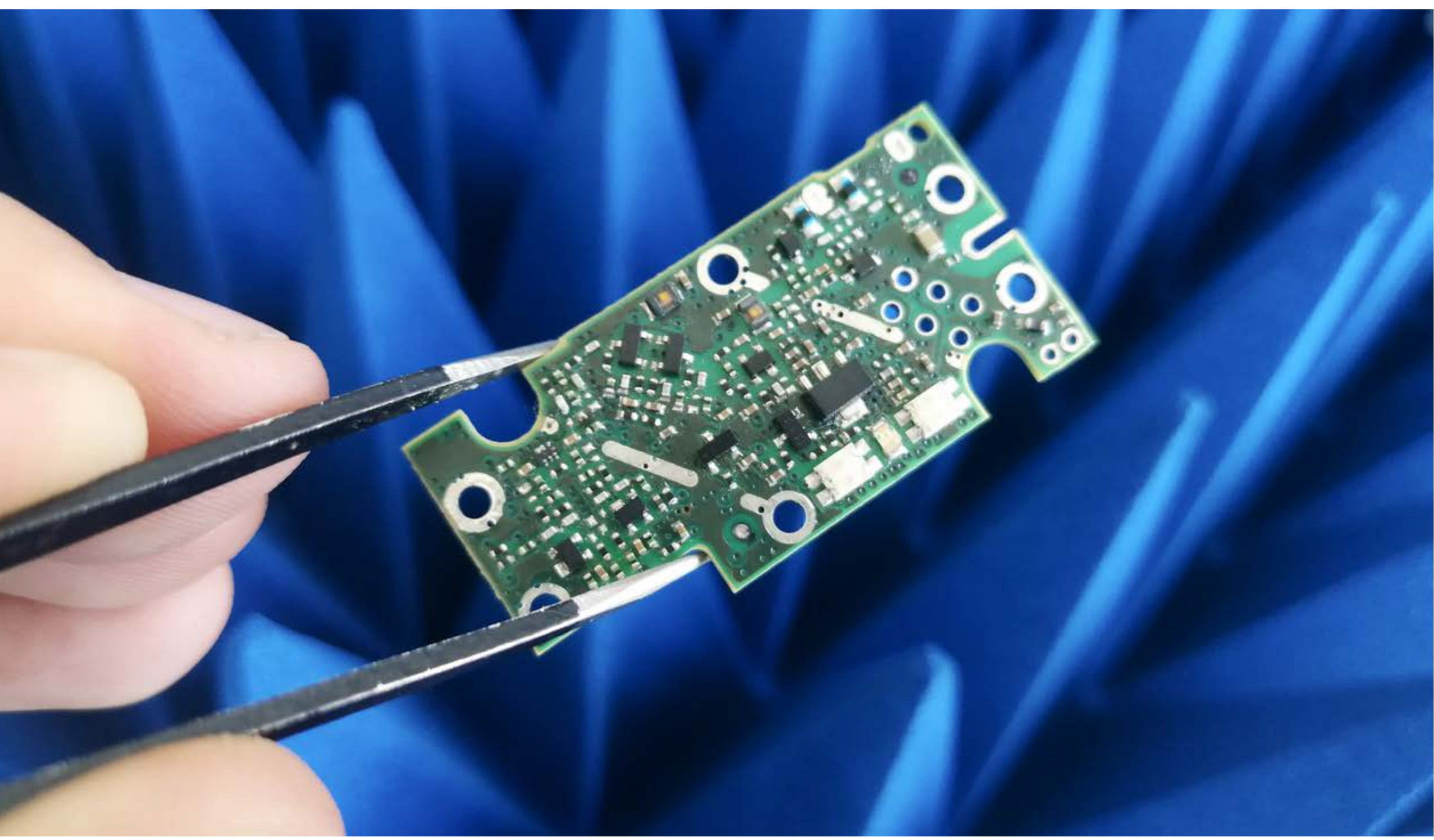
Abstract: *Explosive growth in technologies like portable electronics, Internet of Things (IoT) devices, and autonomous vehicles has led to a world full of electromagnetic interference. Efficient EMC testing is more critical than ever, and is dependent on high-quality test equipment. Historically, not a lot of education has been provided on the careful considerations needed for determining and selecting the proper quality test equipment demanded for this testing. This paper walks through the important considerations for selecting test equipment, specifically for EMC testing.*

Keywords: *amplifier, power amplifier, EMC, testing, RF, microwave, solid state*



EMC TEST EQUIPMENT SELECTION AND SIZING

Introduction

Electromagnetic compatibility (EMC) testing has been around for decades and will continue as long as there are electronic devices in use. What has become apparent, is that the need for EMC testing has continued to grow nearly exponentially throughout its existence. Test environments and requirements across all industries continue to evolve at a rapid pace. While this rapid growth certainly drives the need for new and additional test equipment to accommodate new requirements, the growth also drives the need for educated and experienced EMC engineers and test personnel.

The problem is that this growth tends to outpace available EMC resources. It is not uncommon to see engineers and technicians with little or no EMC test experience thrust into positions that even a seasoned EMC engineer could have difficulty with. Again, formal EMC education is not always readily available to some organizations and test programs often don't have the available time for someone to get up to speed. That said, this paper is intended to examine the thought process behind selecting and sizing appropriate test equipment when the need arises. There are numerous types of EMC testing, which require numerous types of test equipment. Significant amounts of time could be spent on each one of these tests, but in the interest of brevity, we will focus the efforts of this paper on radiated immunity (RI) and RF conducted immunity (CI).

Defining Test Requirements

The first step in selecting the proper equipment for RI and CI testing is to understand the requirements of the test itself. Across all industries, RI and CI testing share a lot of commonalities. However, when you dive into the respective test standards, you begin to realize that there are, in fact, some significant differences. An example of these differences for RI can be seen in *Table 1*. This table is not intended to be comprehensive; however, it does identify some of the key differences between some of the more common test standards in today's electronics marketplace.

To the uninitiated, some of these differences may not seem that drastic. For example, looking at the cost of an amplifier needed for 200 V/m testing at a 1 meter test distance versus the cost of an amplifier for 200 V/m testing at 2 meters, one might change their mind. Another example involves required modulations. Sizing equipment for a 10 V/m MIL-STD-461 RS103 system may not be sufficient to use for a 10 V/m IEC 61000-4-3 system. The reason is that IEC 61000-4-3 requires a 1 kHz, 80% amplitude modulated signal. This type of modulation increases the overall amplitude of the signal, if not adjusted as in the case of other standards. Therefore, this test would need to be calibrated at 18 V/m, rather than just 10 V/m. This brings up another key difference between these two test standards. IEC uses what's termed a 'substitution method' of testing, where the intended field must be calibrated prior to running a test. In this case, field probes are not used during test. Conversely, MIL-STD-461 allows the use of field probes to actively measure the field during testing, negating the need for calibration.

Again, these are examples and the list could go on and on. The important takeaway here is to ensure that the test requirements are fully realized and understood prior to investigating test equipment. Purchasing the wrong test equipment can prove to be a costly mistake in terms of lost test time and overall expenditures.

Table 1 – Example Differences Between Common RI Standards

Radiated Immunity	Frequency	Test Level	Modulation	Distance	Leveling Method
IEC 61000-4-3 ed 3.0 2006	80MHz-6GHz, product and usage dependent.	1-30V/m, and Special.	1kHz AM, 80% Calibrate CW at 1.8x target field level.	3m recommended; 1m minimum	substitution
MIL-STD-461, RS103 components and subsystems	30MHz-18GHz required 2MHz-40GHz optional extended	5 - 200V/m, application dependent	1kHz 50% duty PM	1m, or greater	closed loop
DO-160G Section 20.5 (Anechoic Chamber Method) 2010	100MHz-18GHz	1-490 V/m CW, 150-7200V/m Pulse; Category and freq dependent	CW, and Pulse	1m, or greater. Allows <1m at high freqs if far-field	substitution
ISO 11451-2:2015 Fourth edition Road vehicles vehicle test methods, Off-vehicle external radiation sources	10kHz - 18GHz	user defined; 20-100V/m typical, frequency and Test Level Category dependent; or Custom	CW 10kHz - 18GHz AM 1kHz 80% 10kHz - 800MHz PM 577us, 4600us period 800MHz - 1.2GHz PM 577us, 4600us period 1.4GHz - 2.7GHz PM 3us, 3333 us period 1.2GHz - 1.4GHz PM 3us, 3333 us period 2.7GHz - 18GHz Peak Conservation/Constant Peak	no part of radiating antenna closer than 0.5m; antenna phase center ≥2m horizontally from reference point.	substitution
ISO 11452-2 3rd edition Jan 2019; component test	80MHz - 18GHz	user defined; 25-100V/m typical, frequency and Test Level Category dependent; or Custom	CW 80MHz - 18GHz AM 1kHz 80% 80MHz - 800MHz PM 577us, 4600us period 800MHz - 18GHz Peak Conservation/Constant Peak	1m	substitution

Table 1: Example Differences Between Common RI Standards.

Component Category Considerations

Once you are clear on what your test requirements are, you can start considering your options for test equipment. As a matter of staying organized, we will break down equipment according to various categories here.

A. Amplifiers

The foundation for proper amplifier selection is in under-standing critical amplifier specifications. Amplifiers have a broad spectrum of specification parameters. Each of these parameters certainly has relevance for various applications, however, there are a few key parameters to keep in mind relating to EMC testing.

First, let's look at power. When looking at an amplifier spec sheet, you may see various definitions of power like rated power, P^{sat}, P1dB, and so on. *Figure 1* shows an example of the various power levels of a 500 watt (rated power) amplifier.

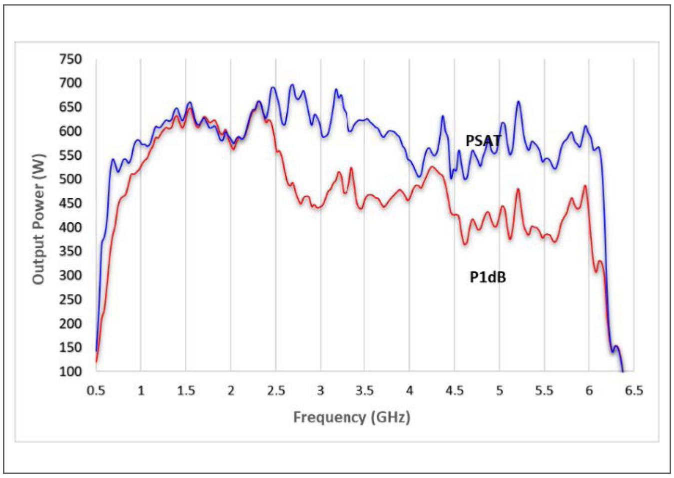


Figure 1: Various Power Ratings of a 500 Watt Amplifier

P1dB refers to the amp's 1 dB compression point. This is the power level where, theoretically, a 10 dB increase in input power produces a 9 dB increase in output power. Effectively, the P1dB power is the top end of the amplifier's linear region. Beyond the P1dB point, the amplifier will go further into compression. What this means to an EMC engineer, is that up to the P1dB point, the amplifier will operate within its linear region. This is important when testing to standards that have linearity requirements. For example, IEC 61000-4-3, the test method used for testing most commercial electronic products in today's marketplace has a specific test as part of its calibration routine to verify that the amplifier used is operating in its linear region. If the amp is not, the test system fails calibration and cannot be used. If this is the test method you're designing your system around, it would be wise to size your amplifiers according to their P1dB specification.

P^{sat} is a common nomenclature for saturated power. Here, the amplifier is outside of its linear region, and an increase in input power will have no increase in output power. As we just discussed, P^{sat} would not be the best choice for sizing an amplifier if you're testing commercial products. However, many other test standards do not have such stringent linearity requirements. Standards like MIL-STD-461, DO-160, and ISO 11451/11452 for the military, aviation, and automotive industries respectively, fall into this category. In these cases, it would be acceptable to size an amplifier according to its P^{sat}.

The last power definition we'll touch on is rated power. The most important thing to remember about rated power is that there is no 'textbook' definition for rated power. It is a manufacturer-specific definition. One manufacturer may consider their rated power to be P^{sat}, another may use P1dB, and another may use an entirely different definition. A 1,000 watt amplifier from Company A is not necessarily the same as a 1,000 watt amplifier from Company B. The point is, when looking at the rated power of an amplifier, it's extremely important to understand the manufacturer's definition of rated power.

Regardless of the definition of power you're considering, it is always important to add margin onto what you think you need. In EMC testing, there are always unknowns. Poorly matched transducers, chamber loading/reflections, poor cables, and many more factors can result in the need for more power than expected.

Another important amplifier parameter to consider is amplifier harmonics. Harmonics are unwanted signals occurring at multiples of the fundamental frequency, and are an inherent type of distortion to all amplifiers. In EMC testing, it's important to limit this type of distortion for two key reasons (among others). One being the repeatability of a test. RI and CI tests are swept in frequency and equipment under test (EUTs) are tested at a single frequency at a time, unless you are testing using multi-tone methodology. If an EUT fails and there is a great amount of harmonic distortion, it may not be clear whether the EUT failed as a result of the incident fundamental frequency or from one of its harmonics. A second reason is due to the prevalence of broadband measurement equipment. In most cases, EMC tests utilize broadband power meters to measure amplifier power and broadband field probes to measure the generated electric field. These types of devices are not frequency-selective and therefore cannot differentiate between a fundamental and harmonic signal. Additionally, if the EUT is a broadband device it may also fail as a result of the total spectrum power, including the fundamental and harmonics, rather than failing from any single signal.

Lastly, we'll briefly discuss mismatch tolerance. Mismatch tolerance is the ability of an amplifier to handle unmatched loads, and thus varying amounts of reflected power. In EMC applications, especially at lower frequencies, transducers (antennas/clamps/etc.) can be a very poor match to 50 Ohms (typical nominal output impedance of RF amplifiers). Field reflections/standing waves can cause significant reflected power as well. During test, it is important to continue to deliver forward power as well as protect the amp from reflected power damage.

B. Antennas

Similar to amplifiers, antennas have many specification parameters, and certain parameters are more relevant in relation to EMC testing. When choosing equipment for radiated immunity, proper antenna selection is critical. Selecting the wrong antenna could mean limited exposure areas, insufficient fields, and other problems.

The first, and possibly most important, parameter to consider is the measured field strength of an antenna. This is empirical data of electric field strength produced by a given input power. This is highly useful for determining amp/antenna combinations for target immunity field strengths. Again, it's very important to size the amp with margin (6 dB is good target, 3 dB minimum) as non-free space conditions can contribute considerable loss (not just cables!). Measured data can be scaled for other power inputs. Also, the measured field is typically lowest at the lowest operable frequency, corresponding to the lowest antenna gain. Keep in mind that test distance greatly affects field strength. *Figures 2* and *3* show the measured field strength of a horn antenna at both 1 meter and 3 meter test distances. The difference caused by gain is apparent.

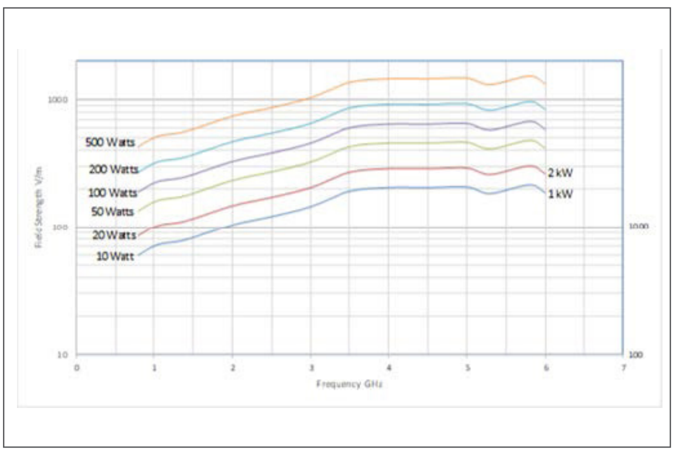


Figure 2: Measured Field Strength at 1 Meter.

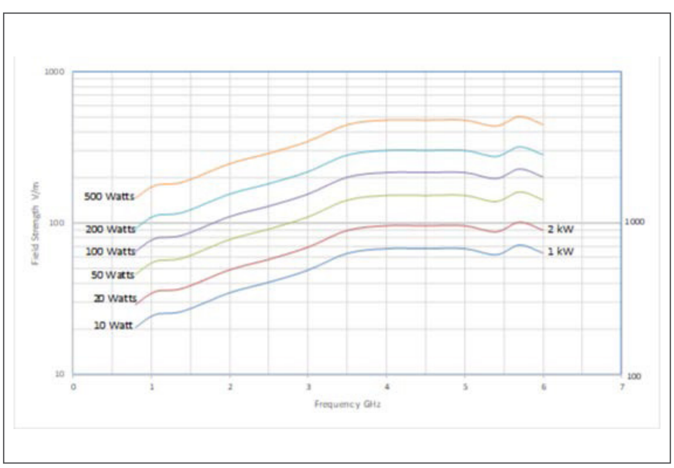


Figure 3: Measured Field Strength at 3 Meters.

In general, the more power that is put into an antenna, the more field is generated. However, there is no antenna that can handle infinite power. Input power is often limited by the power handling of the RF connector on the antenna, but there are other factors that can limit the power further. Some antenna manufacturers will specify just a single power level for power handling. This, unfortunately, is ambiguous. Input power ratings really vary over frequency with power rating typically decreasing as frequency increases. *Figure 4* shows the power handling of the same antenna represented in *Figures 2* and *3*.

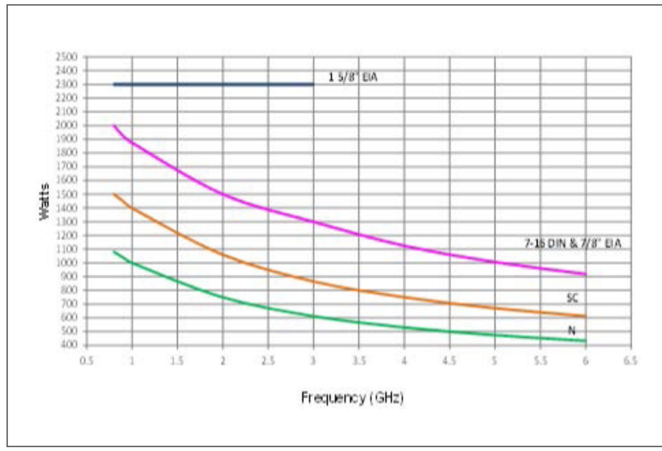


Figure 4: Antenna Power Handling.

When a single value is presented, this can sometimes be misconstrued as the maximum power rating over the full band. If this isn't made clear, it can be very easy to input this power level at a higher frequency and cause damage to the antenna. It should also be noted that these power levels are almost always defined as continuous or average power. Some immunity applications require high field strength pulsed tests. In these cases, large amounts of power are applied to the antenna but in very short durations and duty cycles. In these scenarios, the average power is very low, and therefore the antenna can handle much higher 'peak' power. Peak power handling of antenna is less well defined as voltage breakdown becomes the primary failure mechanism, and there are difficulties in characterizing this type of failure.

C. Measurement Equipment

The last equipment category we'll touch on is measurement equipment. The most common types of measurement equipment used in immunity testing are RF power meters and electric field probes. Typically, both of these types of devices are broadband measurement devices, measuring RMS power or electric field of continuous wave (CW) signals. As we discussed before, this can present problems when harmonics or other unwanted signals are present, as these signals would contribute to the measured power or field. This is why it's so important to limit harmonics and other unwanted signals. If frequency-selective measurements are desired, a receive antenna would need to be used along with a spectrum analyzer or EMI receiver. However, it should be noted that this method is typically not allowed in most test standards.

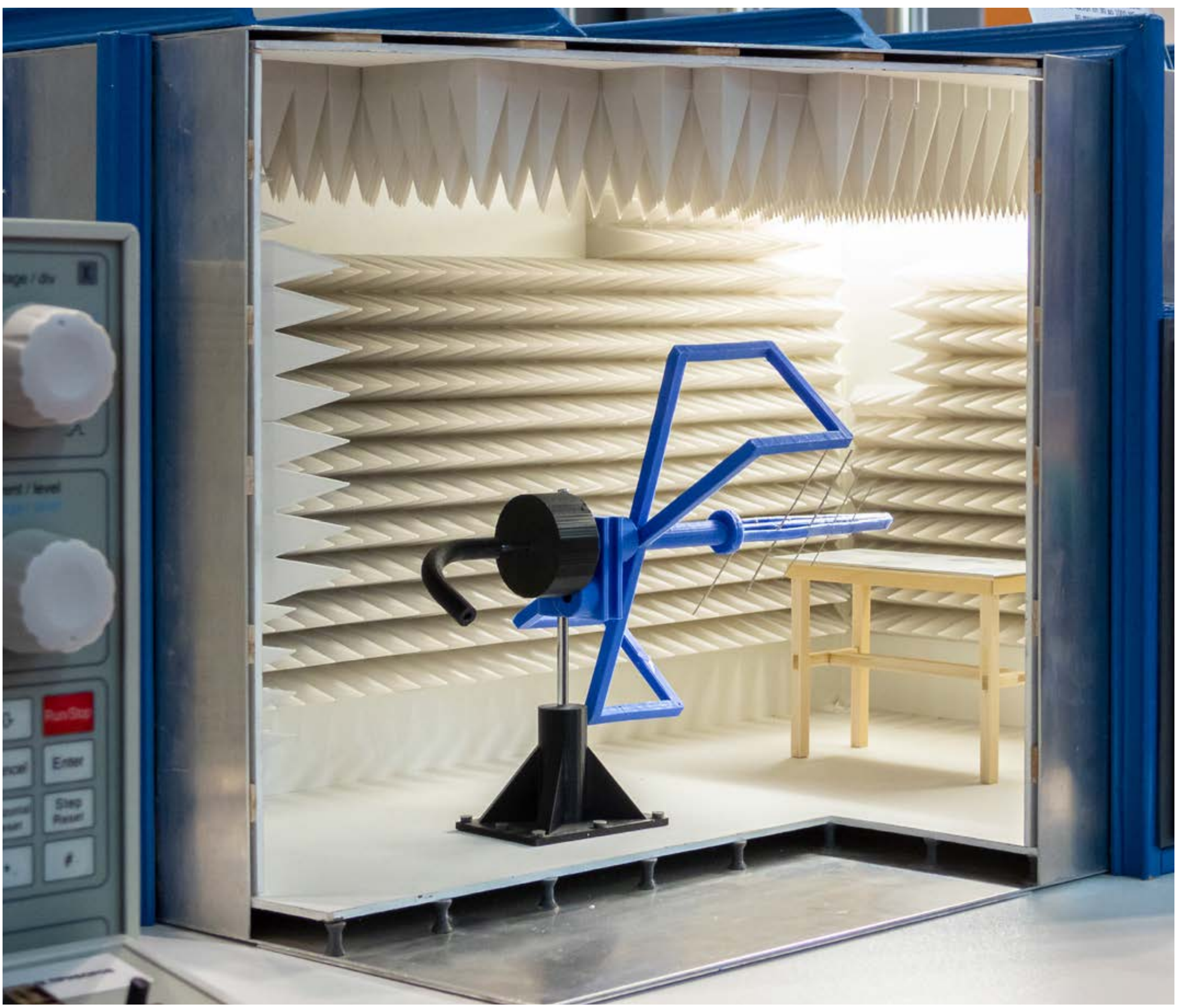
Another inherent problem of these devices is their ability, or rather inability, to accurately measure modulated signals. The majority of test standards require some type of modulation to be applied to the test signal. Traditional RF power meters and electric field probes are only capable of measuring CW signals, so either the test must first be calibrated without modulation applied, or the intented test signal must first be generated as a CW signal, then modulation applied. Either way, extra steps are involved. The adjective 'traditional' was used intentionally, as technologies are evolving, and some new RF power meters and electric field probes have the capability of measuring modulated signals. While these types of devices are gaining traction, the bulk of test standards are still written around the use of their traditional average measurement counterparts.

Summary

As you can see, there are many factors to consider when selecting equipment for EMC testing. It's important to fully understand the multitude of requirements and specifications of not only the equipment itself, but the standards documents that dictate the tests. Of these equipment parameters, many are typically presented for a given piece of equipment, but not all parameters may be relevant to your particular application. With an in-depth knowledge of these parameters, it can be much easier to select the proper equipment for EMC testing applications.

About the Author

Flynn Lawrence is the Supervisor of Applications Engineering for AR. Flynn is actively engaged in new application and product development, worldwide sales and customer support, as well as hardware demonstrations and training. Prior to AR, Flynn was an EMC Systems and Test engineer working on military and commercial space programs.



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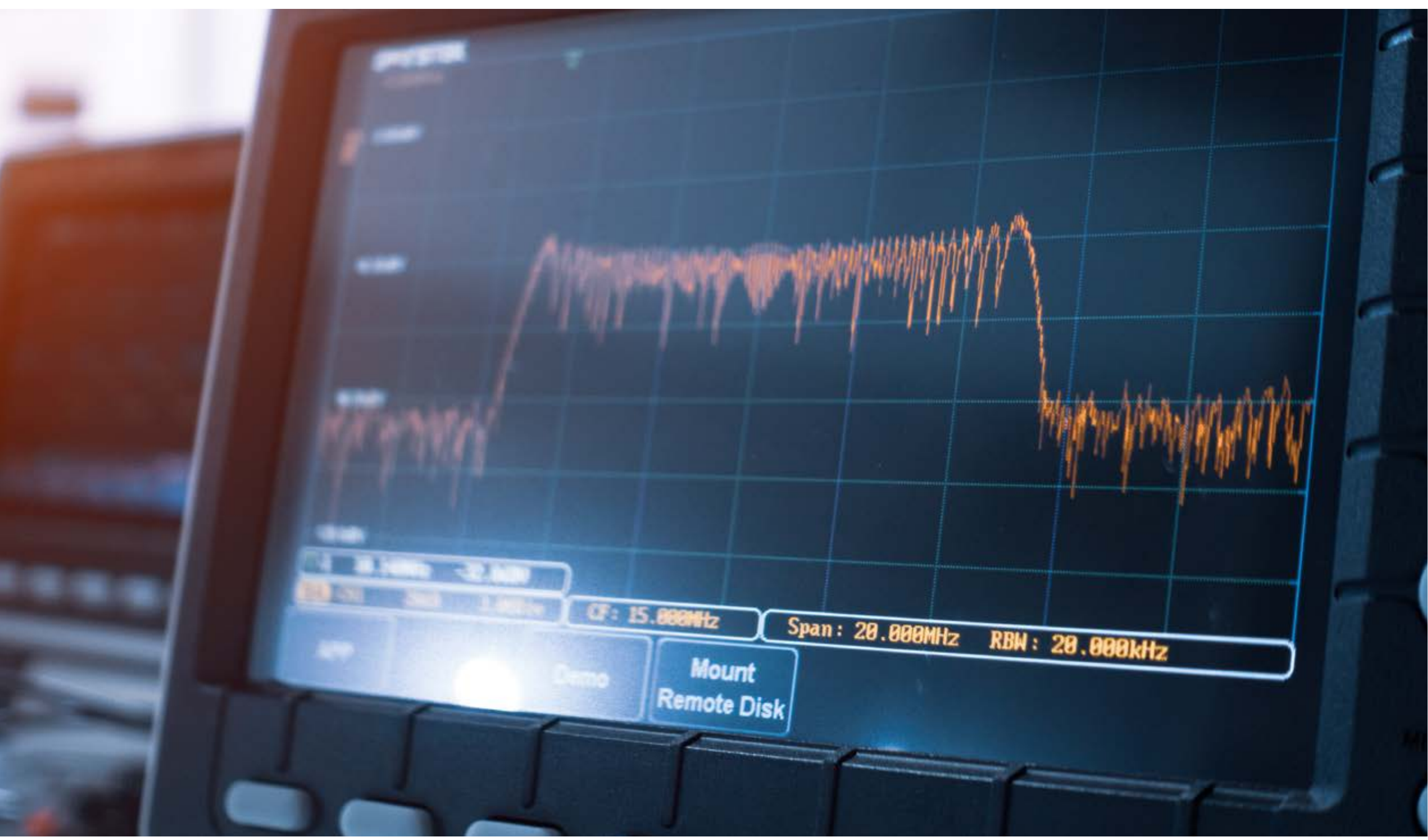
CPI Communications & Power Industries

FLEXIBILITY KEY TO TRENDS IN EMI PRE-COMPLIANCE DEBUGGING

Chris Armstrong
Director of Product Marketing & SW Applications, Rigol Technologies

EMI analysis continues to expand as more companies add electronic control and wireless remote capabilities to their products. The need to drive speed and efficiency throughout the design process means these engineers need to conduct EMI pre-compliance testing on the same bench as the debugging embedded and RF signals. Modern instruments often combine debugging and pre-compliance modes to help engineers save valuable time and resources in their design process. The availability of flexible instrumentation to fit these needs is helping to drive new test trends. To visualize and resolve more issues as early in the design as possible engineers require flexible solutions capable of capturing and visualizing issues across the digital, analog, and RF domains. In addition to traditional EMI pre-compliance scanning new solutions make it possible to capture emissions in real time, debug EMI in the time domain, and combine these capabilities in multi-domain analysis.



FLEXIBILITY KEY TO TRENDS IN EMI PRE-COMPLIANCE DEBUGGING

Real-Time Debugging and Visualization
Capturing emissions of interest can be done in a number of ways, but real-time debugging and visualization solutions are gaining popularity because of how easy it is to move between emissions testing and debugging. Real-time visualization makes it simple to directly capture RF emissions in real time. Without waiting for a scan or potentially missing short duration emissions, real-time visualization seamlessly captures the spectrum even allowing the engineer to trigger directly on a frequency or power envelope. Visualizing RF signals over time is also simplified with the fast capture and response of a real-time system.

Figure 1 shows how emission detection and debugging are combined in real-time spectrum analysis. With real-time, engineers can trigger on power levels across a spectrum as shown in the bottom panel. The top panel shows the time domain view. This signal is not constant but appears for a short duration about once per millisecond. With this information engineers can start looking for the likely root cause of this signal when it appears in a design revision. This approach is much more efficient than backtracking from a failed compliance test to find the cause of an issue made more complex over multiple revisions. The left panel in *Figure 1* shows a spectrogram view. This shows how the spectrum changes over longer time periods helping engineers determine likely contributors to the emission.

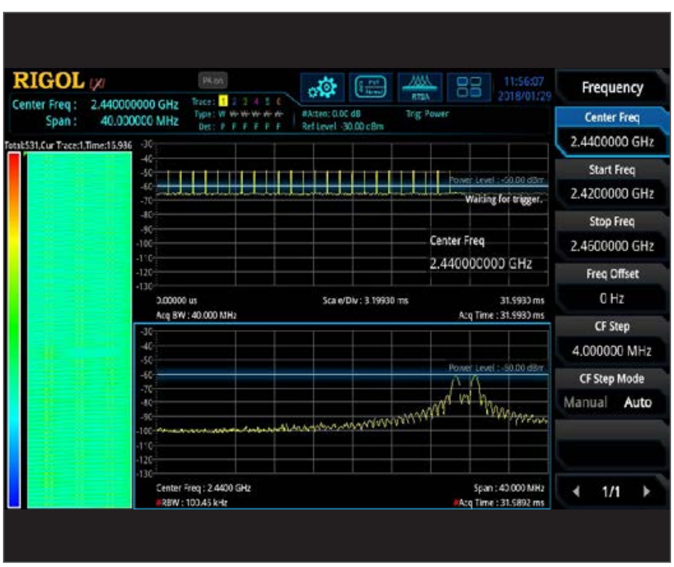


Figure 1: Debugging emissions with real-time spectrum analysis.

EMI Pre-Compliance in the Time Domain
Real-time visualization enables engineers to trigger and isolate emissions as well as helping to determine root cause, but often the underlying issue is a digital or analog signal that requires debugging of multiple signals together. One of the fastest growing EMI trends lies in using an advanced analysis oscilloscope to debug these emissions directly in the time domain. Modern oscilloscopes have the capability to accurately visualize the frequency content of embedded signals using enhanced FFTs.

Engineers use this ability to visualize the spectrum over time and correlate analog and digital signals as shown in *Figure 2*. This is an effective method for isolating time domain signals that might be causing emissions tor are related to bugs. Use the oscilloscope's FFT to find the frequencies within a signal, locate the source of a problematic signal, and confirm the digital state that leads to the issue. The ability to correlate multiple analog and digital signals, while comparing their RF energy simplifies debugging for these types of signals.

Figure 2: Debugging emissions in the time domain.

Scanning for Emissions
The traditional method of EMI pre-compliance testing includes scanning the broader spectrum looking for signals or problems. This method provides a high-performance scan of the instrument's entire span making it ideal for capturing unexpected emissions. Using CISPR average and quasi-peak detectors add additional insights to emissions behavior. Most engineers do not have access to a chamber for their normal debugging and product updates. In benchtop debugging, engineers use these swept measurements with a near field probe. This captures emissions near the probe perfect for identifying and locating emission sources and areas of concern in fixtures, enclosures, and cabling. Signals can be captured and compared between versions to identify emissions improvements or issues in the latest revision.

Figure 3 shows a 1 GHz scan using near field probes with multiple trace types. This is a common setup for monitoring emissions while sniffing a board with the probe. This method quickly captures a variety of emissions. Signals of interest captured in this mode can be further evaluated using real-time debugging.

Figure 3: Scanning for Emissions with a near field probe.

Multi-Domain Analysis

When efficient debugging is needed to resolve EMI challenges, the best approach is to combine real-time and time-domain debugging. This combination of instruments makes it possible for an engineer to capture detailed emissions in real time and correlate them together with analog and digital signals. Advancements in real-time analysis with available IF output means engineers can now set up triggers for emissions at a frequency or power and immediately view the digital state or embedded analog signals. When needed, trigger on embedded signals and quickly verify the resulting spectrum in real time. The flexibility of these multi-domain test setups makes it easy to isolate emissions or debug signals within a normal debug workflow for engineers. One of the biggest advantages of this approach is that design changes can be evaluated from multiple perspectives. When engineers make changes that they are concerned may have an emissions impact, the instruments can be set up to trigger on the new state and capture the resulting spectrum. When engineers find an emission they can easily synchronize the RF content with the correct state data to determine which design changes may have exacerbated the issue.

EMI Mode Verification

Pre-compliance measurements are ultimately about being confident about your design when it's time to send the product out for final compliance testing. The ability to capture emissions and design problems in real time and then debug them helps reduce wasted effort and rework. In order to capture everything that might be found in a compliance test requires dedicated EMI capabilities. Even without a fully compliant test chamber, EMI measurements can closely match those from a lab. This EMI mode verification requires multiple simultaneous detectors, limit line evaluation, final test verification, and segment definition. Some instruments include a dedicated EMI mode to facilitate this analysis. The EMI mode shown in *Figure 4* combines all of these capabilities into an instrument test solution. One of the key advantages to this test methodology is the ability to quickly verify emissions found during a segment scan against multiple detectors and limits. With the correct test setup, this analysis helps engineers stay focused on emissions or signals that are likely big enough to cause compliance issues, while allowing them to ignore emissions that won't impact the final compliance test.

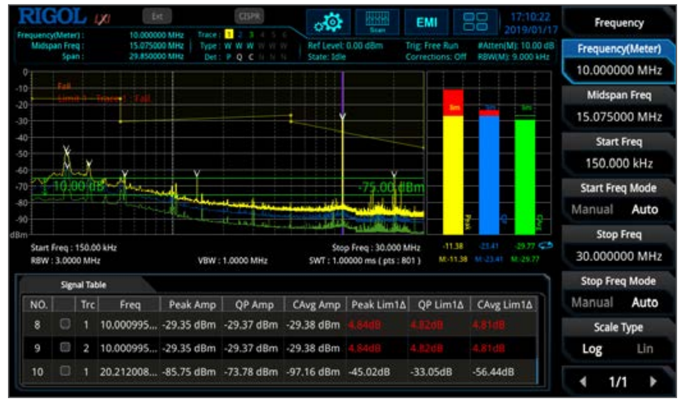


Figure 4: EMI mode verifying emissions against limit lines with multiple detectors.

EMI pre-compliance measurements provide important feedback to engineers throughout the design process. Visualizing and debugging emissions and their root causes is a challenging and time consuming task for any engineering organization. The emergence of flexible real-time spectrum and time domain analysis for multi-domain debugging enables engineers to quickly discover issues and solve complex problems on their bench. With a modern oscilloscope and a real-time spectrum analyzer working together, these test techniques provide a flexible set of debug capabilities that empower engineers to solve problems faster and more efficiently. Getting products to market faster by enabling real-time debugging and building confidence in the design as a project moves into final EMI compliance testing. These debugging modes offer a complete set of EMI pre-compliance capabilities throughout the design process from first hardware to final release. Engineers can now access all these capabilities in a pair of instruments that work together to visualize and debug a wide variety of embedded issues.

About the Author

Chris Armstrong is the Director of Product Marketing & Software Applications at Rigol Technologies North America. Chris brings more than 19 years of experience in test & measurement from sensitive measurement applications to multipurpose bench-top test to integrating complete systems that control instrumentation across a number of interfaces. Chris has a Bachelor of Science in Computer Science & Engineering from the University of Toledo and an MBA from Case Western Reserve University.

CASE STUDY: POOR PC BOARD LAYOUT CAUSES RADIATED EMISSIONS

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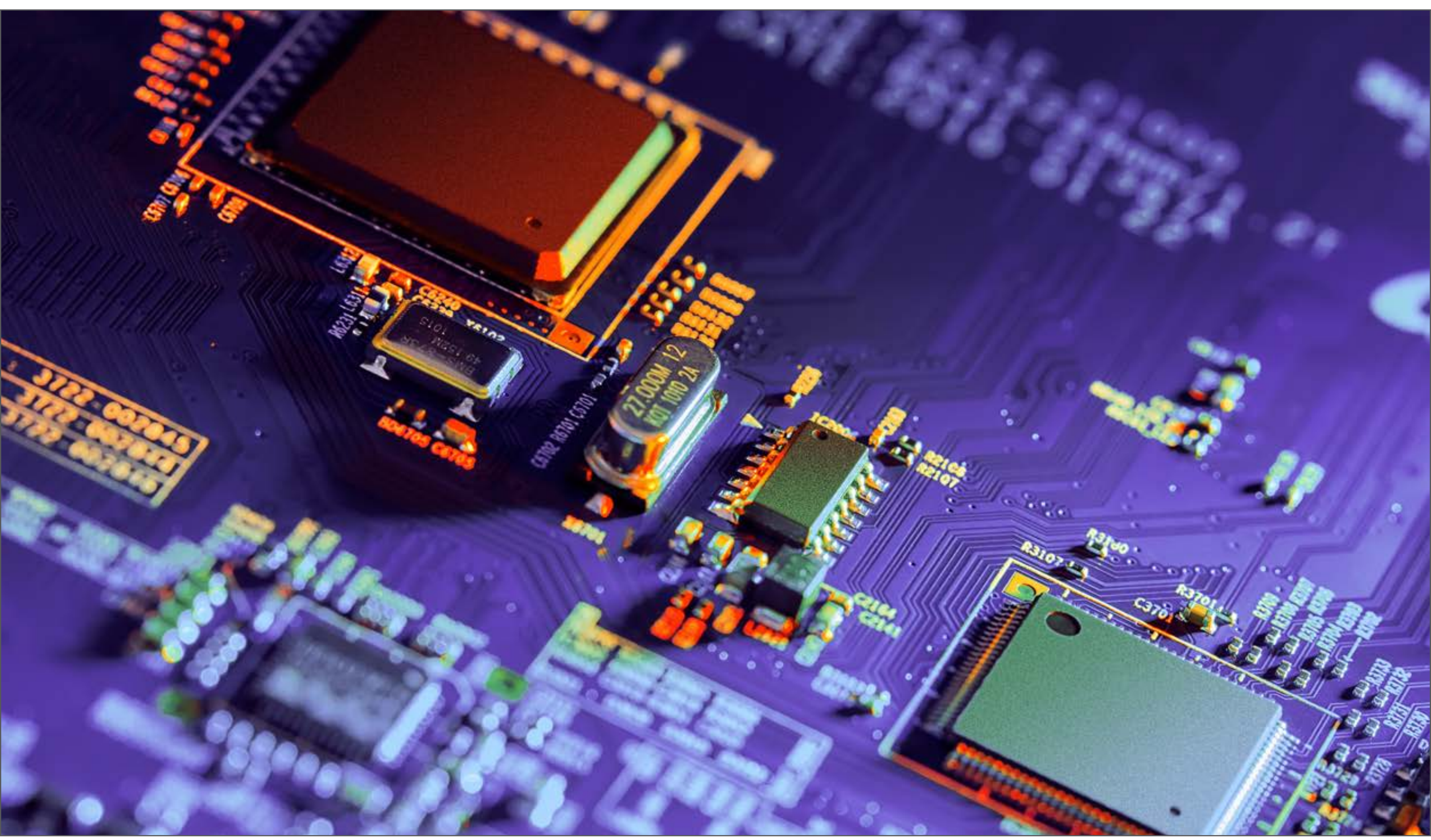
In this case study we're going look at some recent radiated emissions fault finding we performed for a customer. This highlights how one might go about the fault finding process, some of the considerations you might have when coming up with a solution, and how poor PCB layout can give you an emissions headache.



CASE STUDY: POOR PC BOARD LAYOUT CAUSES RADIATED EMISSIONS

Background
A new customer discovered a radiated emissions problem involving a product at an advanced stage in the production cycle. They had results (a low quality photo of scan result, *Figure 1*) from another test lab that showed a failure at two frequencies (with marginal results at others) and they needed some assistance in improving the EMC performance. The first thoughts when reviewing the failing results was that of power supply noise causing the broad hump around 80 MHz and then harmonics of a digital clock signal causing spikes from 130 MHz upwards.

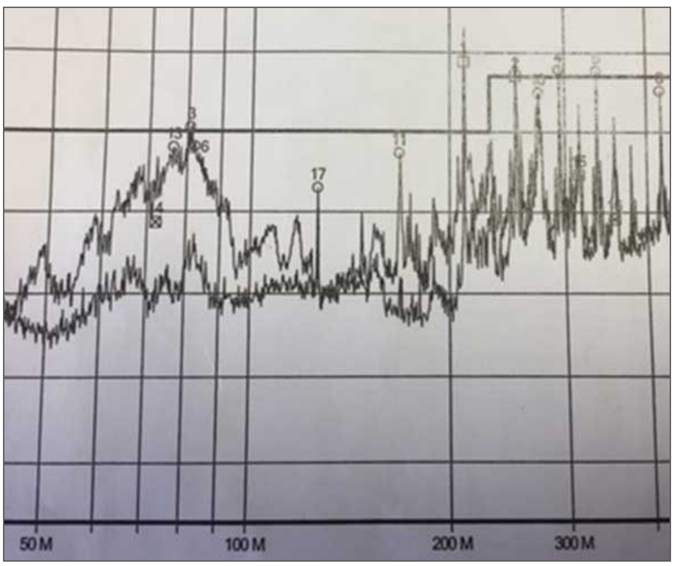


Figure 1: The original test results showing failure around 210 MHz and other frequencies of concern.

Before any testing starts, it is important to understand the product in terms of cost sensitivity, product volume, and design lifecycle as this will ultimately guide the work and the measures employed to improve emissions. There's no point adding a $/€/£5 clip on ferrite core to a product that is high volume/low cost as this would affect the Bill of Materials (BOM) cost too much. Similarly, for a low volume high margin/value product there's no point in redesigning the PCB to add a single common mode choke filter when the BOM cost could accept the more costly ferrite core, which can be easily fitted in production with a single snap.

With this equipment falling into this latter category and being ready for production, there was a desire to try and find effective modifications that could be easily applied without scrapping or significant rework of existing inventory and without incurring too many delays.

Experiments
The engineer from the customer was very enthusiastic and keen to learn more about EMC testing and the problem resolution process. It's always a pleasure to work with people who are both interested and interesting, and it was a most enjoyable time working with him. He had brought two units: one "vanilla" unmodified unit and one with a significantly modified wiring loom for experimentation. Needless to say, he was quite keen to know if the modifications he'd made with the wiring loom would improve the emissions.

The product consisted of a two-part metal enclosure enclosing some low frequency control components with a plastic housing on the front of the unit housing a LCD panel, buttons, and a control PCB.

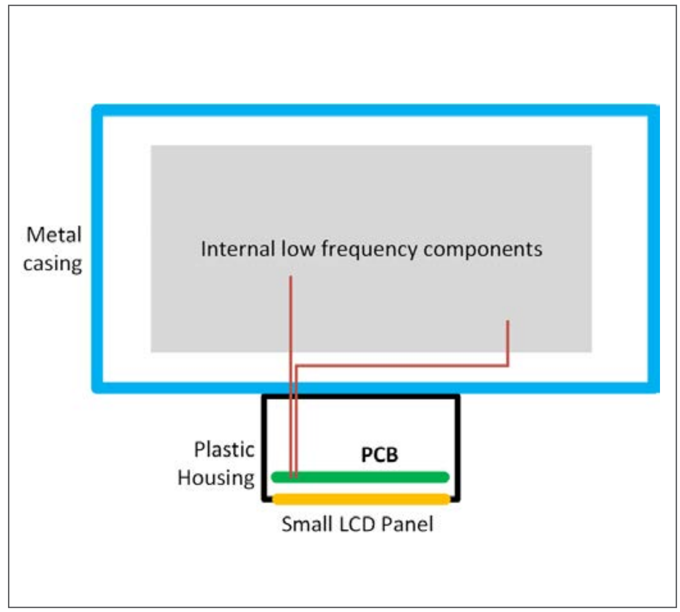


Figure 2: Block diagram of the equipment under test.

The improved and shortened cable routing sample that the customer brought improved the emissions slightly but not to the point of passing the EN 61326-1 Class B limits. We spent a while disconnecting cables from the control PCB that sent us down a couple of false avenues; disconnecting the power lead giving the best results (I wonder why…). Similarly, removing the lid from the metal case, disconnecting internal components and removing all external cabling had very little effect. All of which pointed towards emissions directly from the PCB being the main problem.

Being systematic during such an analysis is very important, trying as best you can to change only one thing at once and always questioning your assumptions.

PC Board Noise Analysis
Near field probing using a 15 mm diameter loop probe showed a little bit of pickup around the PCB. However, switching to a 1 cm^2 capacitive plate probe around the PCBs, power supply and cable assemblies showed that the noisiest area by far was the CPU/SDRAM interface with widespread harmonics from 84 MHz (the clock) up

into the 1-2 GHz region. Using a pre-amplifier for this probing is a good way to get a lower noise floor–either the one built in to the spectrum analyser or a cheap external one will result in another 10 dB of measurement range. Probing the connector pins with a spectrum analyzer, preamplifier and high bandwidth passive probe showed minimal energy at the frequencies of interest on the cables leaving the control PCB. The conclusion was that the problem was caused by direct radiation from the control PCB itself.

Measuring the SDRAM clock (*Figure 3*) with the spectrum analyzer identified where the three most problematic peaks were coming from; all harmonics derived from the 42 MHz clock. The data and address lines in the interface will also have emissions based on these frequencies albeit the emissions are "smeared" over the spectrum due to the lower frequency and varying duty cycles of these signals.

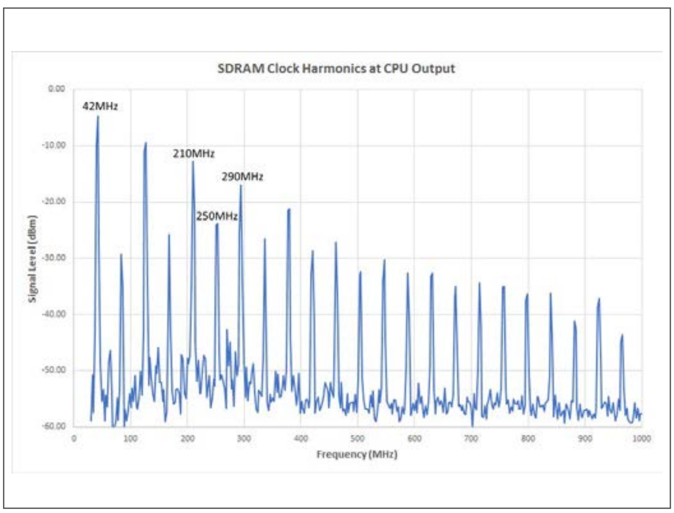


Figure 3: SDRAM clock harmonics.

Well, since we know where it's coming from what can we do about it without changing too much?

PC Board/Schematic Analysis

On visual inspection the PCB looked OK, perhaps lacking a few ground stitching vias, but not terribly laid out. It was only when the Gerber files were viewed in detail that several problems became obvious.

While the PCB used 4 layers (good), it appeared to be under-utilized with no coherent solid planes or defined co-planar reference traces of any kind on any of the layers. In doing so, the return path for the high frequency current was undefined resulting in the HF return currents finding their own uncontrolled route to minimize the loop area to the outbound trace, using stray capacitances to achieve this goal.

Take for example the SDRAM clock trace highlighted in yellow in the *Figure 4*.

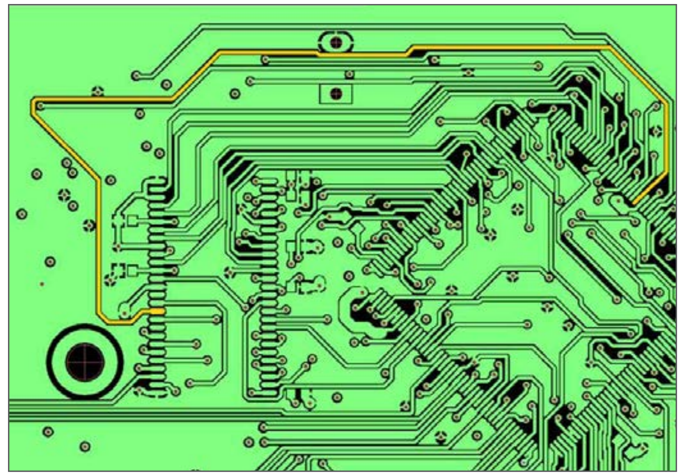


Figure 4: Clock trace from CPU to SDRAM.

Bearing in mind that there isn't a conventional ground or reference plane on the adjacent layer, where does the return current flow? Neither of the coplanar traces accompany the clock all the way back to the driver at the CPU end (on left). Just considering this very important trace the return path is compromised. You can also see the same thing for several other traces in this CPU <-> SDRAM interface.

So, while the PCB probably passed the Design Rule Check after what looked like an auto-route operation, the DRC doesn't care about or understand EMC and signal integrity.

Fix

Re-lay out the PCB with coherent HF return planes and everyone is happy.

Meanwhile, back in the real world where the manufacturer has stock of the built up PCB and has invested a lot of time and money into the product development, this isn't realistic for getting the product out of the door.

The fix ended up being threefold:

1. Turning on Spread Spectrum Clocking of the SDRAM interface. Changing the PLL configuration within the CPU to a 1% downspread of the clock reduces the energy at one specific frequency. This isn't always available and shouldn't be relied upon as a "get out of jail free" card but it certainly helps.
2. Changing the SDRAM clock divider from 2 to 3 reduced the output clock frequency to bring some of the higher energy harmonics below the 230 MHz knee in the Class B limits giving increased margin in the key area of emissions.
3. Scraping away top surface copper around mounting holes and addition of copper tape to display area.

(Side note: see this interesting article on the history of Spread Spectrum Clocking)

Modifications 1 and 2 are relatively easy to implement within the product firmware and help reduce the energy causing the emissions at source, the most effective way to solve an EMC problem. As for the last one? I hate to break out the copper tape. It's a useful diagnostic tool but I always feel that it is a weapon of last resort when dealing with EMC problems. Despite the negative connotations (in my head) it is a good product to use in this situation being available off the shelf from a variety of manufacturers.

In this product the LCD panel had a metallic (possibly galvanized steel by the crystalline appearance) back plate with a conductive finish that just about covered the noisy traces on the PCB. The idea behind the copper tape was to provide a low(er) impedance path from PCB trace – radiated field – LCD panel rear – PCB "ground".

Taking a cross section through the unmodified front panel (Figure 5) one would expect to see RF currents flowing through the stray capacitance between PCB and display as the HF current takes the lowest impedance (note not resistance) path back to the source that created them. The current flow through these capacitances creates the radiated fields measured by the antenna and receiver in the radiated emissions test setup. Reduce or control these currents and you can reduce the overall energy being delivered to the measurement system and improve your test result! This is the concept in placing an "image plane" near potentially radiating circuit traces, causing cancellation of the radiating fields.

(Side note: see this interesting article on the development and theory of the image plane concept, originally presented by Robert German, Henry Ott, and Clayton Paul in 1990 during the IEEE International Symposium on EMC).

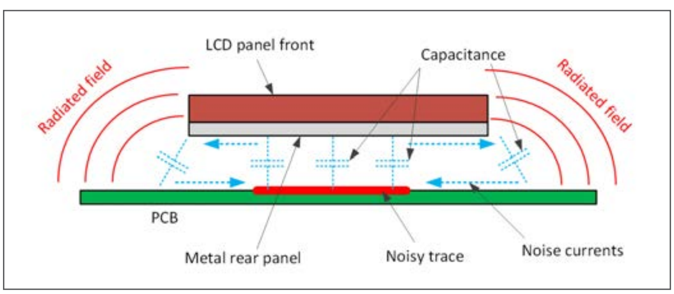


Figure 5: Cross section through the front panel showing predicted noise currents.

This is, of course, happening in three dimensions, which makes the visualization a little bit trickier to imagine.

Now let's take a look at the eventual modification. With the addition of the copper tape to connect the metallized LCD rear panel to the PCB (*Figure 6*) we are reducing and controlling the return path impedance. While we aren't reducing the levels of noise current, we can at least give them a more readily defined path. This does not eliminate the radiated field entirely, it does reduce it significantly.

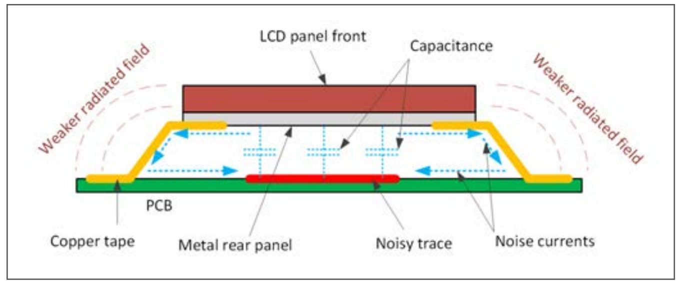


Figure 6: Front panel cross section with copper tape modification.

So how was this achieved in practice? *Figure 7* shows the crude implementation during development. The conductive adhesive copper tape extends from the mounting bosses in the front panel plastic moulding (onto which the PCB mounts) and onto the metallized panel with sufficient area to form a good RF contact. Note that the capacitance of the two surfaces (tape and panel) in close proximity can be just as significant to the impedance as the actual resistance through the adhesive. Also, the top left piece of tape passes under the LCD control flexi PCB through a gap, which is a bit difficult to place but all part of the effective solution.

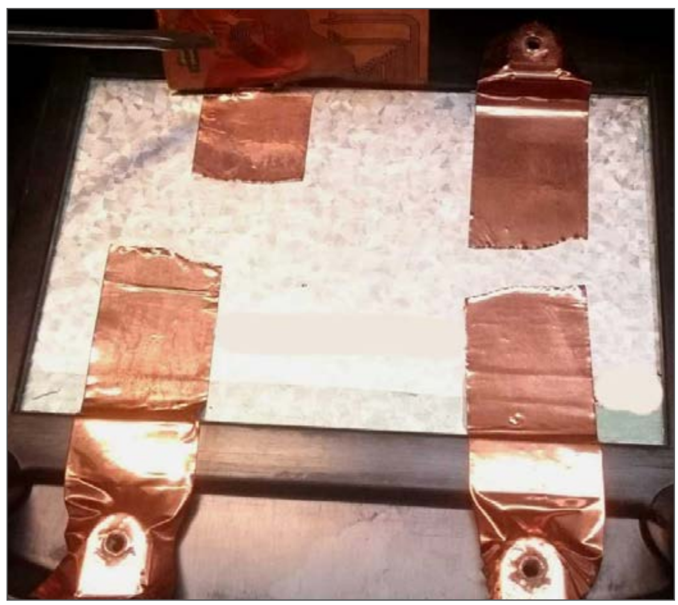


Figure 7: FA crude but effective copper tape modification.

This modification also necessitated scraping away the solder resist on the PCB around the PCB mounting holes and tinning the pads to provide a reliable electrical contact back to the PCB. This is easily achieved with a small hand held grinding tool like a Dremel running at low speed.

Outcome

This radiated emissions peak scan result shows the original unit as received from the customer (green) and the final modified unit at the end of testing (blue). The combination of the three modifications discussed above has ultimately reduced the emissions in the 180 MHz to 350 MHz band by up to 15 dB with a 3 dB margin in the 600

MHz to 900 MHz band. Improvements in this area would require a more complete shielding solution or preferably a re-layout of the PCB as mentioned above. Thanks to the addition of the Spread Spectrum Clocking, the Quasi Peak measurements were approximately 5dB lower than the peak readings below giving a better margin to the limit.

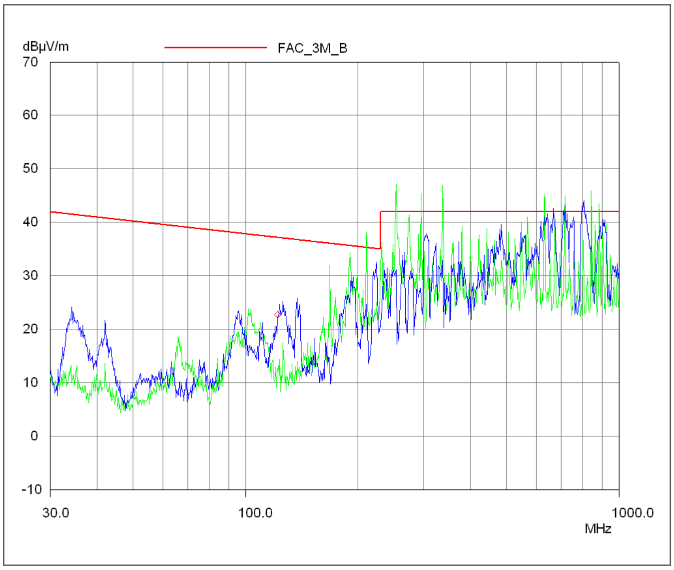


Figure 8: Peak detector radiated emissions before (green trace) and after (blue trace)

The customer wanted to close the loop by taking the product back to the accredited laboratory where they had conducted their original set of tests. A week or so later, a call came through from them to say that it had passed with similar margins to that measured in our anechoic chamber.

As part of the follow up we delivered a full design review report and layout recommendations to the customer to aid their future development of the product line. Ultimately, we ended up with a happy customer with a compliant product and are now excited to be collaborating with them on a new design.

“This final report is a fascinating read and proves the value to be had by considering EMC at the very early stages of product design (not just PCB layout). Many thanks for the support. We’ll certainly be in touch again.”

Conclusion

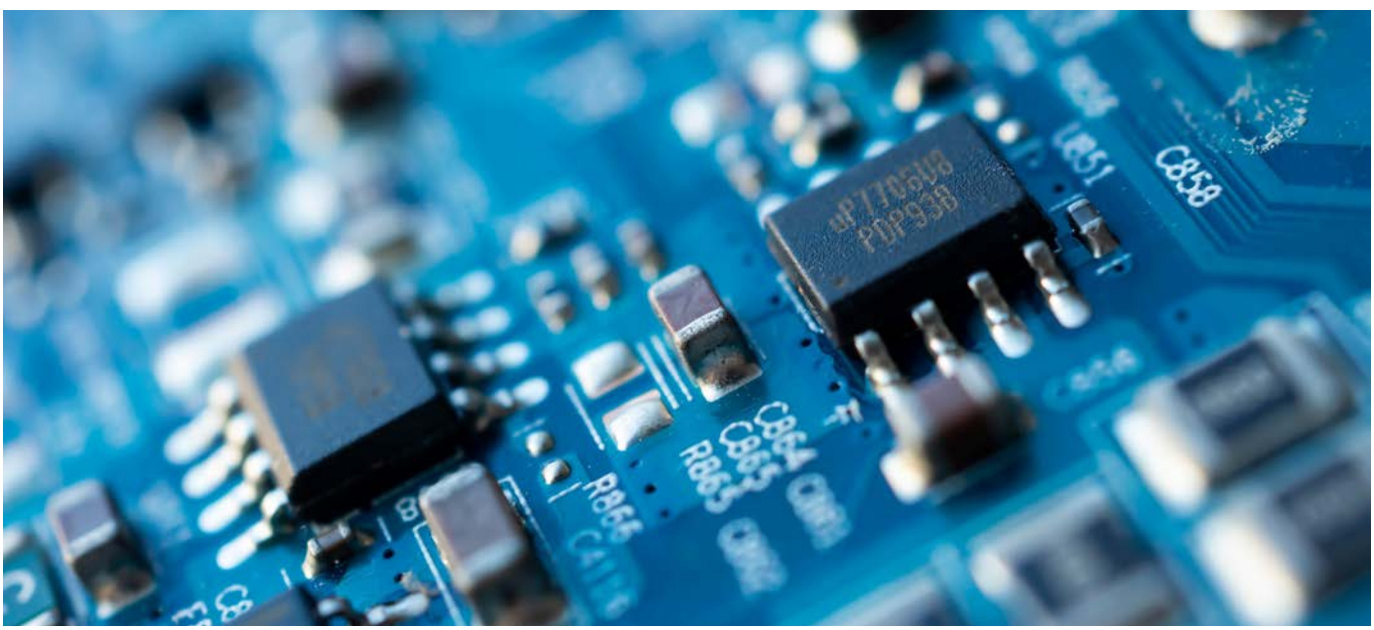
There are several useful lessons that one could take from this case study like “consider EMC at the start of the project” or “don’t operate your memory interface faster than you really need to”.

But the one thing you should take from this is get your PCB layout right.

There’s so much to discuss about this that it certainly lies outside the scope of this article. Books have been written about it. Big books. Most of the EMC problems you will face will be dictated, or at least heavily influenced, by the layout of the circuit board. This is where the noise is being generated after all!

If you have poor return paths for HF signals you will likely have radiated emissions issues to deal with. Fill your inner planes as much as possible with a good quality RF return path like a circuit ground and connect to it often. Avoid the use of the auto-router if possible or at least route the critical nets by hand. Think about loop areas, decoupling and transmission lines. Invest in training. Consider a third party design review.

The consequences of a poor PCB layout? Hopefully you’ve just read about them.



COMMON COMMERCIAL EMC STANDARDS

Commercial Electromagnetic Compatibility (EMC) Standards

ANSI	
Document Number	Title
C63.4	Methods of Measurement of Radio-Noise Emissions from Low-Voltage Electrical and Electronic Equipment in the Range of 9 kHz to 40 GHz

IEC	
Document Number	Title
IEC 60050-161	International Electrotechnical Vocabulary. Chapter 161: Electromagnetic compatibility
IEC 60060-1	High-voltage test techniques. Part 1: General definitions and test requirements
IEC 60060-2	High-voltage test techniques - Part 2: Measuring systems
IEC 60060-3	High-voltage test techniques - Part 3: Definitions and requirements for on-site testing
IEC 60118-13	Electroacoustics - Hearing aids - Part 13: Electromagnetic compatibility (EMC)
IEC 60255-26	Measuring relays and protection equipment - Part 26: Electromagnetic compatibility requirements
IEC 60364-4-44	Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbance
IEC 60469	Transitions, pulses and related waveforms - Terms, definitions and algorithms
IEC 60533	Electrical and electronic installations in ships - Electromagnetic compatibility (EMC) - Ships with a metallic hull
IEC 60601-1-2	Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests
IEC 60601-2-2	Medical electrical equipment - Part 2-2: Particular requirements for the basic safety and essential performance of high frequency surgical equipment and high frequency surgical accessories
IEC 60601-4-2	Medical electrical equipment - Part 4-2: Guidance and interpretation - Electromagnetic immunity: performance of medical electrical equipment and medical electrical systems
IEC 60728-2	Cabled distribution systems for television and sound signals - Part 2: Electromagnetic compatibility for equipment
IEC 60728-12	Cabled distribution systems for television and sound signals - Part 12: Electromagnetic compatibility of systems

IEC (continued)	
Document Number	Title
IEC/TS 60816	Guide on methods of measurement of short duration transients on low-voltage power and signal lines
IEC 60870-2-1	Telecontrol equipment and systems - Part 2: Operating conditions - Section 1: Power supply and electromagnetic compatibility
IEC 60940	Guidance information on the application of capacitors, resistors, inductors and complete filter units for electromagnetic interference suppression
IEC 60974-10	Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements
IEC/TR 61000-1-1	Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms
IEC/TS 61000-1-2	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena
IEC/TR 61000-1-3	Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems
IEC/TR 61000-1-4	Electromagnetic compatibility (EMC) - Part 1-4: General - Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz
IEC/TR 61000-1-5	Electromagnetic compatibility (EMC) - Part 1-5: General - High power electromagnetic (HPEM) effects on civil systems
IEC/TR 61000-1-6	Electromagnetic compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty
IEC/TR 61000-1-7	Electromagnetic compatibility (EMC) - Part 1-7: General - Power factor in single-phase systems under non-sinusoidal conditions
IEC/TR 61000-2-1	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems
IEC 61000-2-2	Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public low-voltage power supply systems
IEC/TR 61000-2-3	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 3: Description of the environment - Radiated and non-network-frequency-related conducted phenomena

IEC (continued)	
Document Number	Title
IEC 61000-2-4	Electromagnetic compatibility (EMC) - Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances
IEC/TS 61000-2-5	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 5: Classification of electromagnetic environments. Basic EMC publication
IEC/TR 61000-2-6	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances
IEC/TR 61000-2-7	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 7: Low frequency magnetic fields in various environments
IEC/TR 61000-2-8	Electromagnetic compatibility (EMC) - Part 2-8: Environment - Voltage dips and short interruptions on public electric power supply systems with statistical measurement results
IEC 61000-2-9	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 9: Description of HEMP environment - Radiated disturbance. Basic EMC publication
IEC 61000-2-10	Electromagnetic compatibility (EMC) - Part 2-10: Environment - Description of HEMP environment - Conducted disturbance
IEC 61000-2-11	Electromagnetic compatibility (EMC) - Part 2-11: Environment - Classification of HEMP environments
IEC 61000-2-12	Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems
IEC 61000-2-13	Electromagnetic compatibility (EMC) - Part 2-13: Environment - High-power electromagnetic (HPEM) environments - Radiated and conducted
IEC/TR 61000-2-14	Electromagnetic compatibility (EMC) - Part 2-14: Environment - Overvoltages on public electricity distribution networks
IEC 61000-3-2	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
IEC 61000-3-3	Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
IEC/TS 61000-3-4	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
IEC/TS 61000-3-5	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A
IEC/TR 61000-3-6	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication
IEC/TR 61000-3-7	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems - Basic EMC publication
IEC 61000-3-8	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 8: Signaling on low-voltage electrical installations - Emission levels, frequency bands and electromagnetic disturbance levels
IEC 61000-3-11	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems - Equipment with rated current <= 75 A and subject to conditional connection

IEC (continued)	
Document Number	Title
IEC 61000-3-12	Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and <=75 A per phase
IEC/TR 61000-3-13	Electromagnetic compatibility (EMC) - Part 3-13: Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems
IEC/TR 61000-3-14	Electromagnetic compatibility (EMC) - Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
IEC/TR 61000-3-15	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network
IEC TR 61000-4-1	Electromagnetic compatibility (EMC) - Part 4-1: Testing and measurement techniques - Overview of IEC 61000-4 series
IEC 61000-4-2	Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
IEC 61000-4-3	Electromagnetic compatibility (EMC) - Part 4-3 : Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
IEC 61000-4-4	Electromagnetic compatibility (EMC) - Part 4-4 : Testing and measurement techniques – Electrical fast transient/burst immunity test
IEC 61000-4-5	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
IEC 61000-4-6	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
IEC 61000-4-7	Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
IEC 61000-4-8	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
IEC 61000-4-9	Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test
IEC 61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
IEC 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
IEC 61000-4-12	Electromagnetic compatibility (EMC) - Part 4-12: Testing and measurement techniques - Ring wave immunity test
IEC 61000-4-13	Electromagnetic compatibility (EMC) - Part 4-13: Testing and measurement techniques - Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests
IEC 61000-4-14	Electromagnetic compatibility (EMC) - Part 4-14: Testing and measurement techniques - Voltage fluctuation immunity test
IEC 61000-4-15	Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 15: Flickermeter - Functional and design specifications
IEC 61000-4-16	Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques - Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz

IEC (continued)	
Document Number	Title
IEC 61000-4-17	Electromagnetic compatibility (EMC) - Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test
IEC 61000-4-18	Electromagnetic compatibility (EMC) - Part 4-18: Testing and measurement techniques - Damped oscillatory wave immunity test
IEC 61000-4-19	Electromagnetic compatibility (EMC) - Part 4-19: Testing and measurement techniques - Test for immunity to conducted, differential mode disturbances and signalling in the frequency range 2 kHz to 150 kHz at a.c. power ports
IEC 61000-4-20	Electromagnetic compatibility (EMC) - Part 4-20: Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides
IEC 61000-4-21	Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods
IEC 61000-4-22	Electromagnetic compatibility (EMC) - Part 4-22: Testing and measurement techniques - Radiated emissions and immunity measurements in fully anechoic rooms (FARs)
IEC 61000-4-23	Electromagnetic compatibility (EMC) - Part 4-23: Testing and measurement techniques - Test methods for protective devices for HEMP and other radiated disturbances
IEC 61000-4-24	Electromagnetic compatibility (EMC) - Part 4-24: Testing and measurement techniques - Test methods for protective devices for HEMP conducted disturbance
IEC 61000-4-25	Electromagnetic compatibility (EMC) - Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems
IEC 61000-4-27	Electromagnetic compatibility (EMC) - Part 4-27: Testing and measurement techniques - Unbalance, immunity test
IEC 61000-4-28	Electromagnetic compatibility (EMC) - Part 4-28: Testing and measurement techniques - Variation of power frequency, immunity test
IEC 61000-4-29	Electromagnetic compatibility (EMC) - Part 4-29: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests
IEC 61000-4-30	Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods
IEC 61000-4-31	Electromagnetic compatibility (EMC) - Part 4-31: Testing and measurement techniques - AC mains ports broadband conducted disturbance immunity test
IEC/TR 61000-4-32	Electromagnetic compatibility (EMC) - Part 4-32: Testing and measurement techniques - High-altitude electromagnetic pulse (HEMP) simulator compendium
IEC 61000-4-33	Electromagnetic compatibility (EMC) - Part 4-33: Testing and measurement techniques - Measurement methods for high-power transient parameters
IEC 61000-4-34	Electromagnetic compatibility (EMC) - Part 4-34: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests for equipment with input current more than 16 A per phase
IEC TR 61000-4-35	Electromagnetic compatibility (EMC) - Part 4-35: Testing and measurement techniques - HPEM simulator compendium
IEC 61000-4-36	Electromagnetic compatibility (EMC) - Part 4-36: Testing and measurement techniques - IEMI immunity test methods for equipment and systems
IEC TR 61000-4-37	Electromagnetic compatibility (EMC) - Calibration and verification protocol for harmonic emission compliance test systems
IEC TR 61000-4-38	Electromagnetic compatibility (EMC) - Part 4-38: Testing and measurement techniques - Test, verification and calibration protocol for voltage fluctuation and flicker compliance test systems

IEC (continued)	
Document Number	Title
IEC/TR 61000-5-1	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication
IEC/TR 61000-5-2	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 2: Earthing and cabling
IEC/TR 61000-5-3	Electromagnetic compatibility (EMC) - Part 5-3: Installation and mitigation guidelines - HEMP protection concepts
IEC/TS 61000-5-4	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 4: Immunity to HEMP - Specifications for protective devices against HEMP radiated disturbance. Basic EMC Publication
IEC 61000-5-5	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 5: Specification of protective devices for HEMP conducted disturbance. Basic EMC Publication
IEC/TR 61000-5-6	Electromagnetic compatibility (EMC) - Part 5-6: Installation and mitigation guidelines - Mitigation of external EM influences
IEC 61000-5-7	Electromagnetic compatibility (EMC) - Part 5-7: Installation and mitigation guidelines - Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)
IEC 61000-5-8	Electromagnetic compatibility (EMC) - Part 5-8: Installation and mitigation guidelines - HEMP protection methods for the distributed infrastructure
IEC 61000-5-9	Electromagnetic compatibility (EMC) - Part 5-9: Installation and mitigation guidelines - System-level susceptibility assessments for HEMP and HPEM
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
IEC 61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environments
IEC 61000-6-6	Electromagnetic compatibility (EMC) - Part 6-6: Generic standards - HEMP immunity for indoor equipment
IEC 61000-6-7	Electromagnetic compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations
IEC 61326-1	Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements
IEC 61326-2-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-1: Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications
IEC 61326-2-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-2: Particular requirements - Test configurations, operational conditions and performance criteria for portable test, measuring and monitoring equipment used in low-voltage distribution systems

IEC (continued)	
Document Number	Title
IEC 61326-2-3	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-3: Particular requirements - Test configuration, operational conditions and performance criteria for transducers with integrated or remote signal conditioning
IEC 61326-2-4	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-4: Particular requirements - Test configurations, operational conditions and performance criteria for insulation monitoring devices according to IEC 61557-8 and for equipment for insulation fault location according to IEC 61557-9
IEC 61326-2-5	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-5: Particular requirements - Test configurations, operational conditions and performance criteria for field devices with field bus interfaces according to IEC 61784-1
IEC 61326-2-6	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-6: Particular requirements - In vitro diagnostic (IVD) medical equipment
IEC 61326-3-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-1: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - General industrial applications
IEC 61326-3-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-2: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - Industrial applications with specified electromagnetic environment
IEC 61340-3-1	Electrostatics - Part 3-1: Methods for simulation of electrostatic effects - Human body model (HBM) electrostatic discharge test waveforms
IEC 61543	Residual current-operated protective devices (RCDs) for household and similar use - Electromagnetic compatibility
IEC 61800-3	Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods
IEC 61967-1	Integrated circuits - Measurement of electromagnetic emissions, 150 kHz to 1 GHz - Part 1: General conditions and definitions
IEC 62040-2	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility EMC) requirements
IEC 62041	Power transformers, power supply units, reactors and similar products - EMC requirements
IEC 62153-4-0	Metallic communication cable test methods - Part 4-0: Electromagnetic compatibility (EMC) - Relationship between surface transfer impedance and screening attenuation, recommended limits
IEC 62153-4-1	Metallic communication cable test methods - Part 4-1: Electromagnetic compatibility (EMC) - Introduction to electromagnetic screening measurements
IEC 62153-4-2	Metallic communication cable test methods - Part 4-2: Electromagnetic compatibility (EMC) - Screening and coupling attenuation - Injection clamp method
IEC 62153-4-3	Metallic communication cable test methods - Part 4-3: Electromagnetic compatibility (EMC) - Surface transfer impedance - Triaxial method
IEC 62153-4-4	Metallic communication cable test methods - Part 4-4: Electromagnetic compatibility (EMC) - Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
IEC 62153-4-5	Metallic communication cables test methods - Part 4-5: Electromagnetic compatibility (EMC) - Coupling or screening attenuation - Absorbing clamp method

IEC (continued)	
Document Number	Title
IEC 62153-4-6	Metallic communication cable test methods - Part 4-6: Electromagnetic compatibility (EMC) - Surface transfer impedance - Line injection method
IEC 62153-4-7	Metallic communication cable test methods - Part 4-7: Electromagnetic compatibility (EMC) - Test method for measuring of transfer impedance ZT and screening attenuation aS or coupling attenuation aC of connectors and assemblies up to and above 3 GHz - Triaxial tube in tube method
IEC 62153-4-8	Metallic communication cable test methods - Part 4-8: Electromagnetic compatibility (EMC) - Capacitive coupling admittance
IEC 62153-4-9	Metallic communication cable test methods - Part 4-9: Electromagnetic compatibility (EMC) - Coupling attenuation of screened balanced cables, triaxial method
IEC 62153-4-10	Metallic communication cable test methods - Part 4-10: Electromagnetic compatibility (EMC) - Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets - Double coaxial test method
IEC 62153-4-11	Metallic communication cable test methods - Part 4-11: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of patch cords, coaxial cable assemblies, pre-connectorized cables - Absorbing clamp method
IEC 62153-4-12	Metallic communication cable test methods - Part 4-12: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of connecting hardware - Absorbing clamp method
IEC 62153-4-13	Metallic communication cable test methods - Part 4-13: Electromagnetic compatibility (EMC) - Coupling attenuation of links and channels (laboratory conditions) - Absorbing clamp method
IEC 62153-4-14	Metallic communication cable test methods - Part 4-14: Electromagnetic compatibility (EMC) - Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method
IEC 62153-4-15	Metallic communication cable test methods - Part 4-15: Electromagnetic compatibility (EMC) - Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with triaxial cell
IEC 62236-1	Railway applications - Electromagnetic compatibility - Part 1: General
IEC 62236-2	Railway applications - Electromagnetic compatibility - Part 2: Emission of the whole railway system to the outside world
IEC 62236-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle
IEC 62236-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock - Apparatus
IEC 62236-4	Railway applications - Electromagnetic compatibility - Part 4: Emission and immunity of the signalling and telecommunications apparatus
IEC 62236-5	Railway applications - Electromagnetic compatibility - Part 5: Emission and immunity of fixed power supply installations and apparatus
IEC 62305-1	Protection against lightning - Part 1: General principles
IEC 62305-2	Protection against lightning - Part 2: Risk management
IEC 62305-3	Protection against lightning - Part 3: Physical damage to structures and life hazard

IEC (continued)	
Document Number	Title
IEC 62305-4	Protection against lightning - Part 4: Electrical and electronic systems within structures
IEC 62310-2	Static transfer systems (STS) - Part 2: Electromagnetic compatibility (EMC) requirements
IEC/TR 62482	Electrical installations in ships - Electromagnetic compatibility - Optimising of cable installations on ships - Testing method of routing distance

CISPR	
Document Number	Title
CISPR 11	Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
CISPR 14-1	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission
CISPR 14-2	Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 2: Immunity – Product family standard
CISPR 15	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
CISPR 16-1-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus
CISPR 16-1-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2: Radio disturbance and immunity measuring apparatus - Coupling devices for conducted disturbance measurements
CISPR 16-1-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-3: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Disturbance power
CISPR 16-1-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-4: Radio disturbance and immunity measuring apparatus - Antennas and test sites for radiated disturbance measurements
CISPR 16-1-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-5: Radio disturbance and immunity measuring apparatus - Antenna calibration sites and reference test sites for 5 MHz to 18 GHz
CISPR 16-1-6	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-6: Radio disturbance and immunity measuring apparatus - EMC antenna calibration
CISPR 16-2-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-1: Methods of measurement of disturbances and immunity - Conducted disturbance measurements
CISPR 16-2-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-2: Methods of measurement of disturbances and immunity - Measurement of disturbance power
CISPR 16-2-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements

CISPR (continued)	
Document Number	Title
CISPR 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement (To be withdrawn in 2020)
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement (To be withdrawn in 2020)
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements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MILITARY RELATED DOCUMENTS & STANDARDS

The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts.

MIL-HDBK-235-1D Military Operational Electromagnetic Environment Profiles Part 1D General Guidance, 03 April 2018.

MIL-HDBK-237D Electromagnetic Environmental Effects and Spectrum Certification Guidance for the Acquisition Process, 20 May 2005. (Notice 1 Validation 04 April 2013)

MIL-HDBK-240A Hazards of Electromagnetic Radiation to Ordnance (HERO) Test Guide, 10 Mar 2011.

MIL-HDBK-263B Electrostatic Discharge Control Handbook for Protection of Electrical and Electronic Parts, Assemblies and Equipment (Excluding Electrically Initiated Explosive Devices), 31 Jul 1994.

MIL-HDBK-274A Electrical Grounding for Aircraft Safety, 14 Nov 2011. (Notice 1 Validation 16 August 2016)

MIL-HDBK-335 Management and Design Guidance Electromagnetic Radiation Hardness for Air Launched Ordnance Systems, Notice 4, 08 Jul 2008. (Notice 5 Cancellation 01 August 2013)

MIL-HDBK-419A Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, 29 Dec 1987. (Notice 1 Validation 20 February 2014)

MIL-HDBK-454B General Guidelines for Electronic Equipment, 15 Apr 2007. (Notice 1 Validation 12 December 2012)

MIL-HDBK-1195, Radio Frequency Shielded Enclosures, 30 Sep 1988.

MIL-HDBK-2036 Preparation of Electronic Equipment Specifications, 1 November 1999

MIL-STD-188-124B Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications-Electronics Facilities and Equipment, 4 April 2013.

MIL-STD-220C Test Method Standard Method of Insertion Loss Measurement, 14 May 2009. (Notice 2 Validation 08 October 2019)

MIL-STD-331D Fuze and Fuze Components, Environmental and Performance Tests for, 31 May, 2017.

MIL-STD-449D Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973. (Notice 1 18 May 1976, Notice 2 Validation 04 April 2013)

MIL-STD-461F Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 Dec 2007.

MIL-STD-461G Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015.

MIL-STD-464C Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010. (MIL-STD-464D to be released in 2020)

MIL-STD-704F Aircraft Electric Power Characteristics, Change Notice 1, 05 December 2016.

MIL-STD-1275E Characteristics of 28 Volt DC Power Input to Utilization Equipment in Military Vehicles, 22 March 2013 (MIL-STD-1275F expected release in 2020)

MIL-STD-1310H Standard Practice for Shipboard Bonding, Grounding, and Other Techniques for Electromagnetic Compatibility Electromagnetic Pulse (EMP) Mitigation and Safety, 17 Sep 2009. (Notice 1 Validation 12 August 2014)

MIL-STD-1377 Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of EM Radiation to Ordnance; Measurement of, 20 Aug 1971.

MIL-STD-1399 Section 300B Interface Standard for Shipboard Systems, Electric Power, Alternating Current, Cancelled 25 September 2018.

MIL-STD-1399 Section 300 Part 2 Medium Voltage Electric Power, Alternating Current, 25 September 2018

MIL-STD-1541A Electromagnetic Compatibility Requirements for Space Systems,Cancelled 27 April 2017.

MIL-STD-1542B Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991. MIL-STD-1605 Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 15 Nov, 1991.

MIL-STD-1605A (SH) Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 8 October 2009 (Validation Notice 1, 12 August 2014)

MIL-STD-1686C Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment (Excluding Electrically Initiated Explosive Devices). 25 Oct 1995.

ADS-37A-PRF Electromagnetic Environmental Effects (E3) Performance and Verification Requirements, 28 May 1996.

DOD-STD-1399 Section 070 Part 1 D.C. Magnetic Field Environment, Notice 1, 30 Nov 1989.

DoDI 3222.03 DoD Electromagnetic Environmental Effects (E3) Program, Change Notice 2, 10 October 2017. DoDD 4650.01 Policy and Procedures for Management and Use of the Electromagnetic Spectrum, 09 Jan 2009.

DoDI 6055.11 Protecting Personnel from Electromagnetic Fields, 19 Aug 2009.

TOP 01-2-511A Electromagnetic Environmental Effects System Testing, 20 November 2013

TOP 01-2-620 High-Altitude Electromagnetic Pulse (HEMP) Testing, 10 November 2011

TOP 01-2-622 Vertical Electromagnetic Pulse Testing, 11 September 2009

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY (EMC) STANDARDS

The following list of automotive EMC standards was developed by Dr. Todd Hubing, Professor Emeritus of Clemson University Vehicular Electronics Lab (http://www.cvel.clemson.edu/auto/auto_emc_standards.html). A few of these standards have been made public and are linked below, but many others are considered company confidential and are only available to approved automotive vendors or test equipment manufacturers.

While several standards are linked on this list, an internet search may help locate additional documents that have been made public. Permission to republish has been approved.

CISPR (Automotive Emissions Requirements)	
Document Number	Title
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	Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement

ISO (Automotive Immunity Requirements)	
Document Number	Title
ISO 7637-1	Road vehicles – Electrical disturbances from conduction and coupling – Part 1: Definitions and general considerations
ISO 7637-2	Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only
ISO 7637-3	Road vehicles – Electrical disturbance by conduction and coupling – Part 3: Vehicles with nominal 12 V or 24 V supply voltage – Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
ISO/TR 10305-1	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz
ISO/TR 10305-2	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz
ISO 10605	Road vehicles – Test methods for electrical disturbances from electrostatic discharge
ISO/TS 14907-1	Road transport and traffic telematics – Electronic fee collection – Test procedures for user and fixed equipment – Part 1: Description of test procedures
ISO/TS 14907-2	Road transport and traffic telematics – Electronic fee collection – Test procedures for user and fixed equipment – Part 2: Conformance test for the onboard unit application interface
ISO/TS 21609	Road vehicles – (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment
ISO 11451-1	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology

ISO (Automotive Immunity Requirements) continued	
Document Number	Title
ISO 11451-2	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Off-vehicle radiation sources
ISO 11451-3	Road vehicles – Electrical disturbances by narrowband radiated electromagnetic energy – Vehicle test methods – Part 3: On-board transmitter simulation
ISO 11451-4	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)
ISO 11452-1	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology
ISO 11452-2	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Absorber-lined shielded enclosure
ISO 11452-3	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 3: Transverse electromagnetic mode (TEM) cell
ISO 11452-4	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Bulk current injection (BCI)
ISO 11452-5	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 5: Stripline
ISO 11452-7	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 7: Direct radio frequency (RF) power injection
ISO 11452-8	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 8: Immunity to magnetic fields
ISO 11452-10	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 10: Immunity to conducted disturbances in the extended audio frequency range
ISO 11452-11	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 11: Reverberation chamber
ISO 13766	Earth-moving machinery – Electromagnetic compatibility

SAE (Automotive Emissions and Immunity)	
Document Number	Title
J1113/1	Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (Up to 15 M), and Machines (Except Aircraft) (50 Hz to 18 Ghz)
J1113/2	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft)–Conducted Immunity, 15 Hz to 250 kHz–All Leads
J1113/3	Conducted Immunity, 250 kHz to 400 MHz, Direct Injection of Radio Frequency (RF) Power (Cancelled August 2010)
J1113/4	Immunity to Radiated Electromagnetic Fields-Bulk Current Injection (BCI) Method
J1113/11	Immunity to Conducted Transients on Power Leads
J1113/12	Electrical Interference by Conduction and Coupling – Capacitive and Inductive Coupling via Lines Other than Supply Lines
J1113/13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 13: Immunity to Electrostatic Discharge
J1113/21	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Part 21: Immunity to Electromagnetic Fields, 30 MHz to 18 GHz, Absorber-Lined Chamber
J1113/24	Immunity to Radiated Electromagnetic Fields; 10 kHz to 200 MHz–Crawford TEM Cell and 10 kHz to 5 GHz–Wideband TEM Cell (Cancelled August 2010)
J1113/26	Electromagnetic Compatibility Measurement Procedure for Vehicle Components – Immunity to AC Power Line Electric Fields
J1113/27	Electromagnetic Compatibility Measurements Procedure for Vehicle Components – Part 27: Immunity to Radiated Electromagnetic Fields – Mode Stir Reverberation Method
J1113/28	Electromagnetic Compatibility Measurements Procedure for Vehicle Components–Part 28–Immunity to Radiated Electromagnetic Fields–Reverberation Method (Mode Tuning)
J1113/42	Electromagnetic Compatibility–Component Test Procedure–Part 42–Conducted Transient Emissions (Cancelled Dec 2010, Superseded by ISO 7637-2)
J1752/1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits-Integrated Circuit EMC Measurement Procedures-General and Definition
J1752/2	Measurement of Radiated Emissions from Integrated Circuits – Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz
J1752/3	Measurement of Radiated Emissions from Integrated Circuits – TEM/Wideband TEM (GTEM) Cell Method; TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)
J551/5	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz To 30 MHz
J551/11	Vehicle Electromagnetic Immunity–Off-Vehicle Source (Cancelled March 2010)

SAE (Automotive Emissions and Immunity) continued	
Document Number	Title
J551/12	Vehicle Electromagnetic Immunity–On-Board Transmitter Simulation (Cancelled August 2009)
J551/13	Vehicle Electromagnetic Immunity–Bulk Current Injection (Cancelled August 2009)
J551/15	Vehicle Electromagnetic Immunity–Electrostatic Discharge (ESD)
J551/16	Electromagnetic Immunity – Off-Vehicle Source (Reverberation Chamber Method) – Part 16 – Immunity to Radiated Electromagnetic Fields
J551/17	Vehicle Electromagnetic Immunity – Power Line Magnetic Fields
J1812	Function Performance Status Classification for EMC Immunity Testing
J2628	Characterization–Conducted Immunity
J2556	Radiated Emissions (RE) Narrowband Data Analysis–Power Spectral Density (PSD)

GM	
Document Number	Title
GMW3091	General Specification for Vehicles, Electromagnetic Compatibility (EMC)-Engl; Revision H; Supersedes GMI 12559 R and GMI 12559 V
GMW3097	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility-Engl; Revision H; Supersedes GMW12559, GMW3100, GMW12002R AND GMW12002V
GMW3103	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility Global EMC Component/Subsystem Validation Acceptance Process-Engl; Revision F; Contains Color; Replaces GMW12003, GMW12004 and GMW3106

Ford	
Document Number	Title
EMC-CS-2009.1	Component EMC Specification EMC-CS-2009.1
FORD F-2	Electrical and Electronics System Engineering
FORD WSF-M22P5-A1	Printed Circuit Boards, PTF, Double Sided, Flexible

DaimlerChrysler	
Document Number	Title
DC-10614	EMC Performance Requirements – Components
DC-10615	Electrical System Performance Requirements for Electrical and Electronic Components
DC-11224	EMC Performance Requirements – Components
DC-11225	EMC Supplemental Information and Alternative Component Requirements

Other Automotive Manufacturers	
Audi TL 82466	Electrostatic Discharge
BMW 600 13.0	Electric- / Electronic components in cars
BMW GS 95002	Electromagnetic Compatibility (EMC) Requirements and Tests
BMW GS 95003-2	Electric- / Electronic assemblies in motor vehicles
Chrysler PF 9326	Electrical electronic modules and motors
FIAT 9.90110	Electric and electronic devices for motor vehicles
Freightliner 49-00085	EMC Requirements
Honda 3838Z-S5AA-L000	Noise Simulation Test
Honda 3982Z-SDA-0030	Battery Simulation Test
Hyundai/Kia ES 39110-00	EMC Requirements
Hyundai/Kia ES-95400-10	Battery Simulation Tests
Hyundai/Kia ES 96100-01	EMC Requirements
IVECO 16-2103	EMC Requirements
Lotus 17.39.01	Lotus Engineering Standard: Electromagnetic Compatibility
Mack Trucks 606GS15	EMC Requirements
MAN 3285	EMC Requirements
Mazda MES PW 67600	Automobile parts standard (electronic devices)
Mercedes A 211 000 42 99	Instruction specification of test method for E/E-components
Mercedes AV EMV	Electric aggregate and electronics in cars
Mercedes MBN 10284-2	EMC requirements and tests of E/E-systems (component test procedures)
Mercedes MBN 22100-2	Electric / electronic elements, devices in trucks
Mitsubishi ES-X82010	General specification of environment tests on automotive electronic equipment
Nissan 28401 NDS02	EMC requirements (instruction concerning vehicle and electrical ...)
Nissan 28400 NDS03	Low frequency surge resistance of electronic parts
Nissan 28400 NDS04	Burst and Impulse Waveforms
Nissan 28400 NDS07	Immunity against low frequency surge (induction surge) of electronic parts
Peugeot B217110	Load Dump Pulses
Porsche AV EMC EN	EMC Requirements
PSA B21 7090	EMC Requirements (electric and electronics equipment)
PSA B21 7110	EMC requirements (electric and electronics equipment)
Renault 36.00.400	Physical environment of electrical and electronic equipments
Renault 36.00.808	EMC requirements (cars and electrical / electronic components)
Scania TB1400	EMC Requirements
Scania TB1700	Load Dump Test

Other Automotive Manufacturers	
Smart DE10005B	EMC requirements (electric aggregate and electronics in cars)
Toyota TSC7001G	Engineering standard (electric noise of electronic devices)
Toyota TSC7001G-5.1	Power Supply Voltage Characteristic Test
Toyota TSC7001G-5.2	Field Decay Test
Toyota TSC7001G-5.3	Floating Ground Test
Toyota TSC7001G-5.4	Induction Noise Resistance
Toyota TSC7001G-5.5.3	Load Dump Test-1
Toyota TSC7001G-5.5.4	Load Dump Test-2
Toyota TSC7001G-5.5.5	Load Dump Test-3
Toyota TSC7001G-5.6	Over Voltage Test
Toyota TSC7001G-5.7.3	Ignition Pulse (Battery Waveforms) Test-1
Toyota TSC7001G-5.7.4	Ignition Pulse (Battery Waveforms) Test-2
Toyota TSC7001G-5.8	Reverse Voltage
Toyota TSC7006G-4.4.2	Wide Band-Width Antenna Nearby Test (0.4 to 2 GHz)
Toyota TSC7006G-4.4.3	Radio Equipment Antenna nearby Test (28 MHz ...)
Toyota TSC7006G-4.4.4	Mobile Phone Antenna Nearby Test (835 MHz ...)
Toyota TSC7018G	Static Electricity Test
Toyota TSC7025G-5	TEM Cell Test (1 to 400 MHz)
Toyota TSC7025G-6	Free Field Immunity Test (20 MHz to 1 GHz AM, 0.8 to 2 GHz PM)
Toyota TSC7025G-7	Strip Line Test (20 - 400 MHz)
Toyota TSC7026G-3.4	Narrow Band Emissions
Toyota TSC7203G	Voltage Drop / Micro Drops
Toyota TSC7508G-3.3.1	Conductive Noise in FM and TV Bands
Toyota TSC7508G-3.3.2	Conductive noise in LW, AM and SW Bands
Toyota TSC7508G-3.3.3	Radiated Noise in FM and TV Bands
Toyota TSC7508G-3.3.4	Radiated Noise in AM, SW, and LW Bands
Toyota TSC7203G	Engineering standard (ABS-TRC computers)
Toyota TXC7315G	Electrostatic Discharge (Gap Method)
Visteon ES-XU3F-1316-AA	Electronic Component - Subsystem Electromagnetic Compatibility (EMC) Requirements and Test Procedures
Volvo EMC Requirements	EMC requirements for 12V and 24V systems
Volkswagen VW TL 801 01	Electric and electronic components in cars
Volkswagen VW TL 820 66	Conducted Interference
Volkswagen VW TL 821 66	EMC requirements of electronic components - bulk current injection (BCI)
Volkswagen VW TL 823 66	Coupled Interference on Sensor Cables
Volkswagen VW TL 824 66	Immunity Against Electrostatic Discharge
Volkswagen VW TL 965	Short-Distance Interference Suppression

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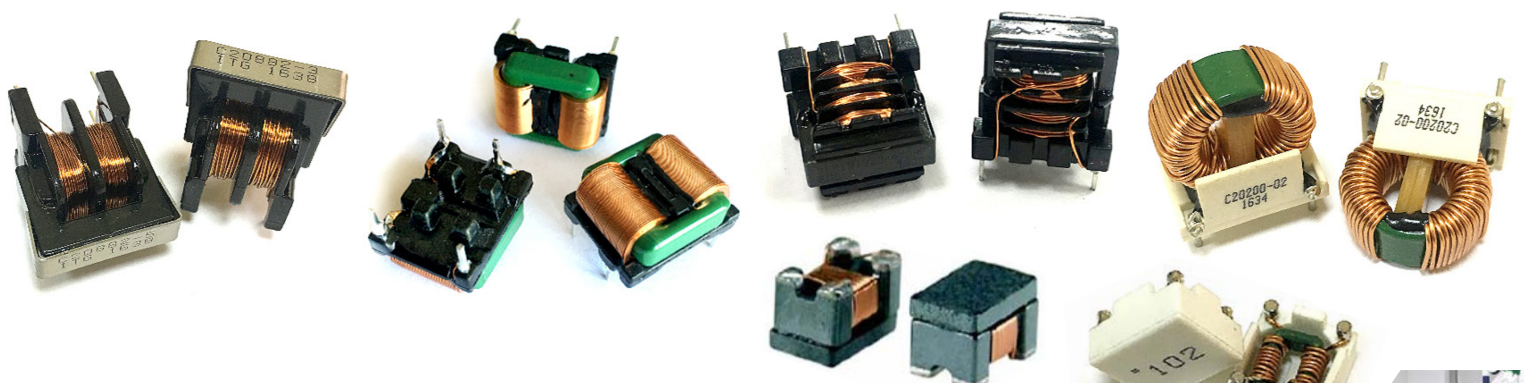

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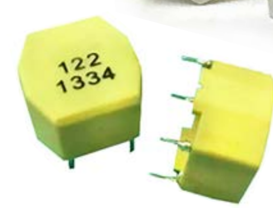

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USEFUL EMC TESTING REFERENCES
(DIRECTORY, BOOKS, ORGANIZATIONS, LINKEDIN GROUPS)

RECOMMENDED BOOKS, MAGAZINES, & JOURNALS

2019 Directory & Design Guide
Since 1971, this publication has set the standard for all things related to EMI/EMC.
https://learn.interferencetechnology.com/2019-directory-and-design-guide/

RECOMMENDED BOOKS

André and Wyatt
EMI Troubleshooting Cookbook for Product Designers
SciTech Publishing, 2014.
Includes chapters on product design and EMC theory & measurement. A major part of the content includes how to troubleshoot and mitigate all common commercial EMC test failures.

Archambeault
PCB Design for Real-World EMI Control
Kluwer Academic Publishers, 2002.

Bogatin
Signal & Power Integrity - Simplified
Prentice-Hall, 2018 (3rd Edition).
Great coverage of signal and power integrity from a fields viewpoint.

Hall, Hall, and McCall
High-Speed Digital System Design - A Handbook of Interconnect Theory and Design Practices
Wiley, 2000.

Joffe and Lock
Grounds For Grounding
Wiley, 2010.
This huge book includes way more topics on product design than the title suggests. Covers all aspects of grounding and shielding for products, systems, and facilities.

Johnson and Graham
High-Speed Digital Design - A Handbook of Black Magic
Prentice-Hall, 1993.
Practical coverage of high speed digital signals and measurement.

Johnson and Graham
High-Speed Signal Propagation - Advanced Black Magic
Prentice-Hall, 2003.
Practical coverage of high speed digital signals and measurement.

Kimmel and Gerke
Electromagnetic Compatibility in Medical Equipment
IEEE Press, 1995.
Good general product design information.

Mardiguian
EMI Troubleshooting Techniques
McGraw-Hill, 2000.
Good coverage of EMI troubleshooting.

Mardiguian
Controlling Radiated Emissions by Design
Springer, 2016.
Good content on product design for compliance.

Montrose
EMC Made Simple
Montrose Compliance Services, 2014.
The content includes several important areas of EMC theory and product design, troubleshooting, and measurement.

Morrison
Digital Circuit Boards - Mach 1 GHz
Wiley, 2012.
Important concepts of designing high frequency circuit boards from a fields viewpoint.

Morrison
Grounding And Shielding - Circuits and Interference
Wiley, 2016 (6th Edition).
The classic text on grounding and shielding with up to date content on how RF energy flows through circuit boards.

Morrison
Fast Circuit Boards
Wiley, 2018.
Morrison explains how signals propagate via transmission lines and why it's so important to include reference planes for every signal layer.

Ott
Electromagnetic Compatibility Engineering
Wiley, 2009.
The "bible" on EMC measurement, theory, and product design.

USEFUL EMC TESTING REFERENCES (CONTINUED)
(DIRECTORY, BOOKS, ORGANIZATIONS, LINKEDIN GROUPS)

RECOMMENDED BOOKS (CONTINUED)

Paul
Introduction to Electromagnetic Compatibility
Wiley, 2006 (2nd Edition).
The one source to go to for an upper-level course on EMC theory.

Sandler
Power Integrity - Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems
McGraw-Hill, 2014.
The latest information on measurement and design of power distribution networks and how the network affects stability and EMC.

Smith and Bogatin
Principles of Power Integrity for PDN Design - Simplified
Prentice-Hall, 2017.
Getting the power distribution network (PDN) design right is the key to reducing EMI.

Williams
EMC For Product Designers
Newnes, 2017.
Completely updated text on product design for EMC compliance.

Weston
Electromagnetic Compatibility - Methods, Analysis, Circuits, and Measurement
CRC Press, 2017 (3rd Edition).
A comprehensive text, primarily focused on military EMC.

Wyatt
EMC Desk Reference
Interference Technology, 2017.
A handy guide with technical articles and pertinent EMC reference information.

Wyatt & Jost
Electromagnetic Compatibility (EMC) Pocket Guide
SciTech Publishing, 2013.
A handy pocket-sized reference guide to EMC.

EMC STANDARDS ORGANIZATION

ANSI
http://www.ansi.org

ANSI Accredited C63
http://c63.org/index.htm

IEEE Standards Association
http://standards.ieee.org

SAE
http://www.sae.org

SAE EMC Standards Committee
http://www.sae.org/standards/

IEC
http://iec.ch

CISPR
http://www.iec.ch/emc/iec_emc/iec_emc_players_cispr.htm

ETSI
http://www.etsi.org

LINKEDIN GROUPS

EMC Experts

EMC Testing and Compliance

Electromagnetic Compatibility Forum

ESD Experts

EMC Troubleshooters

EMC & DESIGN CONFERENCES 2020

The following is a partial listing of major EMC and electronics design conferences planned for 2020 in order of date. If your conference is not listed, please contact: info@interferencetechnology.com

MARCH 15-19

Applied Power Electronics Conference (APEC)
March 15 to 19, 2020
New Orleans, Louisiana, USA
www.apec-conf.org
Electronics Conference (APEC) brings together nearly 6,000 professionals, from around the world, for five days of powerful networking, hands-on learning, and strategic business development, including a vast exposition featuring the latest products and services.

APRIL 7

EMC LIVE 2020 | EMC Testing
April 7, 2020
Online Event
www.emc.live
EMC Live 2020 is a series of free online learning events for engineers. For the first time ever, it's expanding into five topic-specific, one-day events. Each day will focus on one of the five most popular EMC topics in the industry:

- March 3rd | MIL-Aero EMC
- April 7th | EMC Testing
- June 9th | Automotive EMC
- September 1st | IoT, Wireless, 5G EMC
- November 10th | EMC Fundamentals

APRIL 20-24

2020 DoD E3 Program Review
April 20-24, 2020
Albuquerque, NM
www.fbcinc.com/e/DoDE3/
The Program Review is an information exchange forum for DoD Components, the Federal Government, and Industry E3 and Spectrum Management and related professionals to collaborate, network, and meet to discuss policy and regulations, acquisition trends, operational supportability, and emerging technology. It also features dozens of technical presentations, several training seminars, and many working groups, ad hoc meetings, and exhibitions. The proposed theme of this year's event is TBD.

MAY 20-21

EMC & Compliance International 2020 Exhibition & Workshops
May 20-21, 2020
Newbury Racecourse
www.emcuk.co.uk
In co-operation with EMC Standards, we are re-launching the event as "EMC & Compliance International" as an independent event back at the updated Newbury Racecourse. The Training Workshops by Keith Armstrong & the Technical Workshops also organized by Keith will be running alongside the exhibition. If you are in the EMC or related Compliance business, then this is an event not to be missed.

EMC & DESIGN CONFERENCES 2020 (CONTINUED)

8th International Conference on Antennas and Electromagnetic Systems (AES2020)
June 1-4, 2020
Marrakesh, Morocco
www.aesconference.org
The 8th International Conference on Antennas and Electromagnetic Systems (AES 2020) will be held in the fascinating city of Marrakesh – Morocco, from 1 to 4 June 2020. AES 2020 will feature several Plenary and Invited Lectures by world leading experts on all aspects of Antennas, Electromagnetics, Propagation, and Measurements.

2020 IEEE International Symposium on EMC, SI&PI
July 27-31, 2020
Reno, Nevada
www.emc2020.emcss.org
The 2020 IEEE International Symposium on EMC+SIPI is the leading event of EMC and Signal & Power Integrity techniques to engineers of all backgrounds. The Symposium features five full days of training, innovative sessions, interactive workshops & tutorials, experiments & demonstrations, and social networking events. Register now – we look forward to seeing you there!

EMC Europe 2020 – International Symposium on Electromagnetic Compatibility
September 7-11, 2020
Rome, Italy
www.emceurope2020.org
EMC research and conferences in Europe have a long tradition. From the series of independent EMC Symposia based in Wroclaw, Zurich, and Rome, running every second year, has emerged EMC Europe which is organized every year in a European city to provide an international forum for the exchange of technical information on EMC. The 2020 EMC Europe Symposium will be held at the Engineering Faculty of Sapienza University of Rome, from September 7-11, 2020. The Symposium will cover the entire scope of electromagnetic compatibility including emerging technologies. Oral and Poster Sessions, Workshops, Tutorials, Short-Courses, and Special Sessions will be organized.

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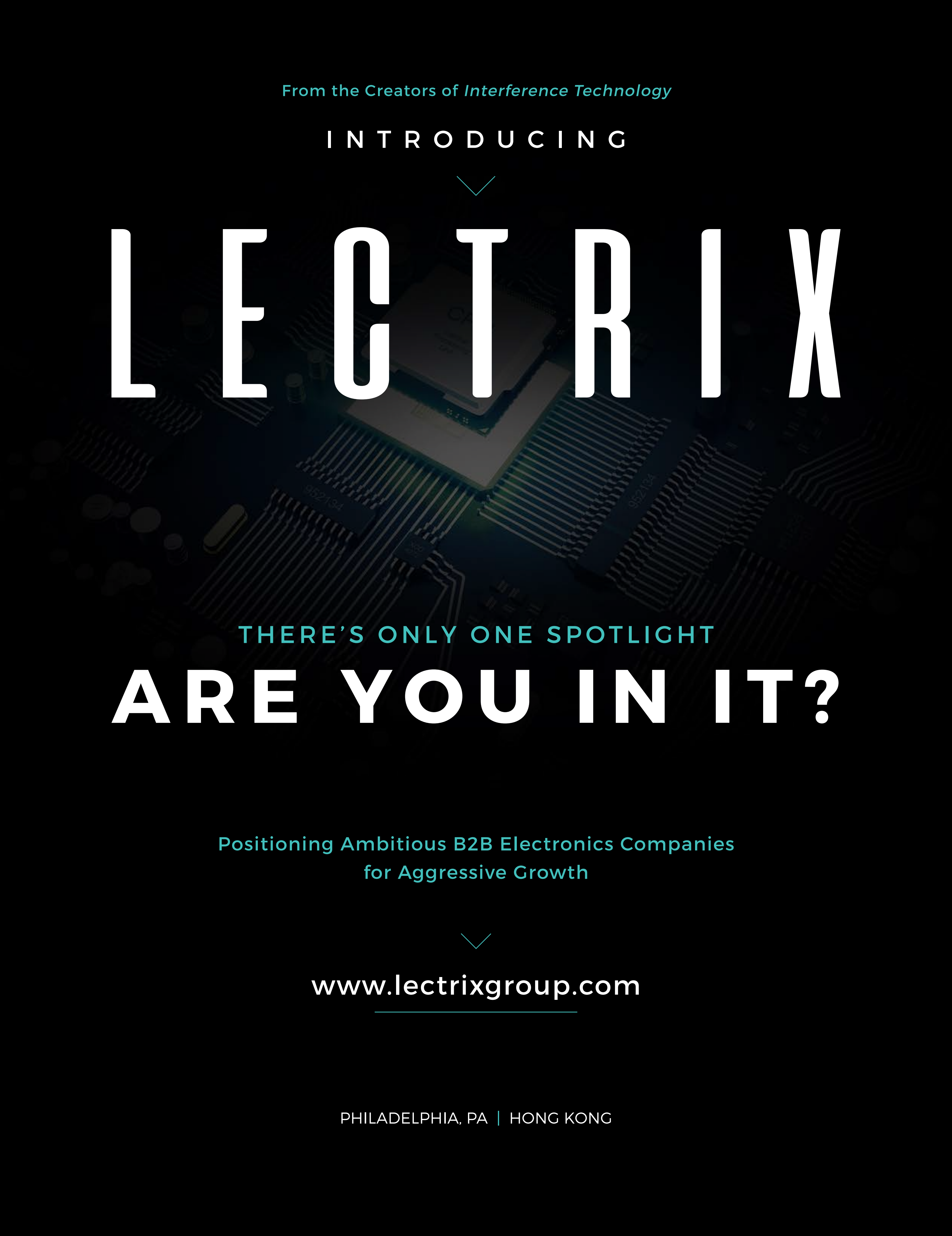
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