$39.95

INTERFERENCE TECHNOLOGY PRESENTS

EMC

DESK REFERENCE

BY: KENNETH WYATT

INTERFERENCE TECHNOLOGY®


Outstanding perspectives.
With EMC solutions from the market leader.
We provide everything you need for development, precompliance and compliance measurements to ensure successful EMC certification.
Exceptionally fast EMI test receivers
Efficient diagnostic tools for detecting EMI
EMC software packages for interactive and fully automatic measurements
Wide range of accessories for performing EMI measurements
Compact and modular broadband amplifiers
RF shielded chambers
Complete EMC test systems
For more information, visit:
www.rohde-schwarz.com/ad/emc
ROHDE&SCHWARZ

INTERFERENCE TECHNOLOGY

EMC DESK REFERENCE

Table of Contents

Why AR Solid State Pulsed Amplifiers Should Be On Your Radar

For automotive and military EMC radiated immunity susceptibility testing, as well as radar and communication applications, there is now a very attractive alternative to Traveling Wave Tube Amplifiers (TWTA's).

AR's new offerings include various frequency ranges and output power levels to meet several standards, or designs can be tailored to suit your specific application. These amplifiers feature a touchscreen control panel, GPIB interface, TTL gating, fault monitoring, and forced air cooling.

Nine New Amplifiers Recently Added!

Features & Benefits For These Rugged Amplifiers Are:

- Octave Frequencies: 1-2 GHz and 2-4 GHz
- Narrowband Frequencies: 1.2-1.4 GHz & 2.7-3.1 GHz
- Power Levels: 1 kW to 150 kW
- Harmonic Distortion of -18dBc @ 1dB compression point
- Pulse Widths to 100 µsec. & Duty Cycles to 10%
- High Mean Time To Failure (MTTF)
- Mismatch Tolerance - Will operate without damage or oscillation with any magnitude and phase of source and load impedance
- Numerous Applications Possible - Automotive, MIL STD 464, DO-160 and Military Radar

Watch Our Pulsed Amps Video
Visit www.arworld.us/pavid or scan this page with the Layar app to watch on your mobile device.

To learn more, visit www.arworld.us/pulsedamps and download Application Note #72A or call us at 215-723-8181.

ISO 9001:2008 Certified

We don't just build great products. We build great products that last.

BUILT TO LAST

rf/microwave instrumentation

Other ar divisions: modular rf • sunar rf motion • receiver systems • ar europe

USA 215-723-8181. For an applications engineer, call 800-933-8181.
In Europe, call ar United Kingdom +44 1908 282766 • ar France +33147917530 • ar Deutschland +49 6101 80270 0 • ar Benelux +31 172 423000

www.arworld.us
Download the AR RF/Microwave Mobile App: www.arworld.us/arApp
Copyright © 2017 AR.
The orange stripe on AR products is Reg. U.S. Pat. & TM. Off.

Introduction

Kenneth Wyatt
Wyatt Technical Services
ken@emc-seminars.com

Thanks for purchasing this new EMC Desk Reference from Interference Technology! We hope you find it a valuable addition to your EMC and product design tools.

Electromagnetic compatibility (EMC) and the related electromagnetic interference (EMI) seems to be one of those necessary evils that must be overcome prior to marketing commercial or consumer electronic products, as well as military and aerospace equipment. Unfortunately, few universities and colleges teach this important information, with the result that products are rarely designed to meet EMC/EMI requirements. EMC or EMI compliance is often left to the end of a project with all the associated schedule delays and unplanned project cost.

The purpose of Interference Technology's EMC Desk Reference is to help product designers learn enough of the basics of EMC and EMI so that the usual design issues are addressed early when costs and design change is minimized. Achieving EMC/EMI is a lot easier once the basics are understood.

Today, with all the myriad of electronic products, including wireless and mobile devices, compatibility between devices is becoming even more important. Products must not interfere with one another (radiated or conducted emissions) and they must be designed to be immune to external energy sources, such as external transmitters and ESD. Most countries now impose some sort of EMC standards to which products must be tested.

BASIC DEFINITIONS

Let's start with some basic definitions between EMC and EMI, and there's a subtle difference. EMC implies that the equipment being developed is compatible within the expected operating environment. For example, a ruggedized satellite communications system when mounted in a military vehicle must work as expected, even in the vicinity of other high-powered transmitters or radars. This usually applies to military and aerospace products and systems.

EMI, on the other hand, is focused more with one product interfering with existing radio, television, or other communications systems, such as mobile telephone. It also includes immunity to external energy, such as electrostatic discharge and power line transients. This usually applies to commercial, consumer, medical, and scientific products.

WHY DO PRODUCTS RADIATE OR ARE SUSCEPTIBLE?

So, why do electronic products radiate or are susceptible to external energy sources? It's all about controlling the energy from internal sources coupling out causing interference, and external energy sources (ESD, etc.) from getting into and disrupting sensitive circuitry.

For example, the most common issue for most products is radiated emissions. We have an energy source and somehow, this energy source couples harmonic currents to an "antenna-like structure", such as an I/O cable. See *Figure 1*.

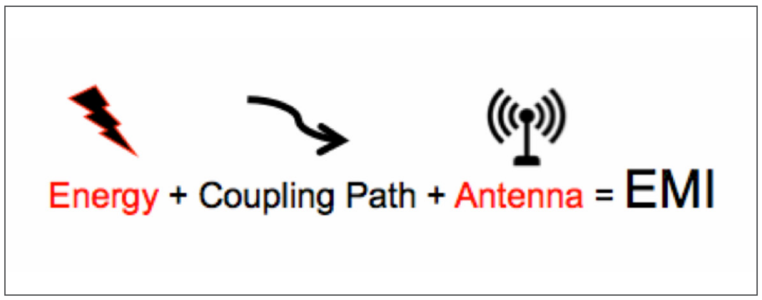


Figure 1 - A simple model for radiated emissions. Take away any of the three elements and you have no EMI.

Internal energy sources might include high frequency clocks or any high speed, fast-edged digital signal. These may be transferred via conduction, radiation, inductive, or capacitive coupling mechanisms. For example, a common situation is harmonics of a fast-edged clock (say an Ethernet clock) coupling to an I/O cable, which acts as an antenna and radiates. If these harmonic emissions are over certain limits, the product fails the test and must be redesigned to reduce or eliminate the coupling.

The reverse is also common. A good example is external ESD energy coupling to a poorly shielded I/O cable and allowing a high transient current to disrupt (or destroy) sensitive circuitry.

DIFFERENTIAL MODE VERSUS COMMON MODE CURRENTS

Finally, I want to touch on the difference between differential mode and common mode currents. We'll be explaining that currents flow in loops in the next article, but I'd just like to introduce the concept, as most digital designers tend to think in terms of voltage, rather than current, and it's usually the current that creates EMI.

Referring to *Figure 2*, the differential mode current (in blue) is the digital signal itself (in this example, shown as a ribbon cable). As described above, the conduction current and associated return current flow simultaneously as the signal wave front moves along the transmission line formed by the microstrip and return plane.

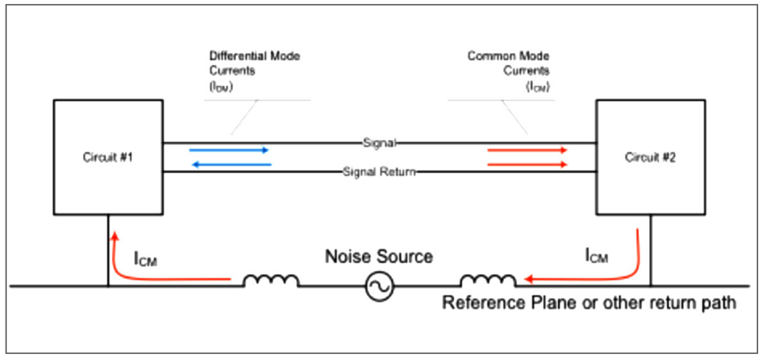


Figure 2 - An example of differential and common mode currents.

The common mode current (in red) is a little more complex in that it may be generated in a number of ways. In the figure, the impedance of the return plane results in small voltage drops due to multiple simultaneous switching noise (SSN) by the ICs. These voltage drops induce common noise currents to flow all over the return (or reference) plane and hence, couple into the various signal traces.

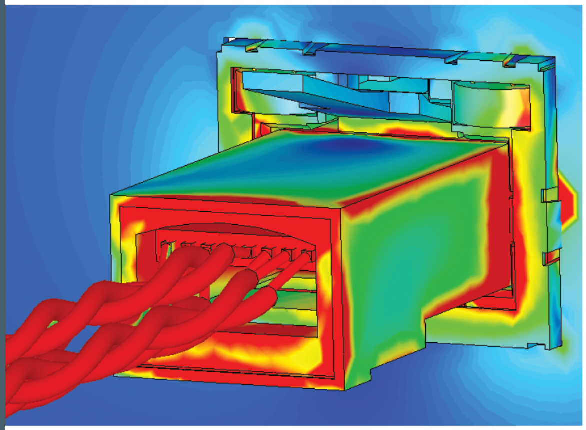
Besides SSN, common mode currents can also be created by gaps in return planes, poorly terminated cable shields, or unbalanced transmission line geometry. We'll be describing these in more detail in the next article. The problem is that these harmonic currents tend to escape out along the outside of shielded I/O or power cables and radiate. These currents can be very small, on the order of µA. It takes just 5 to 8 µA of current to fail the FCC class B test limit.

The three top product failures I see consistently as a consultant are (1) radiated emissions, (2) radiated susceptibility, and (3) electrostatic discharge. We'll discuss these and more in this EMC Desk Reference.

For this EMC Desk Reference, we'll start off describing some common product design issues, discuss how to perform your own in-house pre-compliance testing, describe a step-by-step approach to radiated emissions troubleshooting, and wrap up with a host of additional reference material, such as lists of common EMC standards, additional reference articles, books, and many other useful equations, charts and tools. Our hope is that you'll find this new reference a handy addition to your EMC tool kit. As ever, we may have missed something of value. If you have any comments or suggested additions, please contact me: kwyatt@interferencetechnology.com.

Make the Connection

Find the simple way through complex EM systems with CST STUDIO SUITE



Components don't exist in electromagnetic isolation. They influence their neighbors' performance. They are affected by the enclosure or structure around them. They are susceptible to outside influences. With System Assembly and Modeling, CST STUDIO SUITE helps optimize component and system performance.

Involved in EMC/EMI analysis? You can read about how CST technology is used for EMC/EMI analysis at www.cst.com/emc.

If you're more interested in microwave components or signal integrity analysis, we've a wide range of worked application examples live on our website at www.cst.com/apps.

Get the big picture of what's really going on. Ensure your product and components perform in the toughest of environments.

Choose CST STUDIO SUITE –
Complete Technology for 3D EM.

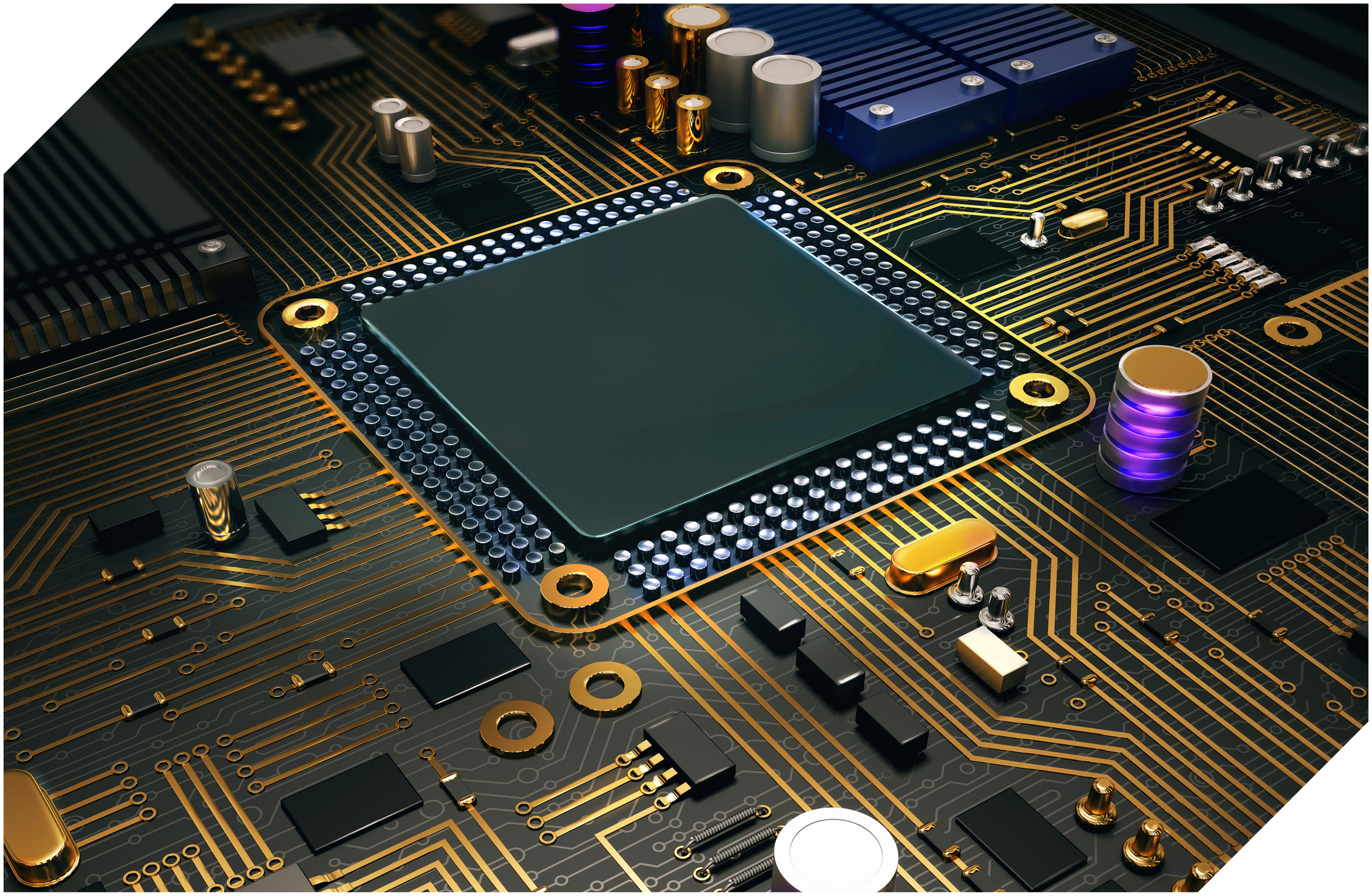
CST *joins* SIMULIA

CST, a Dassault Systèmes company | www.cst.com | info@cst.com

EMC Desk Reference

ARTICLES

Notes:



The Top Five Reasons Products Fail EMI Testing

Kenneth Wyatt
Wyatt Technical Services
ken@emc-seminars.com

Introduction

The three top product failures I see constantly in my consulting practice are (1) radiated emissions, (2) radiated susceptibility, and (3) electrostatic discharge. After reviewing and testing hundreds of products over the years, I've come to the conclusion that products fail these tests for five common reasons (somewhat in order of incidence);

1. ***PC Board Design** - Poor layout and layer stack-up*
2. ***Cable Shield Termination and Pigtails** - Cable shields are not terminated to enclosure or lack of common mode filtering for unshielded products, plus shield pigtails used*
3. ***Gaps in the Return Path** - High frequency clocks or signals crossing gaps in the return path*
4. ***Power Distribution Design** - Poor power distribution network (PDN) design*
5. ***Shielding Design** - Apertures or slots in the shielded enclosure that are too long*

1. PC BOARD DESIGN

The single most important factor in achieving EMC/EMI compliance revolves around the printed circuit board design. It's important to note that not all information sources (books, magazine articles, or manufacturer's application notes) are correct when it comes to designing PC boards for EMC compliance - especially sources older than 10 years, or so. In addition, many "rules of thumb" are based on specific designs, which may not apply to future or leveraged designs. Some rules of thumb were just plain lucky to have worked.

PC boards must be designed from a physics point of view and the most important consideration is that high frequency signals, clocks, and power distribution networks (PDNs) must be designed as transmission lines. This means that the signal or energy transferred is propagated as an electromagnetic wave. PDNs are a special case, as they must carry both DC current and be able to supply energy for switching transients with minimal simultaneous switching noise (SSN). The characteristic impedance of PDNs is designed with very low impedance (0.1 to 1.0 Ohms, typically). Signal traces, on the other hand, are usually designed with a characteristic impedance of 50 to 100 Ohms.

Understanding PC board design is all about two important concepts: (1) all currents flow in loops and (2) high frequency signals are propagated as electromagnetic waves in transmission lines. These two concepts are closely related and coupled to one another.

Currents Flow In Loops - Circuit theory suggests that current flows in loops from source to load and back to the source. In many cases of product failure, the return path has not been well defined and in some cases, the path is broken. The problem we circuit designers often miss is defining the return path of a high frequency signal back to the source. If you think about it, we don't even draw these return paths on the schematic diagram - just showing it as a series of various "ground" symbols.

So what is "high frequency"? Basically, anything higher than 50 to 100 kHz. For frequencies less than this, the return current will tend to follow the shortest path back to the source (path of least resistance). For frequencies above this, the return current tends to follow directly under the signal trace and back to the source (path of least impedance). See *Figure 1*.

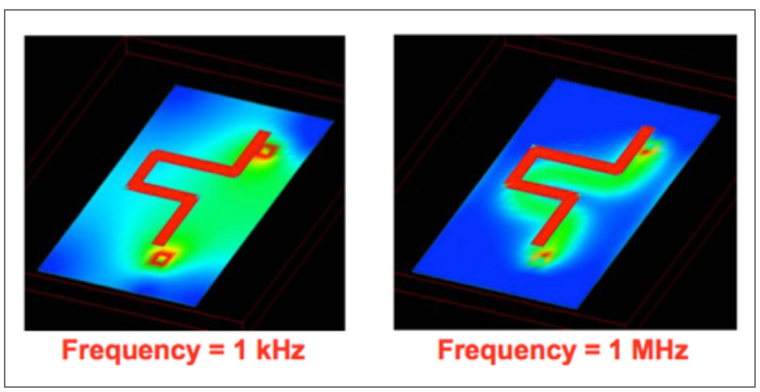


Figure 1 - Simulation showing the return path (in green) at low and high frequencies. Images, courtesy Keysight Technologies.

To reduce EMI, we need to minimize the area of these loops. Undefined return paths often result in large current loops from source to load and back to source. These large current loops start to look like loop antennas, coupling noise currents to "antenna-like" structures, such as cables, in your product or system.

Where some board designs go wrong is when high *dV/dt* return signals, such as those from low frequency DC-DC switch mode converters or high *di/dt* signals from digital logic and clock return signals get comingled with I/O circuit return currents, sensitive RF modules (especially receivers), or sensitive analog return currents. Just be aware of the importance of designing defined signal and power supply return paths. That's why the use of solid return planes under high frequency signals and then segregating digital, power, and analog circuitry on your board is so important.

How Signals Move - At frequencies greater than about 50 to 100 kHz, digital signals start to propagate as electromagnetic waves in transmission lines. As shown in *Figure 2*, a high frequency signal propagates along a transmission line (circuit trace over return plane, for example), and the wave front induces a conduction current in the copper trace and back along the return plane. Of course, this conduction current cannot flow through the PC board dielectric, but the charge at the wave front repels a like charge on the return plane, which "appears" as if current is flowing. This is the same principle where capacitors appear to "pass" AC current, and Maxwell called this effect "displacement current".

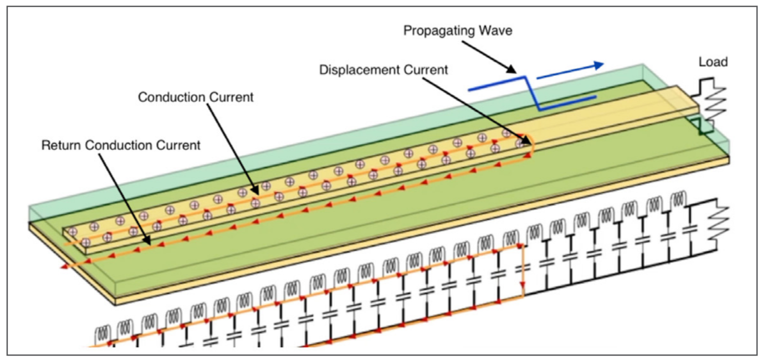


Figure 2 - A digital signal propagating along a microstrip with currents shown. Figure, courtesy Eric Bogatin.

The signal's wave front travels at some fraction of the speed of light, as determined by the dielectric constant of the material, while the conduction current is comprised of a high density of free electrons moving at about 1 cm/second. The actual physical mechanism of near light speed propagation is due to a "kink" in the E-field, which propagates along the molecules of copper. The important thing is that this combination of conduction and displacement current must have an uninterrupted path back to the source.

A high electric field is generated by high frequency digital signals occurring between the microstrip and return plane (or trace). If the return path is broken, the electric field will "latch on" to the next closest metal, which will not likely be the return path you want. When the return path is undefined, then the electromagnetic field will "leak" throughout the dielectric and cause common mode currents to flow all over the board. The uncontrolled field will also cause cross-coupling of clocks or other high speed signals to dozens of other circuit traces within that same dielectric through coupling to vias within the dielectric layer. The resulting common mode currents will tend to

Notes:

couple to "antenna-like structures", such as I/O cables or slots/apertures in shielded enclosures, resulting in EMI.

Circuit Board Stack-Ups - Most of us were taught the "circuit theory" point of view and it is important when we visualize how return currents want to flow back to the source. However, we also need to consider the fact that the energy of the signal is not only the current flow, but an electromagnetic wave front moving through the dielectric, or a "field theory" point of view. Keeping these two concepts in mind just reinforces the importance of designing transmission lines (signal trace with return path directly adjacent), rather than just simple circuit trace routing. A successful PC board design accounts for both viewpoints.

In order to satisfy both the circuit and field theory viewpoints, we now see the importance of adjacent power and power return planes, as well as adjacent signal and signal return planes. Signal or power routed referenced to a single plane will always have a defined return path back to the source. *Figure 3* shows how the electromagnetic field stays within the dielectric on both sides of the return plane. The dielectric is not shown for clarity.

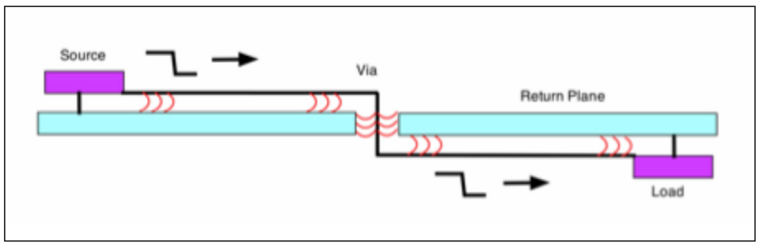


Figure 3 - A signal trace passing through a single reference plane.

On the other hand, referring to *Figure 4*, if a signal passes through two reference planes, things get a lot trickier. If the two planes are the same potential (for example, both are return planes), then simple connecting vias may be added adjacent to the signal via. These will form a nice defined return path back to the source.

If the two planes are differing potentials (for example, power and return), then stitching capacitors must be placed adjacent to the signal via. Lack of a defined return path will cause the electromagnetic wave to propagate throughout the dielectric, causing cross coupling to other signal vias and leakage and radiation out the board edges as shown.

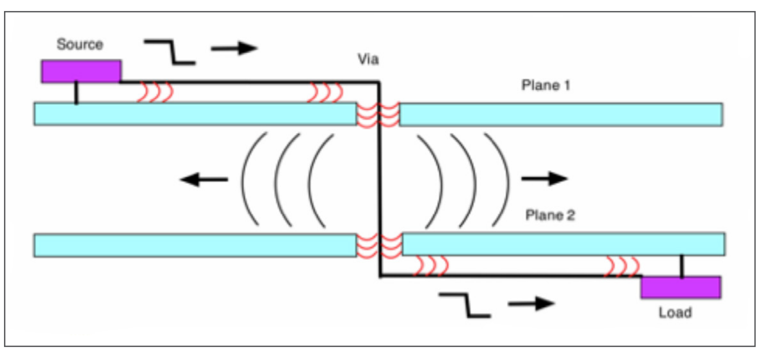


Figure 4 - A signal trace passing through two reference planes. If the reference planes are the same potential (signal or power returns, for example), then stitching vias next to the signal via should be sufficient. However, if the planes are different potentials (power and return, for example), then stitching capacitors must be installed very close to the signal via. Lack of a defined return path will cause the electromagnetic field to leak around the dielectric, as shown, and couple into other signal vias or radiate out board edges.

For example, let's take a look at a poor (but very typical) board stack-up that I see often (*Figure 5*).

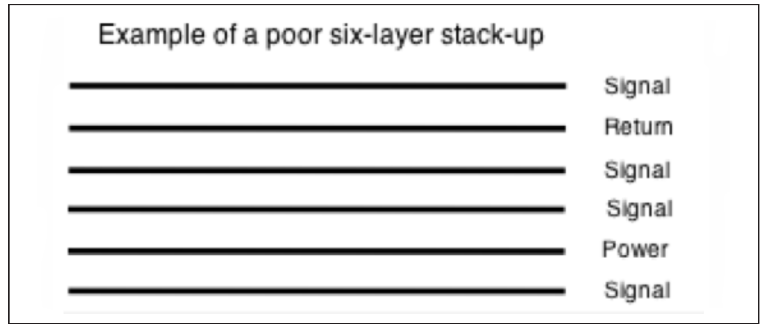


Figure 5 - A six-layer board stack-up with very poor EMI performance.

Notice the power and power return planes are three layers apart. Any PDN transients will tend to cross couple to the two signal layers in between. Similarly, few of the signal layers have an adjacent return plane, therefore, the propagating wave return path will jump all over to whatever is the closest metal on the way back to the source. Again, this will tend to couple clock noise throughout the board.

A better design is shown in *Figure 6*. Here, we lose one signal layer, but we see the power and power return planes are adjacent, while each signal layer has an adjacent signal (or power) return plane. It's also a good idea to run multiple connecting vias between the two return planes in order to guarantee the lowest impedance path back to the source. The EMI performance will be significantly improved using this, or similar designs. In many cases, simply rearranging the stack-up is enough to pass emissions.

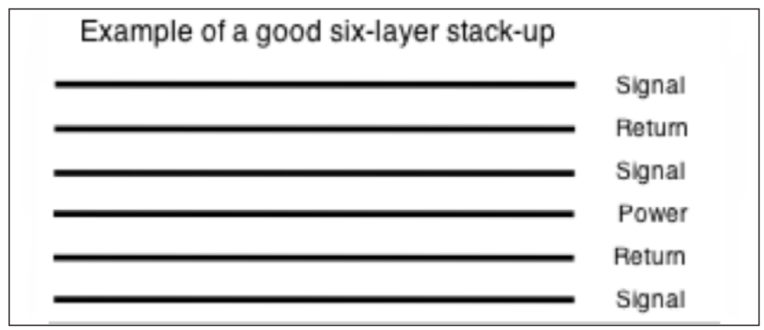


Figure 6 - A six-layer board stack-up with good EMI performance. Each signal layer has an adjacent return plane and the power and power return planes are adjacent.

Note that when running signals between the top and bottom layers, you'll need to include "stitching" vias between the return planes and stitching capacitors between the power and power return planes right at the point of signal penetration in order to minimize the return path. Ideally, these stitching vias should be located within 1 to 2 mm of each signal via.

Other Tips - Other design tips include placement of all power and I/O connectors along one edge of the board. This tends to reduce the high frequency voltage drop between connectors, thus minimizing cable radiation. Also, segregation of digital, analog, and RF circuits is a good idea, because this minimizes cross coupling between noisy and sensitive circuitry. Of course, high-speed clocks, or similar high-speed signals, should be run in as short and as direct a path as possible. These fast signals should not be run long board edges or pass near connectors.

Refer to *References 1, 2, 3,* and *4* for further details on PC board design and how fields move through transmission lines

2. CABLE SHIELD TERMINATION

Cable Penetration - The number one issue I find when tracking down a radiated emissions problem is cable radiation. The reason cables radiate is that they penetrate a shielded enclosure without some sort of treatment - either bonding the cable shield to the metal enclosure or common mode filtering at the I/O or power connector (*Figure 7* and *8*). This occurs frequently, because most connectors are attached directly to the circuit board and are then poked through holes in the shield. Once the cable is plugged in, it is "penetrating the shield" and EMI is the usual result.

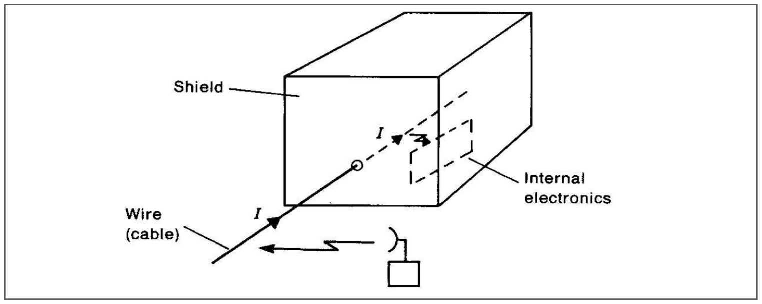


Figure 7 - Penetrating the shield with a cable defeats the shield. This example shows how external energy sources can induce noise currents in I/O cables, which can potentially disrupt internal circuitry. The reverse is also true, where internal noise currents can flow out the cable and cause emissions failures. Figure, courtesy Henry Ott.

There are four combinations or cases that must be considered: shielded or unshielded products, and shielded or unshielded cables. Power cables are usually unshielded for consumer/commercial products and so require power line filtering at the point of penetration or at the connector of the circuit board. Shielded cables must have the shield bonded (ideally in a 360 degree connection) to the product's shielded enclosure. If the product does not have a shielded enclosure, then filtering (usually common mode) must be added at the point of penetration or at the I/O connector of the PC board. *Figure 8* shows the usual result when connectors simply poke through a shielded enclosure.

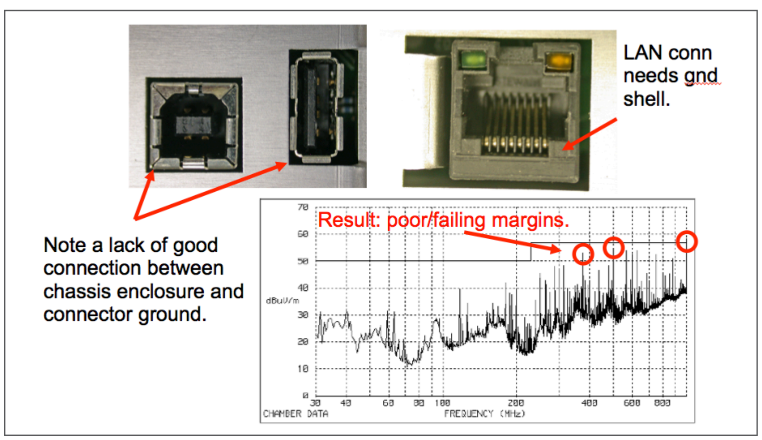


Figure 8 - Result of a penetrating cable through a shielded enclosure, because of un-bonded I/O connectors to the shielded enclosure.

Cable Shield Terminations - Another potential issue is if the I/O cable uses a "pigtail" connection to the connector shell (*Figure 9*). Ideally, cable shields should be terminated in a 360-degree bond for lowest impedance. Pigtails degrade the cable shield effectiveness by introducing a relatively high impedance. For example, a 1-inch pigtail connection has 12 Ohms impedance at 100 MHz and gets worse the higher you go in frequency, thus defeating the cable shield.

This is especially problematic for HDMI cables, because the HDMI working group (http://www.hdmi.org) failed to specify the method for terminating the cable shield to the connector. Fortunately, they are aware of the issue and will better define a proper termination method in the next revision of the standard. In the meantime, there is no guaranty that a particular cable, when used for formal certification testing, will work well, or not. Trial and error of several brands is recommended.

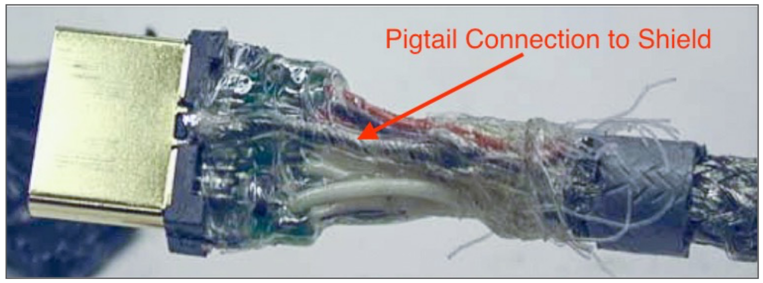


Figure 9 - An example of a poor cable shield termination in an HDMI cable. Figure, courtesy Dana Bergey.

Here are the results in testing eight different brands of HDMI cable (*Figure 10*). Each was driven with a signal generator and measured in an EMI chamber while sweeping the frequency. For a detailed report of this test, refer to *Reference 5*.

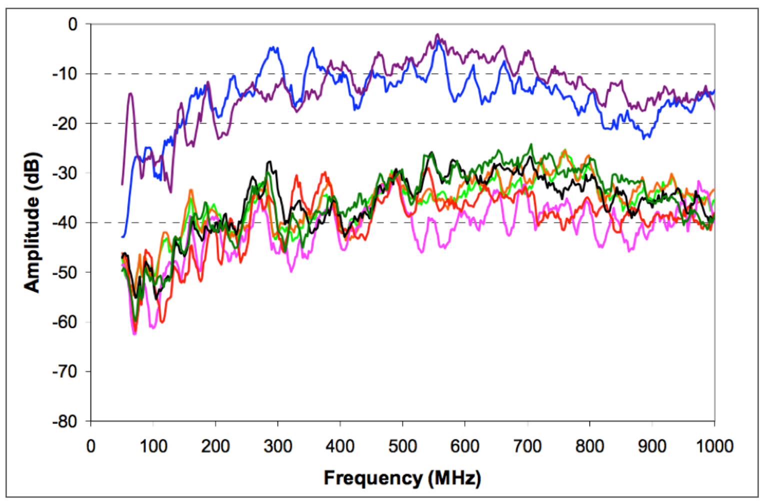


Figure 10 - The results of testing eight HDMI cables from 30 to 1000 MHz. As you can see, two of these exhibited 25 dB worse emissions across the band. Courtesy, Dana Bergey.

3. GAPS IN THE RETURN PLANE

Breaks or gaps in the return path are major causes of radiated emissions, radiated susceptibility, and ESD failures. Let's come back to the issue of a gap or slot in the return plane mentioned earlier and show an example of why it's bad news for EMI. When the return path is interrupted, the conduction current is forced around the slot, or otherwise finds the nearest (lowest impedance) path back to the source. The

Notes:

Notes:

electromagnetic field is forced out and the field will "leak" all over the board. I have an article and good demonstration video of this and how it affects common mode currents and ultimately, EMI. See *Figure 11* and *Reference 6*. This would be a great demo to construct and show your own colleagues!

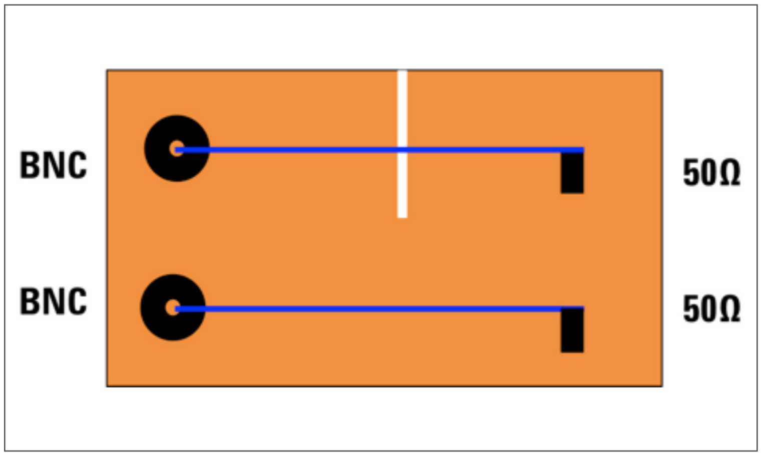


Figure 11 - shows a demonstration test board with transmission lines terminated in 50 Ohms. One transmission line has a gap in the return plane and the other doesn't. A 2 ns pulse generator is connected to one of the two BNC connectors in turn and the harmonic currents in a wire clipped to the return plane are measured with a current probe.

The difference between the gapped and un-gapped traces is shown in *Figure 12*. Note the harmonic currents are 10 to 15 dB higher for the gapped trace (in red). Failing to pay attention to the signal and power return paths is a major cause of radiated emissions failures.

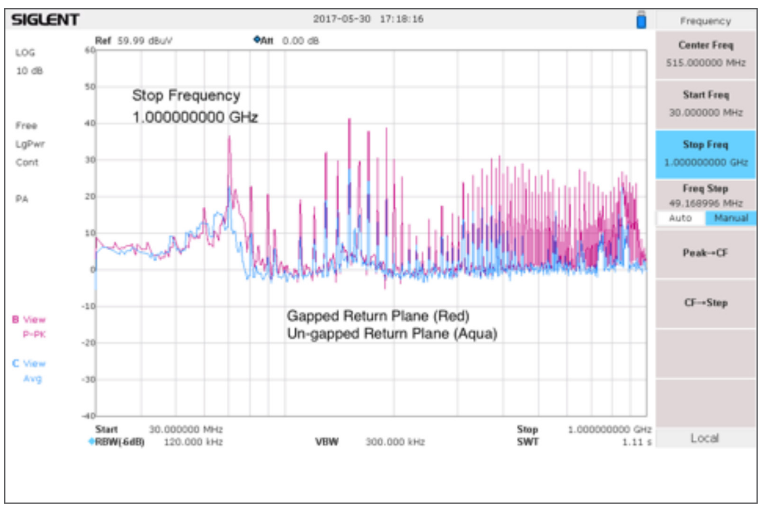


Figure 12 - The resulting common mode currents on an attached wire as measured with a current probe. The trace in aqua is the un-gapped return path and the trace in red, the gapped return path. The difference is 10 to 15 dB higher for the gapped return path. These harmonic currents will tend to radiate and will likely cause radiated emissions failures.

4. POWER DISTRIBUTION NETWORK DESIGN

Power distribution network (PDN) design requires a low impedance (0.1 to 1.0 Ohms, typically) transmission line through at least 30 MHz. The purpose of a PDN is to transfer energy from the power source (often a voltage regulator module on the PC board) to the switching IC as fast as possible.

When the output stage of a digital IC switches from high to low or from low to high, there is a period of time when both output devices are partially turned on. This causes a large current pulse between the supply rail and power return pin of the IC. This "shoot through" current pulse tends to lower the supply voltage, causing what's known as simultaneous switching noise (SSN) on the power rail. This SSN tends to propagate throughout the PC board. A well designed PDN minimizes this SSN.

Capacitors, in the form of bulk, decoupling, and board capacitance, are used to store enough energy to overcome the tendency of the power rail voltage to decrease. *Figure 13* shows a typical circuit model of a PDN with the power source on the left, supplying energy to the IC on the right. In between, we have a series of energy storage capacitors and transmission lines (PC traces). Unfortunately, it takes significant time to transfer the required energy from the power source to the IC. It has been shown that it takes about 600 ps to transfer an amp of current across 1/16th inch of die bonds (*Reference 10*). That's why it's especially important to keep PDNs short and direct as possible.

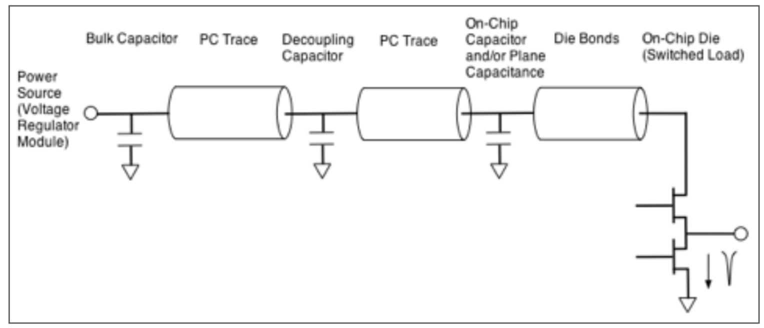


Figure 13 - A typical circuit model of a power distribution network (PDN).

Ideally, the total energy demand will be met by the "on-chip" capacitors, if any, plus the energy stored in the power plane capacitance. However, these are seldom enough storage, so we depend a lot on nearby decoupling capacitors to supply the remaining energy demand. It is critical for the decoupling capacitors to have as little series inductance (in the form of internal inductance and trace inductance) as possible. The greater this series inductance, the harder it is to supply the required energy to the load and SSN results with related noise coupling throughout the PC board.

Assuming the decoupling and any built-in capacitance of the PC board can supply the energy needs, then the job of the bulk capacitor is to "recharge" the energy of the downstream capacitors in between switching transients. For the fastest recharge times, the PDN must be in the form of low impedance transmission lines.

The bulk capacitors 4.7 to 10 µF, typ.) are usually placed near the power input connector and the decoupling capacitors (1 to 10 nF, typ) nearest the noisiest switching devices To achieve the lowest series inductance, all decoupling capacitors should be mounted as close to the IC to be decoupled as possible and right over (or close to) the connecting vias. Multiple vias should be used for each end of the capacitor to further reduce series inductance. More on PDN design may be found in *References 7, 8*, and *9*.

5. SHIELDING DESIGN

The two issues with shielded enclosures is getting all pieces well-bonded to each other and to allow power or I/O cable to penetrate it without causing leakage of common mode currents. Bonding between sheet metal may require EMI gaskets or other bonding techniques. *Figure 14* shows a handy chart for determining the 20 dB attenuation of a given slot length. For example, if a product design requires at least a 20 dB shielding effectiveness, then the longest slot length can be just one-half inch.

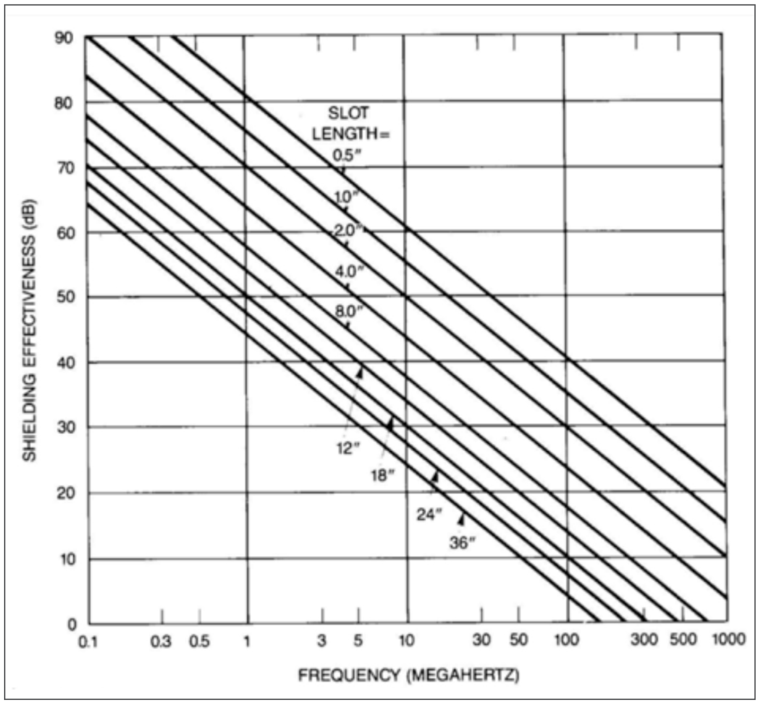


Figure 14 - A chart of attenuation versus slot length. Figure, courtesy Henry Ott.

Slots or apertures in shielded enclosures become issues when the longest dimension approaches a half wavelength. *Figure 15* is a chart of wavelength versus frequency. For example a 6-inch (15 cm) slot has a half wave resonance at 1000 MHz. Generally, ventilation holes should be patterns of round holes no more than 1/4-inch diameter. Patterns of slots may be used, but they should be no longer than 1/2-inch in order to preserve an adequate shielding effectiveness.

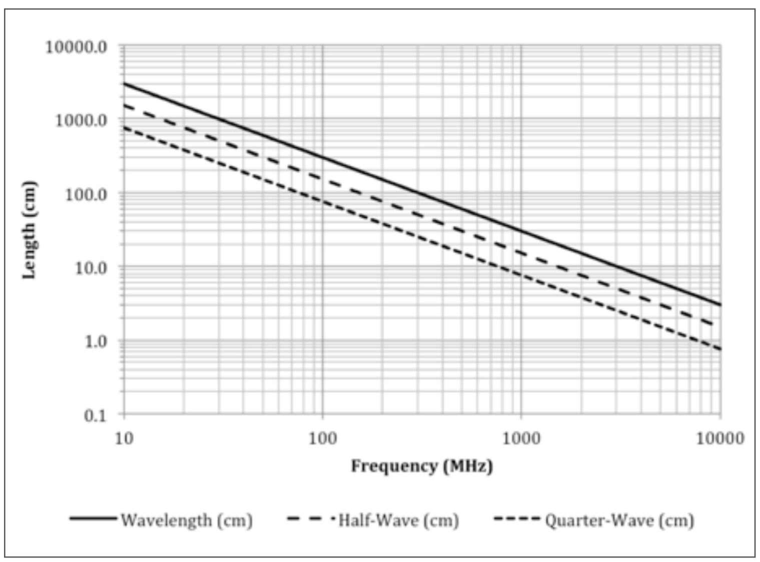


Figure 15 - A handy chart for determining resonant frequency versus cable or slot length in free space. Half-wavelength slots simulate dipole antennas and are particularly troublesome. Figure, courtesy Patrick André.

See *Reference 10* and *11* for more detail on shielding. Interference Technology also has a free downloadable 2016 EMI Shielding Guide with excellent information (*Reference 12*). This guide will be updated later in 2017.

SUMMARY

Paying attention to these five product design faults will go a long way towards lowering the risk of EMI failure during formal compliance testing. Considering a proper EMC design early in project development will save tons of time and money in the end.

REFERENCES

1. Bogatin, Signal Integrity - Simplified, Prentice-Hall, 2009.

2. Morrison, Grounding and Shielding - Circuits and Interference, Wiley, 2016.

3. Morrison, Digital Circuit Boards - Mach 1 GHz, Wiley, 2012.

Beeker, Effective PCB Design, https://www.nxp.com/files-static/training_pdf/WBNR_PCBDESIGN.pdf

Bergey & Altland, EMI Shielding of Cable Assemblies, DesignCon 2008, http://www.magazines007.com/pdf/DC08_Dana_Bergey.pdf

Wyatt, Gaps in Return Planes - Bad News for EMI (with video demo), https://interferencetechnology.com/gaps-return-planes-bad-news-emi/

4. Smith and Bogatin, Principles of Power Integrity for PDN Design, Prentice-Hall, 2017.

5. Sandler, Power Integrity - Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronic Systems, McGraw Hill, 2014.

6. Novak and Miller, Frequency-Domain Characterization of Power Distribution Networks, Artech House, 2007.

7. Ott, Electromagnetic Compatibility Engineering, Wiley, 2009

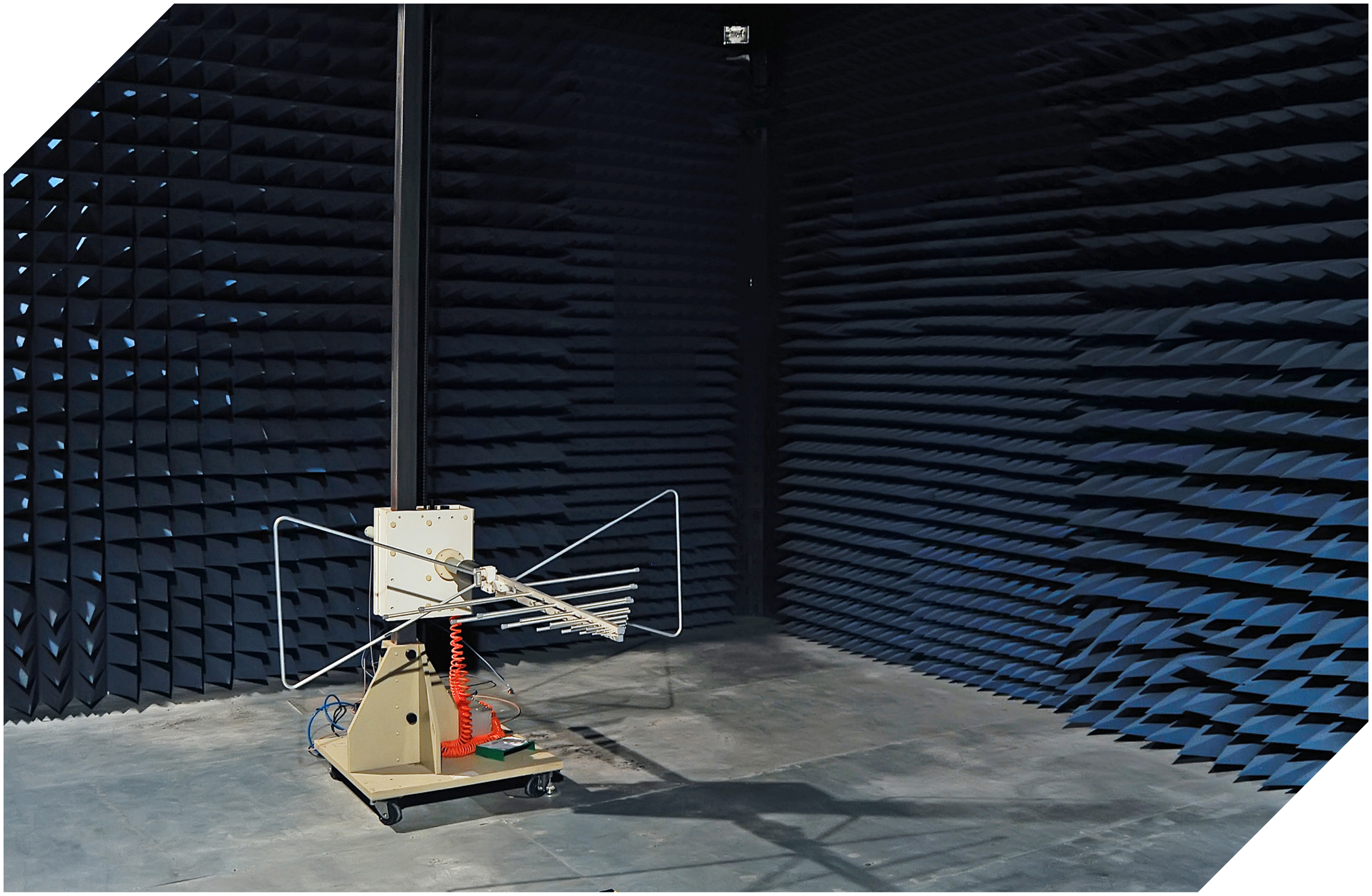
8. André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech, 2014.

9. Interference Technology's 2016 EMI Shielding Guide, http://learn.interferencetechnology.com/2016-emi-shielding-guide/

Notes:

ARTICLES

Notes:



EMI Pre-Compliance Testing

Kenneth Wyatt
Wyatt Technical Services
ken@emc-seminars.com

Introduction

This article describes how I perform pre-compliance testing for the top four EMI issues I constantly run into; conducted emissions, radiated emissions, radiated immunity, and electrostatic discharge. Of these, the last three are the most prevalent issues, with radiated emissions typically being the biggest compliance challenge during certification testing. If your product or system (EUT) has adequate power and I/O port filtering, conducted emissions and the other power line-related immunity tests are not usually an issue.

You might consider assembling your own EMI troubleshooting kit. For your convenience, I've developed a list of recommended equipment useful for troubleshooting EMI. The download link is listed in Reference 1.

Notes:

AMBIENT TRANSMITTERS

One problem you'll run into immediately when testing conducted or radiated emissions outside of a shielded room, is the number of ambient signals from sources like FM and TV broadcast transmitters, cellular telephone, and two-way radio. This is especially an issue when using external antennas. I'll usually run a baseline plot on the analyzer using "Max Hold" mode to build up a composite ambient plot. Then, I'll activate additional traces for the actual measurements. For example, I often have at least two plots or traces on the screen; the ambient baseline and the actual pre-compliance measurement.

Fortunately, there are three ways around this:

1. In most cases, you'll observe a range of product emissions in a harmonic relationship. Very often, these harmonics are created from the same source and if one, or more, are masked by ambient signals, then working on the others that are more visible will generally bring the whole batch down, as well.

2. In some cases there will be a critical harmonic masked by an ambient transmitter. A good example is a 100 MHz harmonic hidden underneath a large FM broadcast station at 99.9 MHz. In this case, I'll try reducing the resolution bandwidth from 100 or 120 kHz down to as little as 1 kHz, or less. This often "filters out" the modulation from the FM station, allowing you to observe the hidden harmonic. This also presumes the harmonic is an unmodulated continuous wave (CW) signal. Just be sure reducing the RBW doesn't also reduce the harmonic amplitude. If your harmonic is modulated, this may not work and you may have to move to a quieter measurement site.

3. Move your pre-compliance testing well away from urban transmitters (easier said than done these days).

Another caution when using spectrum analyzers is that strong nearby transmitters can affect the amplitude accuracy of the measured signals, as well as create mixing products that appear to be harmonics, but are really combinations of the transmitter frequency and mixer circuit in the analyzer. You may need to use an external bandpass filter at the desired harmonic frequency to reduce the affect of the external transmitter. An example would be an FM broadcast band "stop band" filter.

Although more expensive, an EMI receiver with tuned preselection would be more useful than a normal spectrum analyzer in high RF environments. Suppliers, such as Keysight Technologies or Rohde & Schwarz, make EMI receivers. All these techniques to deal with ambient signals are described more fully in *Reference 2*.

CONDUCTED EMISSIONS

This is usually not an issue given adequate power line filtering, however, many low-cost power supplies lack good filtering. Some "no name" brands have no filtering at all! The conducted emissions test is easy to run and only requires a line impedance stabilization network, or LISN (basically an impedance match from the power line to 50 Ohms). *Figure 1* shows a typical LISN.

Figure 1 - A typical line impedance stabilization network, or LISN.

I prefer setting the vertical units from the default dBm to dBμV, so the displayed numbers are positive. Then adjust the Reference Level for even increments along the vertical axis. This is also the same unit used in the test limits of the EMI standard. I also like to set the horizontal scale from linear to log (if possible), so frequencies are easier to read out.

Set up your spectrum analyzer as follows:

1. Frequency 150 kHz to 30 MHz

2. Resolution bandwidth = 9 kHz, per the standard, or 10 kHz is close enough

3. Preamp = Off

4. Set the vertical units to dBμV

5. Adjust the Reference Level so the highest harmonics are displayed and the vertical scale is reading in even 10 dB increments

6. Use average detection initially and CISPR detection on any peaks later

7. Internal attenuation - start with 20 to 30 dB at first and adjust for best display and no analyzer overload.

Obtain a Line Impedance Stabilization Network (LISN) and position it between the product or system under test and the spectrum analyzer. Note the sequence of connection below!

***CAUTION:** It's often important to power up the EUT prior to connecting the LISN to the analyzer. This is because large transients can occur at power-up and may potentially destroy the sensitive input stage of the analyzer. Note that the TekBox LISN has built-in transient protection. Not all do…you've been warned!*

Ideally, you'll want to set up the test according to CISPR 11 or 32 (depending on the type product, ISM or ITE). See *Figure 2* for an example. The LISN is bonded to the ground plane and the EUT is placed on a table 80cm high.

Notes:

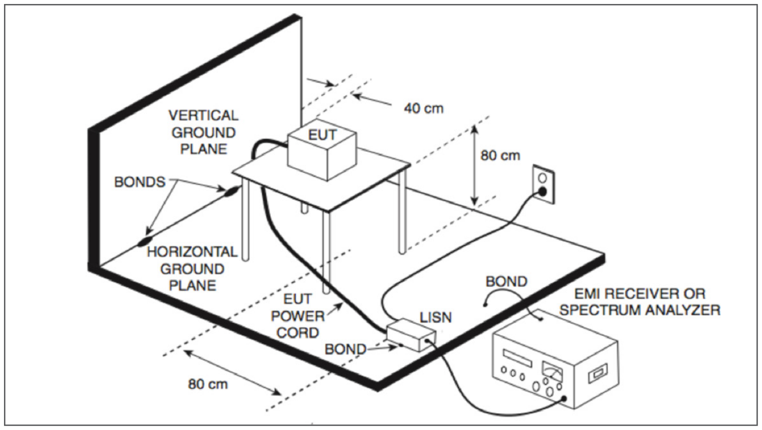


Figure 2 - The suggested test set up for conducted emissions.

Power up the EUT and then connect the 50-Ohm output port of the LISN to the analyzer. Note the harmonics are usually very high at the lower frequencies and taper off towards 30 MHz. Be sure these higher harmonics don't overdrive the analyzer. Add additional internal attenuation, if required.

By comparing the average detected peaks (or quasi peak, if your analyzer offers this option) with the appropriate FCC or CISPR limits, you'll be able to tell whether the EUT is passing or failing prior to formal compliance testing. Refer to the References section for FCC and CISPR conducted emission limits in dBμV.

RADIATED EMISSIONS

This is normally the highest risk test and most prone to fail compliance testing. Therefore, setting up this test in-house should be a priority. Performing an accurate pre-compliance test for radiated emissions requires a calibrated EMI antenna positioned either 3m or 10m away from the product under test. This way, you'll be able to compare the emissions with actual test limits. These antennas can range in price from $1000 to $6000 USD.

The test should be set up in any area large enough and far away from other equipment that could interfere with the testing. Sometimes a parking lot is used. I've more often used a large conference room (*Figure 3*).

Figure 3 - An example of a 3m pre-compliance test set up in a large conference room. Note the DIY turntable for helping maximize emissions.

I prefer setting the vertical units from the default dBm to dBμV, so the displayed numbers are positive. Then adjust the Reference Level for even increments of 10 along the vertical axis. This is also the same unit used in the test limits of the EMI standards and also used in the equation below for calculating the E-field level. I also like to set the horizontal scale from linear to log (if possible), so frequencies are easier to read out.

Set up your spectrum analyzer as follows:

1. Frequency 10 to 500 MHz
2. Resolution bandwidth = 120 kHz, per the standard, or 100 kHz is close enough
3. Preamp = On (or use an external 20 dB preamp if the analyzer lacks this). This may not be required if the harmonic emissions are observable without it.
4. Set the vertical units to dBμV
5. Adjust the Reference Level so the highest harmonics are displayed and the vertical scale is reading in even 10 dB increments
6. Use positive peak detection
7. Set the internal attenuation = zero

You can calculate the E-field (dBμV/m) at a given measurement distance (typically 3m or 10m) by recording the dBμV reading of the spectrum analyzer and factoring in the coax loss, external preamp gain (if used), any external attenuator (if used), and antenna factor (from the antenna calibration provided by the manufacturer). This calculation can then be compared directly with the 3m or 10m radiated emissions test limits using the formula:

E-field (dBμV/m) = SpecAnalyzer (dBμV) - PreampGain (dB) + CoaxLoss (dB) + AttenuatorLoss (dB) + AntFactor (dB)

Refer to the References section for FCC and CISPR radiated emission limits in dBμV/m.

RADIATED IMMUNITY

Most radiated immunity tests are performed from 80 to 1000 MHz (or, in some cases, as high as 2.7 GHz). Common test levels are 3 or 10 V/m. Military or automotive products can go as high as 50 to 200 V/m, depending on the operational environment. The commercial standard for most products is IEC 61000-4-3, whose test setup is quite involved and relatively expensive, in that it requires lots of test equipment and a semi-anechoic chamber designed for a uniform E-field at the EUT position. However, using some simple techniques, you can identify resolve most issues quickly on the work bench.

<u>Handheld Radio</u> - For radiated immunity, we generally start outside the EUT and use license-free handheld transmitters, such as the Family Radio Service (FRS) walkie-talkies (or equivalent) to determine areas of weakness. By holding these low power radios close to the

Notes:

product or system under test, you can often force a failure (*Figure 4*).

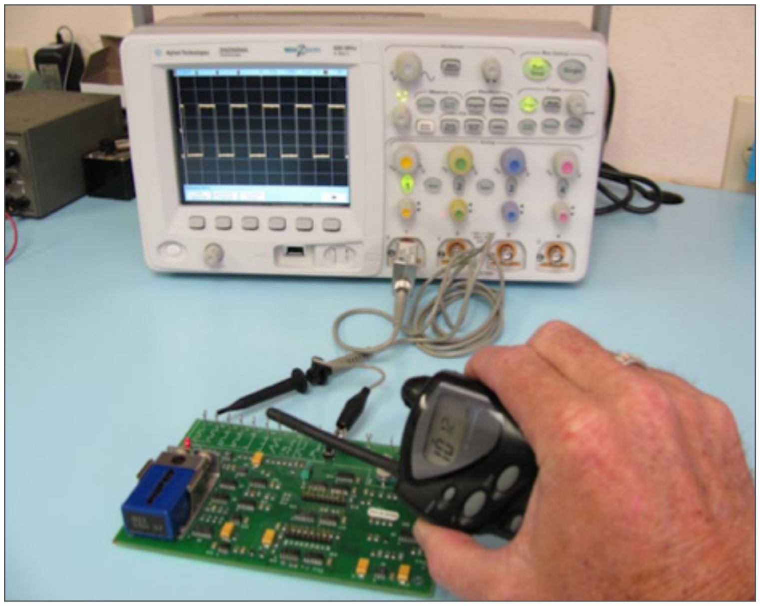


Figure 4 - Using a license-free transmitter to force a failure.

Hold the transmit button down and run the radio antenna all around the EUT. This should include all cables, seams, display ports, etc.

RF Generator - It's very common that only certain frequency bands are susceptible and sometimes the fixed frequency handheld radios are not effective. In that case, I use an adjustable RF generator with attached large size H-field probe and probe all around at known failing frequencies. It also helps to probe the internal cables and PC board to determine areas of sensitivity. For smaller products, as in *Figure 5*, try using the smaller H-field probes for best physical resolution.

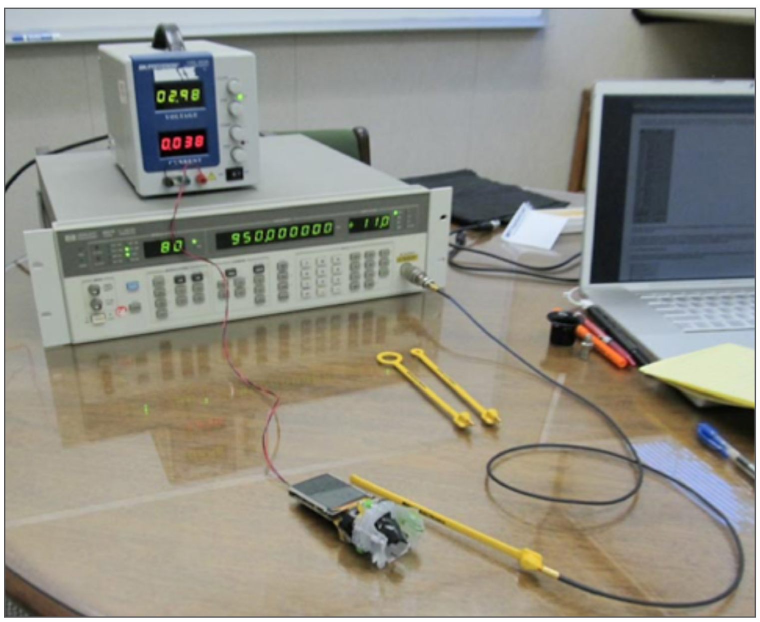


Figure 5 - Using an RF generator and H-field probe to determine areas of sensitivity.

In place of the larger lab-quality RF generators, I also use a smaller USB-controlled RF synthesizer, such as the Windfreak SynthNV (or equivalent) with the near field probe. The SynthNV is USB-controlled and can produce up to +19 dBm RF power from 34 MHz to 4.4 GHz. This also fits into my EMI troubleshooting kit nicely. See *Figure 6*. You'll find a list of recommended generators in *Reference 1*.

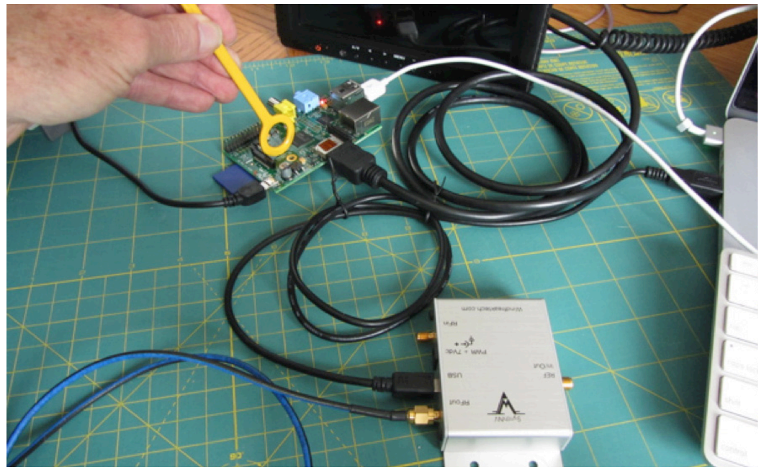


Figure 6 - Using a small synthesized RF generator to produce intense RF fields around the probe tip.

ELECTROSTATIC DISCHARGE

Electrostatic discharge testing is best performed using a test setup as described in the IEC 61000-4-2 standard. This requires a test table and ground planes of certain dimensions. The EUT is placed in the middle of the test table. I usually suggest replacing floor tiles with copper or aluminum 4 x 8-foot sheets, which will fit right into the spaces of the existing tiles (*Figure 7*).

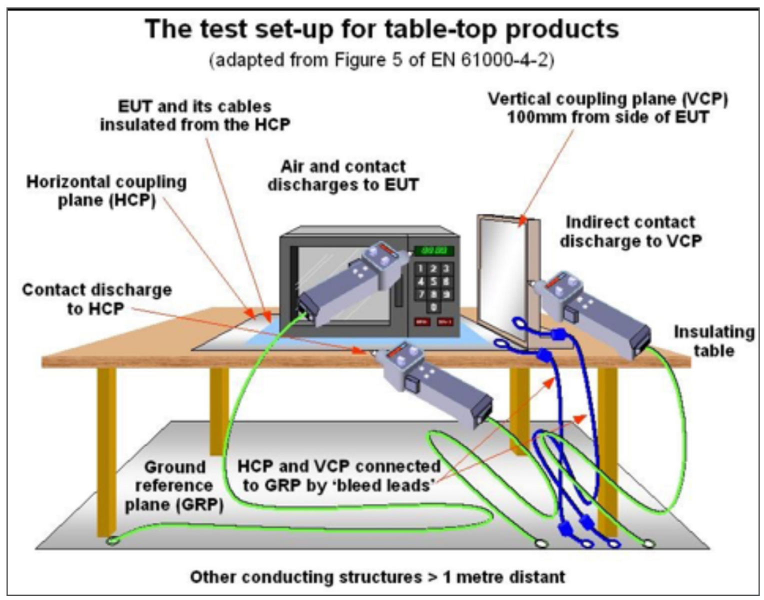


Figure 7 - The ESD test setup according to IEC 6100-4-2. Image, courtesy Keith Armstrong.

Testing requires an ESD simulator, which is available from a number of sources. See *Reference 1*. I use the older KeyTek MiniZap (*Figure 8*), which is relatively small and can be adjustable to +/- 15 kV. There are several other suitable (and newer) designs.

ESD testing is rather complex as far as identifying the test points, but basically, there are two tests - air discharge and contact discharge. Use air discharge for all points where an operator could touch the outside of the EUT. Use contact discharge for all exposed metal where an op-

ARTICLES

Notes:

erator could touch and discharge into. Test both positive and negative polarities. Most commercial tests require 4 kV contact discharge and 8 kV air discharge.

Figure 8 - A typical ESD simulator with air and contact discharge tips. It can produce up to +/- 15 kV.

The test setup also includes horizontal and vertical coupling planes. Use the contact discharge tip into the coupling planes. These planes need a high-impedance discharge path to earth. See the IEC 61000-4-2 standard for details and exact test procedures.

SUMMARY

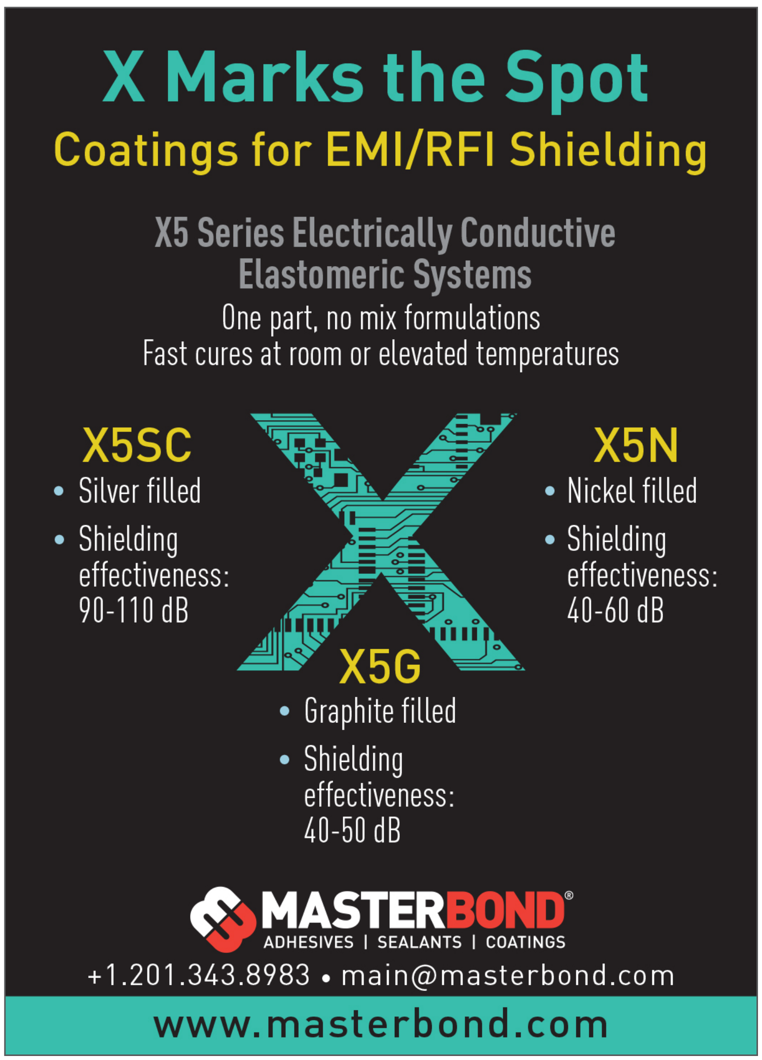
By developing your own EMI pre-compliance tests, you'll save time and money by moving the testing process in-house, rather than scheduling time and the related cost and scheduling delays by depending on commercial test labs.

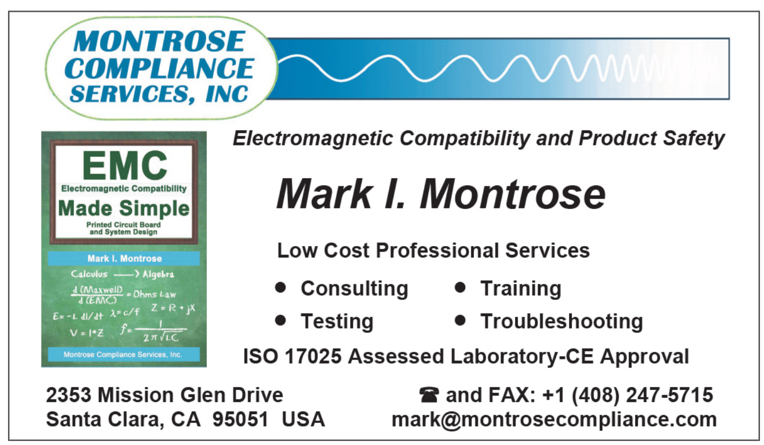
Most of the high-risk EMI tests are easily performed with low-cost equipment. The cost savings by performing troubleshooting at you own facility can mount up to hundreds of thousands of dollars and weeks or months of product delays.

REFERENCES

1. Recommended list of EMI troubleshooting equipment - http://www.emc-seminars.com/EMI_Troubleshooting_Equipment_List-Wyatt.pdf

2. André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech, 2014.





TYPICAL CONVERSION FORMULAS

LOG -> LINEAR VOLTAGE

dBμV to Volts	$V = 10^{((dB\mu V - 120)/20)}$
Volts to dBμV	dBμV = 20 log(V) + 120
dBV to Volts	$V = 10^{(dBV/20)}$
Volts to dBV	dBV = 20log(V)
dBV to dBμV	dBμV = dBV +120
dBμV to dBV	dBV = dBμV - 120

LOG -> LINEAR CURRENT

dBμA to uA	$\mu A = 10^{(dB\mu A/20)}$
μA to dBμA	dBμA = 20 log(μA)
dBA to A	$A = 10^{(dBA/20)}$
A to dBA	dBA = 20log(A)
dBA to dBμA	dBμA = dBA + 120
dBμA to dBA	dBA = dBμA -120

LOG -> LINEAR POWER

dBm to Watts	$W = 10^{((dBm - 30)/10)}$
Watts to dBm	dBm = 10log(W) + 30
dBW to Watts	$W = 10^{(dBW/10)}$
Watts to dBW	dBW = 10log(W)
dBW to dBm	dBm = dBW + 30
dBm to dBW	dBW = dBm - 30

TERM CONVERSIONS

dBm to dBμV	dBμV = dBm + 107 (50Ω) *dBμV = dBm + 10log(Z) + 90*
dBμV to dBm	dBm = dBμV – 107 (50Ω) *dBm = dBμV – 10log(Z) – 90*
dBm to dBμA	dBμA = dBm + 73 (50Ω) *dBμA = dBm – 10log(Z) + 90*
dBμA to dBm	dBm = dBμA – 73 (50Ω) *dBm = dBμA + 10log(Z) – 90*
dBμA to dBμV	dBμV = dBμA + 34 (50Ω) *dBμV = dBμA + 20log(Z)*
dBμV to dBμA	dBμA = dBμV – 34 (50Ω) *dBμA = dBμV – 20log(Z)*

FIELD STRENGTH & POWER DENSITY

dBμV/m to V/m	$V/m = 10^{(((dB\mu V/m) - 120)/20)}$
V/m to dBμV/m	dBμV/m = 20 log(V/m) + 120
dBμV/m to dBmW/m²	$dBmW/m^2 = dB\mu V/m - 115.8$
dBmW/m² to dBμV/m	$dB\mu V/m = dBmW/m^2 + 115.8$
dBμV/m to dBμA/m	dBμA/m = dBμV/m – 51.5
dBμA/m to dBμV/m	dBμV/m = dBμA + 51.5
dBμA/m to dBpT	DBpT = dBμA/m + 2
dBpT to dBμA/m	dBμA/m = dBpT – 2
W/m² to V/m	$V/m = SQRT(W/m^2 * 377)$
V/m to W/m²	$W/m^2 = (V/m)^2 / 377$
μT to A/m	A/m = μT / 1.25
A/m to μT	μT = 1.25 * A/m

E-FIELD ANTENNAS

Correction Factor	dBμV/m = dBμV + AF
Field Strength	$V/m = \frac{\sqrt{30 * watts * Gain_{numeric}}}{meters}$
Required Power	$Watts = \frac{(V/m * meters)^2}{30 * Gain_{numeric}}$

LOOP ANTENNAS

Correction Factors	dBμA/m = dBμV + AF
Assumed E-field for shielded loops	dBμV/m = dBμA/m + 51.5 dBpT = dBμV + dBpT/μV

CURRENT PROBES

Correction Factor	$dB\mu A = dB\mu V - dB_{(ohm)}$

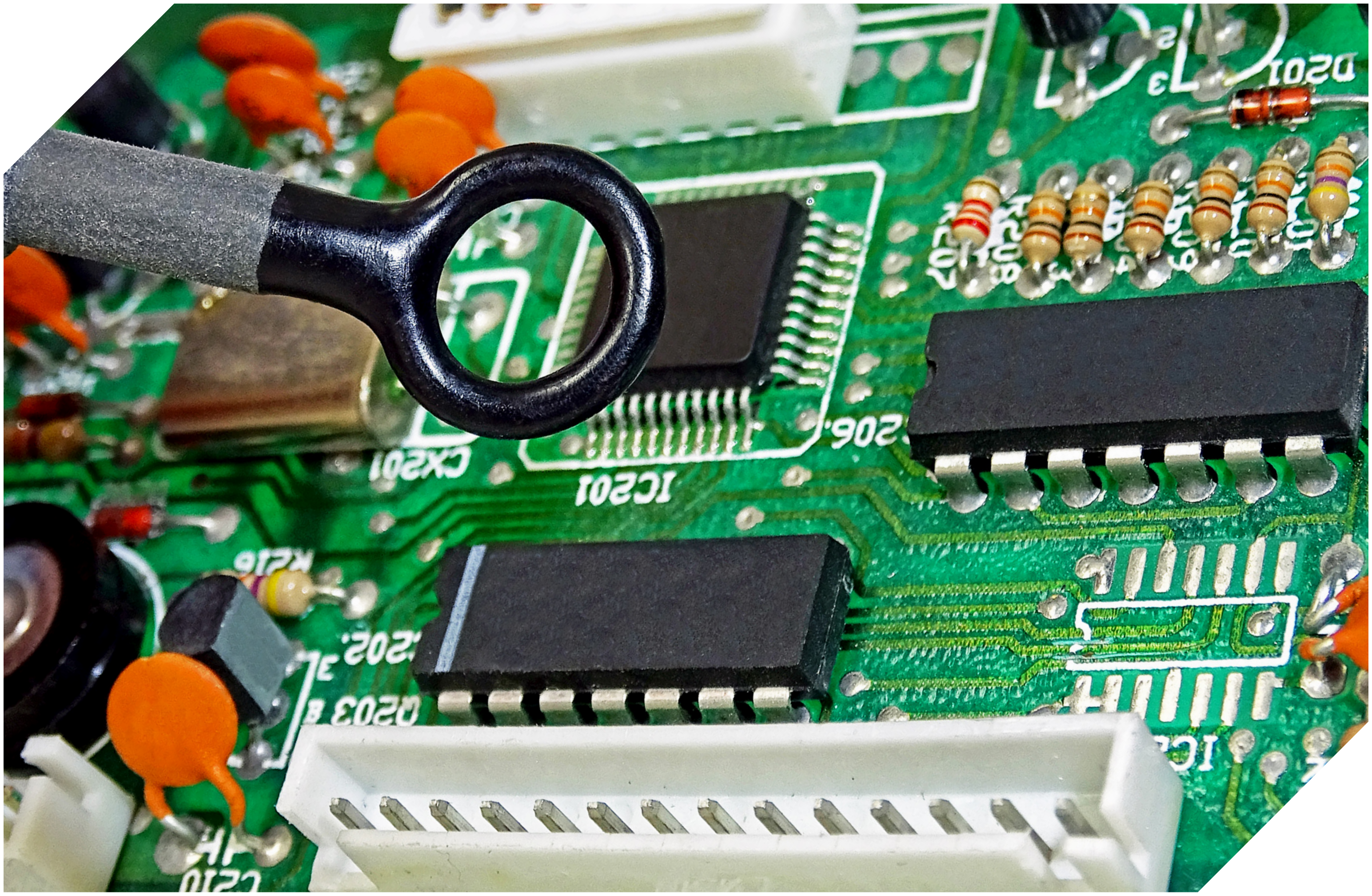
Power needed for injection probe given voltage(V) into 50Ω load and Probe Insertion Loss (I_7)

$$Watts = 10^{((I_7 + 10\log(V^2/50))/10)}$$

The Antenna Specialists
Innovation Quality Performance
Phone: (818)998-0223 ♦ Fax (818)998-6892
http://www.AHSystems.com
A.H. Systems

ARTICLES

Notes:



Radiated Emissions Troubleshooting - Step-By-Step

Kenneth Wyatt
Wyatt Technical Services
ken@emc-seminars.com

Introduction

In this article, I'll describe the steps I usually take to troubleshoot radiated emissions. Radiated emissions is typically the number one compliance failure and I use a three-step process to help troubleshoot the problem. If your product or system (EUT) has adequate power and I/O port filtering, conducted emissions and the other power line-related immunity tests are not usually an issue.

For your convenience, I've developed a list of recommended equipment useful for troubleshooting general EMI issues. You might consider building up your own EMI troubleshooting kit (Figure 1). The download link is listed in Reference 1.

Figure 1 - The troubleshooting kit I've developed over the years can characterize and debug many emissions and susceptibility issues.

Notes:

AMBIENT TRANSMITTERS

One problem you'll run into immediately when testing conducted or radiated emissions outside of a shielded room, is the number of ambient signals from sources like FM and TV broadcast transmitters, cellular telephone, and two-way radio. This is especially an issue when using external antennas. I'll usually run a baseline plot on the analyzer using "Max Hold" mode to build up a composite ambient plot. Then, I'll activate additional traces for the actual measurements. For example, I often have at least two plots or traces on the screen; the ambient baseline and the actual pre-compliance measurement.

Fortunately, there are three ways around this:

1. In most cases, you'll observe a range of product emissions in a harmonic relationship. Very often, these harmonics are created from the same source and if one, or more, are masked by ambient signals, then working on the others that are more visible will generally bring the whole batch down, as well.

2. In some cases there will be a critical harmonic masked by an ambient transmitter. A good example is a 100 MHz harmonic hidden underneath a large FM broadcast station at 99.9 MHz. In this case, I'll try reducing the resolution bandwidth from 100 or 120 kHz down to as little as 1 kHz, or less. This often "filters out" the modulation from the FM station, allowing you to observe the hidden harmonic. This also presumes the harmonic is an unmodulated continuous wave (CW) signal. Just be sure reducing the RBW doesn't also reduce the harmonic amplitude. If your harmonic is modulated, this may not work and you may have to move to a quieter measurement site.

3. Move your pre-compliance testing well away from urban transmitters (easier said than done these days).

Another caution when using spectrum analyzers is that strong nearby transmitters can affect the amplitude accuracy of the measured signals, as well as create mixing products that appear to be harmonics, but are really combinations of the transmitter frequency and mixer circuit in the analyzer. You may need to use an external bandpass filter at the desired harmonic frequency to reduce the affect of the external transmitter. An example would be an FM broadcast band "stop band" filter.

Although more expensive, an EMI receiver with tuned preselection would be more useful than a normal spectrum analyzer in high RF environments. Keysight Technologies or Rohde & Schwarz would be suppliers to consider. All these techniques are described in more detail in *Reference 2*.

RADIATED EMISSIONS

This is normally the highest risk test and most prone to fail compliance testing.

I prefer setting the vertical units from the default dBm to dBμV, so the displayed numbers are positive. Then adjust the Reference Level for even increments of 10 along the vertical axis. This is also the same unit used in the test limits of the EMI standards and also used in the equation below for calculating the E-field level. I also like to set the horizontal scale from linear to log (if possible), so frequencies are easier to read out.

Set up your spectrum analyzer as follows:

1. Frequency 10 to 500 MHz
2. Resolution bandwidth = 120 kHz, per the standard, or 100 kHz is close enough
3. Preamp = On (or use an external 20 dB preamp if the analyzer lacks this). This may not be required if the harmonic emissions are observable without it.
4. Set the vertical units to dBμV
5. Adjust the Reference Level so the highest harmonics are displayed and the vertical scale is reading in even 10 dB increments
6. Use positive peak detection
7. Set the internal attenuation = zero

I perform my initial scan up to 500 MHz, because this is usually the worst case band for digital harmonics. You'll want to also record the emissions at least up to 1 GHz (or higher) in order to characterize any other dominant emissions. Generally speaking, resolving the lower frequency harmonics will also reduce the higher harmonics.

STEP 1 - USE NEAR FIELD PROBING TO IDENTIFY ENERGY SOURCES

Most near field probe kits come with both E-field and H-field probes. Deciding on H-field or E-field probes depends on whether you'll be probing currents - that is, high *di/dt* - (circuit traces, cables, etc.) or high voltages - that is, *dV/dt* - (switching power supplies, etc.) respectively. Both are useful for locating leaky seams or gaps in shielded enclosures.

Start with the larger H-field probe (*Figure 2*) and sniff around the product enclosure, circuit board(s), and attached cables. The objective is to identify major noise sources and specific narrow band and broadband frequencies. Document the locations and dominant frequencies observed. As you zero in on sources, you may wish to switch to smaller-diameter H-field probes, which will offer greater resolution (but less sensitivity).

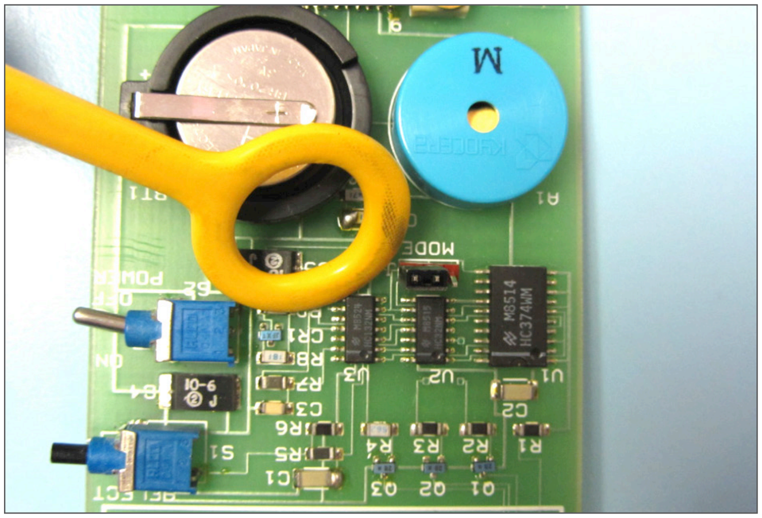


Figure 2 - A near field probe is used to help identify potential sources of emissions.

Notes:

Remember that not all sources of high frequency energy located on the board will actually radiate. This is a very important point! Radiation requires some form of coupling to an "antenna-like" structure, such as an I/O cable, power cable, or seam in the shielded enclosure.

Compare the harmonic frequencies with known clock oscillators or other high frequency sources. It will help to use the Clock Oscillator Calculator, developed by the co-author of my book, Patrick André. See the download link in *Reference 2*.

When applying potential fixes at the board level, be sure to tape down the near field probe to reduce the variation you'll experience in physical location of the probe tip. Remember, we're mainly interested in relative changes as we apply fixes.

Also, H-field probes are most sensitive (will couple the most magnetic flux) when their plane is oriented in parallel with the trace or cable. It's also best to position the probe at 90 degrees to the plane of the PC board. See *Figure 3*.

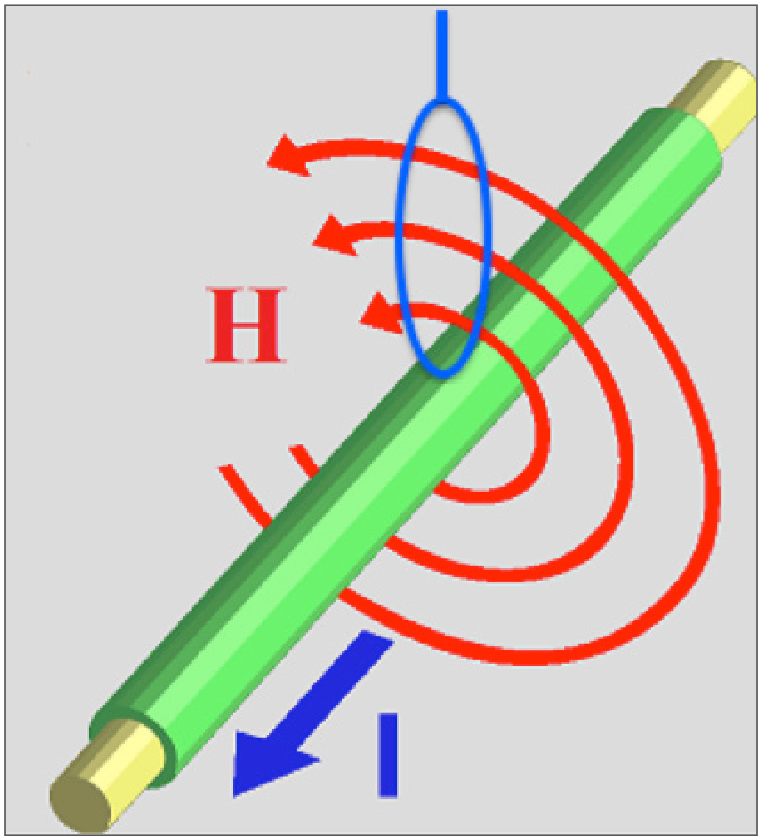


Figure 3 - H-field probes offer the best sensitivity when oriented in relation to the circuit trace or cable, as shown. Figure, courtesy Patrick André.

STEP 2 - USE A CURRENT PROBE TO CHARACTERIZE CABLE CURRENTS

Next, measure the attached common mode cable currents (including power cables) with a high frequency current probe, such as the Fischer Custom Communications model F-33-1, or equivalent (*Figure 4*). Document the locations of the top several harmonics and compare with the list determined by near field probing. These will be the most likely to actually radiate and cause test failures, because they are flowing on antenna-like structures (cables). Use the manufacturer's supplied calibration chart of transfer impedance to calculate the actual current at a particular frequency. Note that it only takes 5 to 8 µA of high frequency current to fail the FCC or CISPR class B test limits.

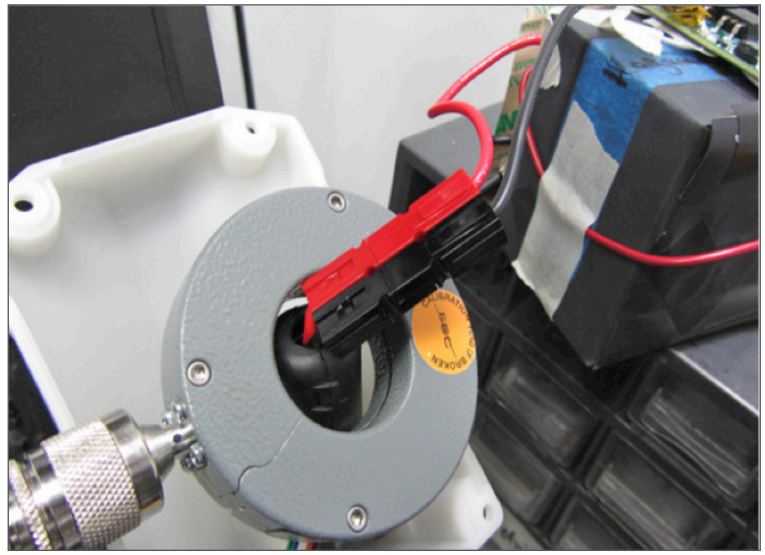


Figure 4 - Use of a current probe to measure high frequency currents flowing on I/O and power cables.

It's a good idea to slide the current probe back and forth to maximize the harmonics. This is because some frequencies will resonate in different places, due to standing waves on the cable.

Its also possible to predict the radiated E-field (V/m) given the current flowing in a wire or cable, with the assumption the length is electrically short at the frequency of concern. This has been shown to be accurate for 1m long cables at up to 200 MHz. Refer to *Reference 3* for details.

STEP 3 - USE AN EXTERNAL ANTENNA TO CONFIRM ACTUAL RADIATED FREQUENCIES

Note that there are two distinct goals when using external EMI antennas;

1. Relative troubleshooting , where you know areas of failing frequencies and need to reduce their amplitudes. A calibrated antenna is not required, as only relative changes are important. The important thing I that harmonic content from the EUT should be easily visible.

2. Pre-compliance testing, where you wish to duplicate the test setup as used by the compliance test lab. That is, setting up a calibrated antenna 3m or 10m away from the product or system under test and determining in advance whether you're passing or failing.

PRE-COMPLIANCE TESTING FOR RADIATED EMISSIONS

If you're desiring to set up a pre-compliance test, (#2 above), then given a calibrated EMI antenna spaced 3m or 10m away from the EUT, you can calculate the E-field (dBµV/m) by recording the dBµV reading of the spectrum analyzer and factoring in the coax loss, external preamp gain (if used), any external attenuator (if used), and antenna factor (from the antenna calibration provided by the manufacturer). This calculation can then be compared directly with the

3m or 10m radiated emissions test limits using the formula:

E-field (dBµV/m) = SpecAnalyzer (dBµV) - PreampGain (dB) + Coax-Loss (dB) + AttenuatorLoss (dB) + AntFactor (dB)

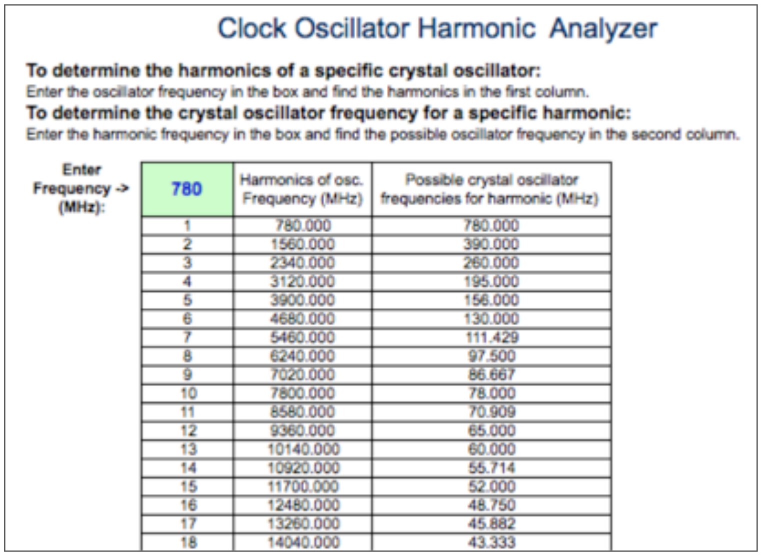
For the purposes of this article, I'll focus mainly on the procedure for troubleshooting using a close-spaced antenna (#1 above) for general characterization of harmonic levels actually being radiated and testing potential fixes. For example, knowing you may be over the limit by 3 dB at some harmonic frequency means your goal should be to reduce that emission by 6 to 10 dB for adequate margin.

For more information on pre-compliance testing, please refer to the article: "EMI Pre-Compliance Testing" in this desk reference.

TROUBLESHOOTING WITH A CLOSE-SPACED ANTENNA

Once you've identified the major energy sources using the near field probes and recorded this harmonic data, plus characterized the internal system and external I/O and power cables using the current probe, you should have a comprehensive list of potential harmonics. You should now have a good picture of which energy sources are producing which harmonics. Very often, the various harmonic signals will be related harmonically to specific clock frequencies.

If there are some unidentified harmonics, you can use the harmonic calculator (*Figure 5*) developed by Patrick André to determine the possible source. This may be downloaded from *Reference 2*.



Clock Oscillator Harmonic Analyzer

To determine the harmonics of a specific crystal oscillator:
Enter the oscillator frequency in the box and find the harmonics in the first column.
To determine the crystal oscillator frequency for a specific harmonic:
Enter the harmonic frequency in the box and find the possible oscillator frequency in the second column.

Enter Frequency -> (MHz): 780	Harmonics of osc. Frequency (MHz)	Possible crystal oscillator frequencies for harmonic (MHz)
1	780.000	780.000
2	1560.000	390.000
3	2340.000	260.000
4	3120.000	195.000
5	3900.000	156.000
6	4680.000	130.000
7	5460.000	111.429
8	6240.000	97.500
9	7020.000	86.667
10	7800.000	78.000
11	8580.000	70.909
12	9360.000	65.000
13	10140.000	60.000
14	10920.000	55.714
15	11700.000	52.000
16	12480.000	48.750
17	13260.000	45.882
18	14040.000	43.333

Figure 5 - A screen capture of the clock oscillator harmonic analyzer, developed by Patrick André. It may be used to display all possible harmonics, given a clock frequency, or for a given harmonic, display all possible clock frequencies that could produce that harmonic.

Once the product's harmonic profile is fully characterized, it's time to see which harmonics actually radiate. This is an important step, because not all harmonics measured will actually become issues. To do this, we use an antenna spaced at least 1m away from the product or system under test to measure the actual emissions (*Figure 6*). Typically, it will be leakage from attached I/O or power cables, as well as leakage in the shielded enclosure. Compare this data to that of the near field and current probes. Can you now determine the probable source(s) of the emissions noted?

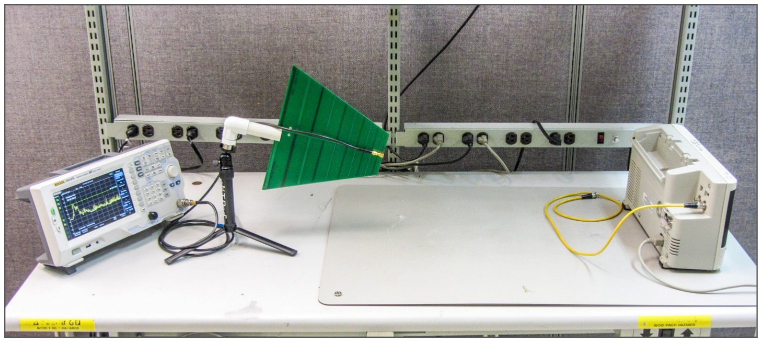


Figure 6 - A typical test setup to measure actual radiated emissions while troubleshooting the causes.

***NOTE:** The antenna shown is available from Kent Electronics (http://www.wa5vjb.com) and is resonant from 400 to 1000 MHz, although I find it useful well beyond those limits. In fact, almost any "hunk of metal", be it a telescoping antenna or simply a wire connected to the spectrum analyzer, will work fine, so long as you can easily observe the product emissions. Be sure to fix the antenna used to the table, so it won't move during troubleshooting.*

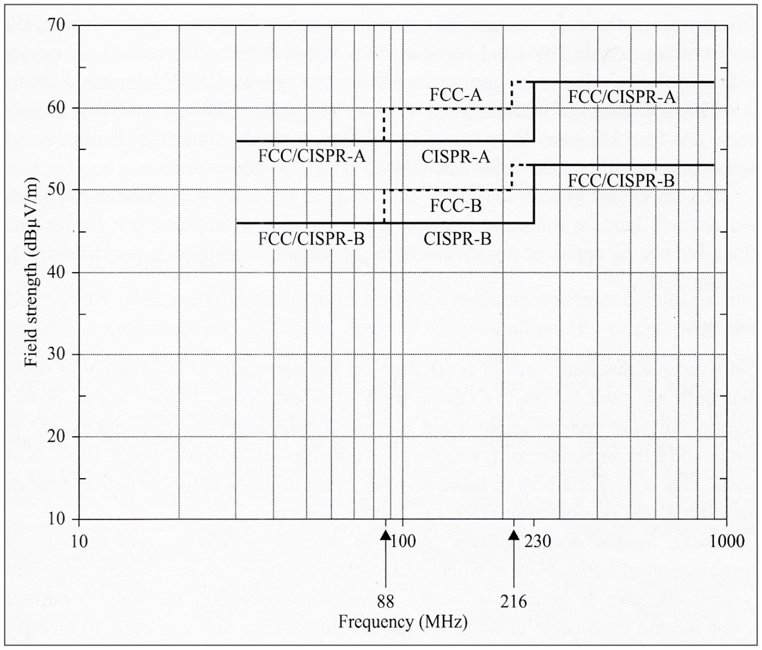


Figure 7 - Adjusted FCC and CISPR radiated emission limits for a 1m test distance. A 6 dB correction factor was added empirically to account for the close in extrapolation from 3m limits. Figure, courtesy, Henry Ott.

TROUBLESHOOTING TIPS AND COMMON ISSUES

There are a number of product design areas that can cause radiated emissions:

1. Poor cable shield terminations is the top issue
2. Leaky product shielding
3. Internal cables coupling to seams or I/O areas
4. High speed traces crossing gaps in the return plane
5. Sub-optimal layer stack-up

Once you've taken the data and have set up the test per *Figure 6*, try to determine if cable radiation is the dominant issue by removing the cables one by one. You can also try installing a ferrite choke on one, or

Notes:

Notes:

more, cables as a test. You can also move each cable around to determine the sensitivity to emissions.

Use the near field probes to determine if leakage is also occurring from seams or openings in the shielded enclosure.

Refer to the references for additional details on system and PC board design issues that can cause emissions failures. More troubleshooting techniques may be found in *References 3, 4, 5* and *6*.

Once the emission sources are identified, you can use your knowledge of filtering, grounding, and shielding to mitigate the problem emissions. Try to determine the coupling path from inside the product to any outside cables. In some cases, the circuit board may need to be redesigned by optimizing the layer stack-up or by eliminating high speed traces crossing gaps in return planes, etc. By observing the results in real time with an antenna spaced some distance away, the mitigation phase should go quickly. Refer to the article, "The Top Five Reasons Products Fail EMI Testing" in this EMC Desk Reference for more troubleshooting ideas.

REFERENCES

1. Recommended list of EMI troubleshooting equipment - http://www.emc-seminars.com/EMI_Troubleshooting_Equipment_List-Wyatt.pdf

Clock Oscillator Calculator (Patrick André) - http://andreconsulting.com/Harmonics.xls

2. André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech, 2014.
3. Interference Technology's 2017 EMC Pre-Compliance Test Guide, http://learn.interferencetechnology.com/2017-emc-pre-compliance-test-guide/
4. Interference Technology's 2017 EMC Fundamentals Guide, http://learn.interferencetechnology.com/2017-emc-fundamentals-guide/
5. Interference Technology's 2017 EMC Testing Guide, http://learn.interferencetechnology.com/2017-emc-testing-guide/

Links To Longer Articles

Notes:

WEB URLs

DIBASE, ELECTROMAGNETIC INTERFERENCE SOURCES AND THEIR MOST SIGNIFICANT EFFECTS, 2011,
https://interferencetechnology.com/electromagnetic-interference-sources-and-their-most-significant-effects/

DUFF, DESIGNING ELECTRONIC SYSTEMS FOR EMC: GROUNDING FOR THE CONTROL OF EMI, 2011,
https://interferencetechnology.com/designing-electronic-systems-for-emc-grounding-for-the-control-of-emi-3/

ARMSTRONG, FUNDAMENTALS OF EMC DESIGN: OUR PRODUCTS ARE TRYING TO HELP US, 2012,
https://interferencetechnology.com/fundamentals-of-emc-design-our-products-are-trying-to-help-us-3/

FORNS, EMC BASICS: DESIGNING TO PREVENT EMI IN ELECTRONIC DEVICES, 2014,
https://interferencetechnology.com/new-techniques-shielding-emi/

LEE, BASICS ON DESIGNING FOR EMC COMPLIANCE, 2012,
https://interferencetechnology.com/basics-on-designing-for-emc-compliance/

TABATABAEI, CLOCKING STRATEGIES FOR EMI REDUCTION, 2010,
https://interferencetechnology.com/clocking-strategies-for-emi-reduction/

MCCUNE, CMOS IS DIFFERENT: PCB DESIGN FOR BOTH LOW NOISE AND LOW EMI, 2013,
https://interferencetechnology.com/cmos-is-different-pcb-design-for-both-low-noise-and-low-emi/

ARMSTRONG, COST-EFFECTIVE EMC DESIGN BY WORKING WITH THE LAWS OF PHYSICS (WEBINAR), 2013,
https://interferencetechnology.com/watch-our-webinar-on-cost-effective-emc-design-by-working-with-the-laws-of-physics/

WYATT, ASSEMBLING A LOW COST EMI TROUBLESHOOTING KIT (PART 1 EMISSIONS),
https://interferencetechnology.com/assembling-low-cost-emi-troubleshooting-kit-part-1-radiated-emissions/

WYATT, ASSEMBLING A LOW COST EMI TROUBLESHOOTING KIT (PART 2 IMMUNITY),
https://interferencetechnology.com/assembling-low-cost-emi-troubleshooting-kit-part-2-immunity/

WYATT, INEXPENSIVE RADIATED IMMUNITY PRE-COMPLIANCE TESTING,
https://interferencetechnology.com/inexpensive-radiated-immunity-pre-compliance-testing/

WYATT, THE HF CURRENT PROBE: THEORY AND APPLICATION,
https://interferencetechnology.com/the-hf-current-probe-theory-and-application/

WYATT, DEVELOPING AN IN-HOUSE EMC PRE-COMPLIANCE TEST LAB,
https://interferencetechnology.com/developing-house-emc-troubleshooting-pre-compliance-test-lab/

WYATT, TROUBLESHOOTING RADIATED EMISSIONS USING LOW-COST BENCH-TOP METHODS,
https://interferencetechnology.com/troubleshooting-radiated-emissions-using-low-cost-bench-top-methods/

High Performance EMI Filters

Engineered To Perform, Built To Last

Delta's high performance EMI/EMC filter provides reliable and quick solutions to many of today's power condition requirements. With 35 years of experience and thousands of filter designs, Delta has a solution for your single or 3-phase power in both AC and DC applications.

- Over 1,000 standard part numbers
- Chassis mount filters rated up to 100A
- Medical grade filters with low leakage current
- 3-Phase filters rated up to 600A
- IEC filters rated up to 20A
- Worldwide safety approvals
- Highly customizable open frame design

ESPSales.US@deltaww.com

www.delta-americas.com/Products/ElectronicComponents

DELTA
Smarter. Greener. Together.

EMC Desk Reference

MANUFACTURERS

Notes:

EMC Equipment Manufacturers Chart

Introduction

T*he 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 pre-com- pliance or full compliance test lab. The list includes ampliers, antennas, current probes, ESD simulators, LISNs, near field probes, RF signal generators, spectrum analyz-ers, 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		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	http://www.ahsystems.com	X	X		X						X			
Aaronia AG	http://www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	https://www.atecorp.com	X	X			X	X	X	X	X	X		X	X
Amplifier Research (AR)	https://www.arworld.us/	X	X			X		X	X	X	X			X
Anritsu	http://www.anritsu.com					X					X			X
Beehive Electronics	http://www.beehive-electronics.com			X							X			
Electro Rent	http://www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	http://www.emtest.com									X	X	X		
EMC Partner	https://www.emc-partner.com						X			X				
Empower RF Systems	http://www.empowerrf.com		X						X					
Emscan	http://www.emscan.com										X			
Fischer Custom Communications	http://www.fischercc.com			X	X			X			X			
Gauss Instruments	https://www.gauss-instruments.com					X								
Haefley-Hippotronics	http://www.haefely-hipotronics.com						X			X				
Instrument Rental Labs	http://www.testequip.com		X			X	X	X	X	X	X		X	X
Instruments For Industry (IFI)	http://www.ifi.com		X						X	X				
Keysight Technologies	http://www.keysight.com			X		X		X			X			X
Microlease	https://www.microlease.com		X			X	X	X	X	X	X		X	X
Milmega	http://www.milmega.co.uk		X						X	X				
Narda/PMM	http://www.narda-sts.it	X	X			X		X	X	X	X			
Noiseken	http://www.noiseken.com						X			X	X			
Ophir RF	http://ophirrf.com		X							X				
Pearson Electronics	http://www.pearsonelectronics.com				X									
Rigol Technologies	https://www.rigolna.com			X	X	X					X			X
Rohde & Schwarz	https://www.rohde-schwarz.com	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	http://siglent.com/			X		X					X			X
Signal Hound	https://signalhound.com			X		X					X			X
TekBox Technologies	https://www.tekbox.net		X	X				X			X	X		
Tektronix	http://www.tek.com			X		X					X			
Teseq	http://www.teseq.com		X		X		X		X	X	X	X		
Test Equity	https://www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thermo Keytek	https://www.thermofisher.com						X			X				
Thurlby Thandar (AIM-TTi)	https://www.aimtti.com					X					X			X
Toyotech (Toyo)	https://toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	http://www.rf-consultant.com													X
Transient Specialists	http://www.transientspecialists.com								X	X		X		
TRSRenTelCo	https://www.trsrentelco.com	X	X			X		X	X	X	X		X	X
Vectawave Technology	http://vectawave.com		X											
Windfreak Technologies	https://windfreaktech.com													X

Notes:

RENT EMC TEST EQUIPMENT

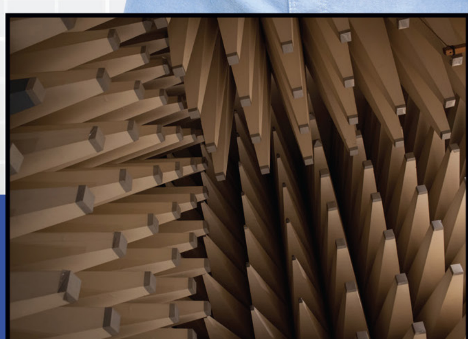
TO MEET A VARIETY OF STANDARDS

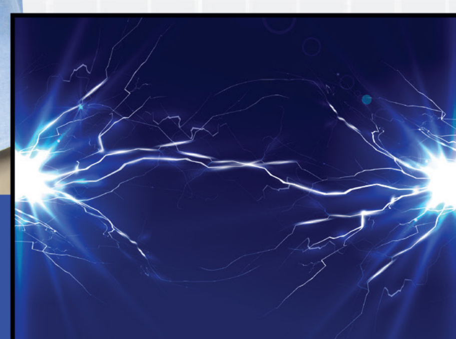
MIL-STD-461 • DO-160 • IEC 61000
IEC 60601-1-2 • ANSI C62 • ISO 7637
MIL-STD-1275 • CISPR and more...

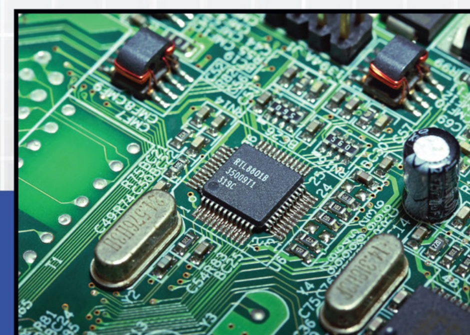
FROM THE LARGEST SUPPLIER OF EMC TEST EQUIPMENT

Amplifiers • ESD Guns • EMI Receivers
Signal Generators • Power Meters
Field Probes & Monitors • Antennas
and more...

Rent TODAY!







ATEC® Advanced Test Equipment Rentals

The Knowledge. The Equipment. The Solution.

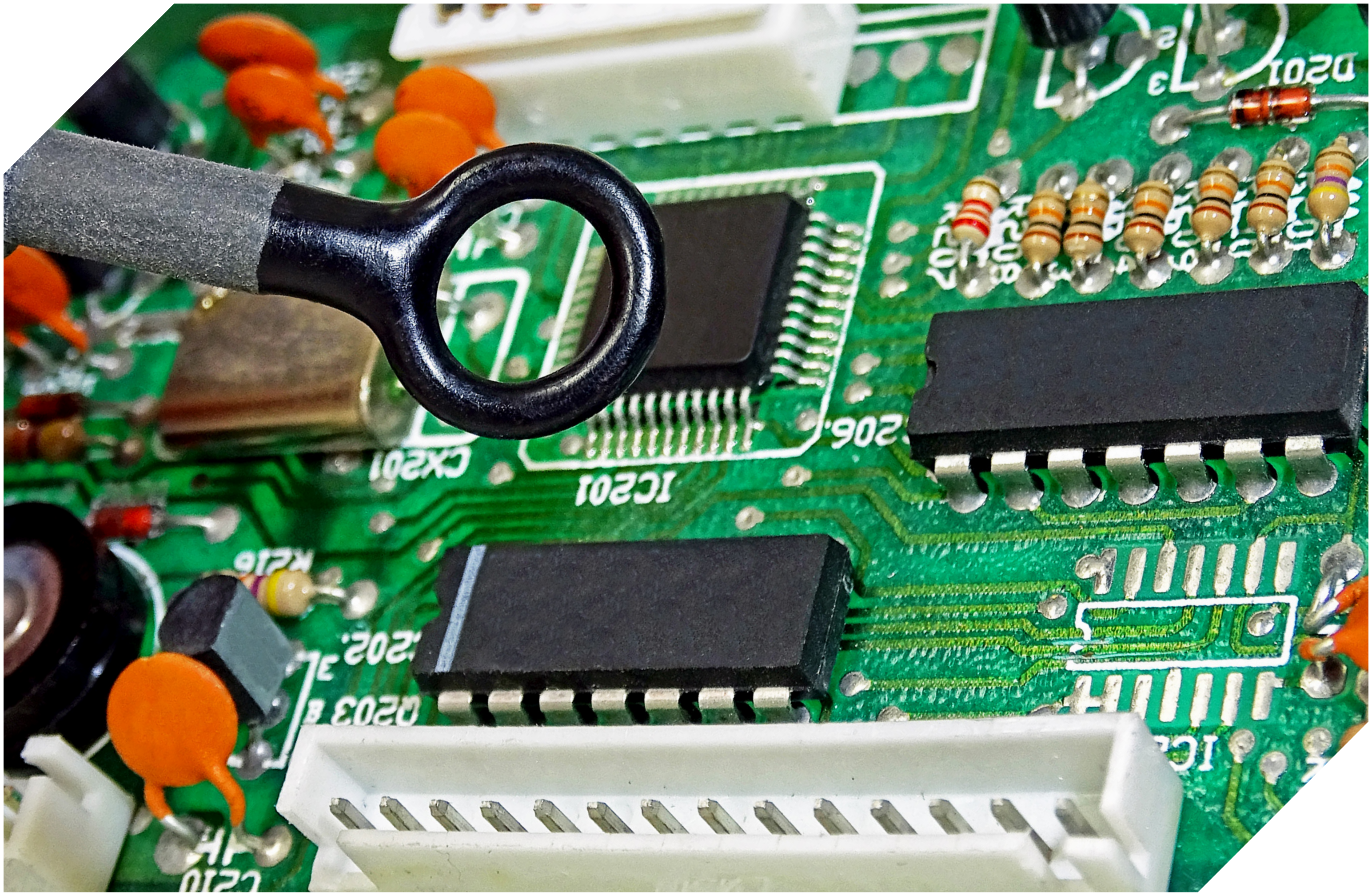
888-544-ATEC (2832) www.atecorp.com

San Diego Test Equipment Symposium
Oct. 24th, 2017 • San Diego
www.atecorp.com/sdtes
Register now!

EMC Desk Reference

STANDARDS

Notes:



Common Commercial, Automotive, Medical, Wireless & Military EMC Standards

Commercial Standards

The following are some of the most common commercial EMC standards. Most standards have a fee associated and most on the list are linked back to the source where they're available. If you're purchasing the printed version of this guide, then refer to the Standards Organizations in the References section for standards purchase information. Note that many Euro Norm (EN) versions of IEC standards may be purchased at a considerable discount from the Estonian Centre for Standardization, https://www.evs.ee.

Notes:

FCC (https://www.ecfr.gov)

Electronic Code of Federal Regulations (e-CFR)
CFR 47 - Part 15 (Radio Frequency Devices)

ANSI (http://webstore.ansi.org)

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 (https://webstore.iec.ch)

Document Number	Title
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 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 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

STANDARDS

Notes:

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 61000-6-7	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 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

CISPR (https://webstore.iec.ch)

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 13	Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement

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 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

STANDARDS

Notes:

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
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement (Withdrawn and replaced by CISPR 32:2015)
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement
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

Automotive Electromagnetic Compatibility Standards

The following abbreviated 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. For a more complete list, refer to the link above. Permission to republish has been granted.

CISPR (Automotive Emissions Requirements) (https://webstore.iec.ch)

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) (https://www.iso.org)

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

Notes:

ISO 10605	Road vehicles -- Test methods for electrical disturbances from electrostatic discharge
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 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 11452-4	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)
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

SAE (Automotive Emissions and Immunity) (http://standards.sae.org)

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
J1113/4	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
J1113/26	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)
J1752/1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits-Integrated Circuit EMC Measurement Procedures-General and Definition

STANDARDS

Notes:

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
J551/15	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 (https://global.ihs.com)

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 (http://www.fordemc.com)

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
DC-11223	EMC Performance Requirements -- Vehicle

Automotive Electromagnetic Compatibility Standards From
<http://www.cvel.clemson.edu/auto/auto_emc_standards.html>

Medical Standards

Collateral Standards (https://webstore.iec.ch)

Document Number	Title
IEC 60601-1-1	Safety requirements for medical electrical systems
IEC 60601-1-2	Electromagnetic disturbances - requirements and tests
IEC 60601-1-3	Radiation protection in diagnostic x-ray equipment
IEC 60601-1-6	General requirements for basic safety and essential performance - Usability
IEC 60601-1-8	General requirements for basic safety and essential performance - Alarm systems
IEC 60601-1-9	Requirements for environmentally conscious design
IEC 60601-1-10	Requirements for the development of physiologic closed-loop controllers
IEC 60601-1-11	Medical electrical equipment and medical electrical systems used in the home healthcare environment
IEC 60601-1-12	Medical electrical equipment and medical electrical systems used in the medical services environment

Other Relevant Standards (https://webstore.iec.ch)

Document Number	Title
CISPR 11	Emission requirements for ISM equipment
IEC 60601-1	General requirements for basic safety and essential performance
IEC TR 60601-4-2	Electromagnetic immunity performance
IEC TR 60601-4-3	Considerations of unaddressed safety aspects in the third edition of IEC 60601-1
IEC TR 62354	General testing procedures for medical electrical equipment
ISO 14708-1	Active implantable medical devices

For more extensive listings of medical standards, download the 2017 Medical EMC Guide:
http://learn.interferencetechnology.com/2017-medical-emc-guide/.

STANDARDS

Notes:

Common Wireless Standards

ETSI Standards (http://www.etsi.org)

Document Number	Title
ETSI EN 300 220	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25MHz to 1000MHz frequency range with power levels ranging up to 500mW
ETSI EN 300 328	Electromagnetic compatibility and Radio Spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive
ETSI EN 300 330	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 9kHz to 25MHz frequency range and inductive loop systems in the 9kHz to 30MHz frequency range
ETSI EN 300 440	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 1GHz to 40GHz frequency range
ETSI EN 301 489-3	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 3: Specific conditions for Short Range Devices (SRD) operating on frequencies between 9kHz and 40GHz
ETSI EN 301 489-17	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 17: Specific conditions for Wideband data and HIPERLAN equipment
ETSI EN 301 893	Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements of article 3.2 of the R&TTE Directive
ETSI EN 303 413	GPS receivers
ETSI EN 303 417	Wireless Power Transfer

Common Military Related Documents and 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. Downloadable from: http://everyspec.com.

Document Number	Title
MIL-HDBK-235-1	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010
MIL-HDBK-1857	Grounding, Bonding and Shielding Design Practices, 27 Mar 1998
MIL-STD-220C	Test Method Standard Method of Insertion Loss Measurement, 14 May 2009
MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973
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

Notes:

MIL-STD-464C	Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010
MIL-STD-1541A	Electromagnetic Compatibility Requirements for Space Systems, 30 Dec 1987
MIL-STD-1542B	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991
MIL-STD-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009
DoDI 3222.03	DoD Electromagnetic Environmental Effects (E3) Program, 24 Aug 2014

Aerospace Standards

AIAA Standards http://www.aiaa.org/default.aspx

Document Number	Title
S-121-2009	Electromagnetic Compatibility Requirements for Space Equipment and Systems

RTCA Standards https://www.rtca.org/

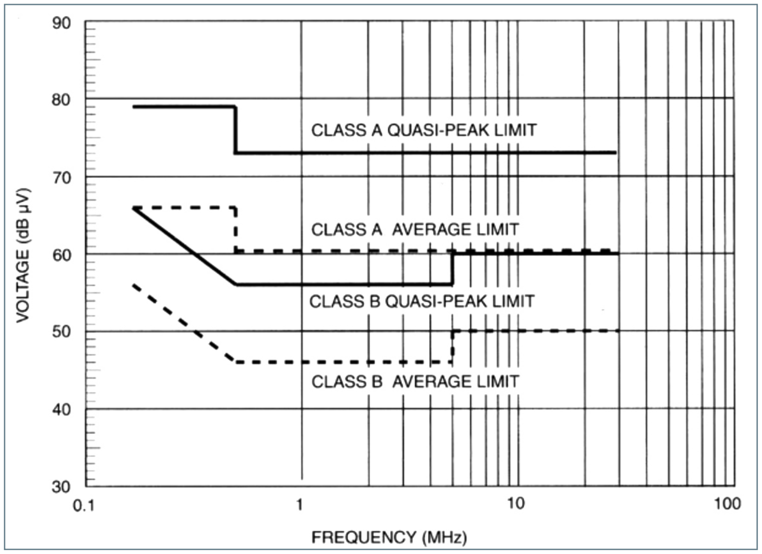
Document Number	Title
DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment
DO-160G Change 1	Environmental Conditions and Test Procedures for Airborne Equipment
DO-233	Portable Electronic Devices Carried on Board Aircraft
DO-235B	Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band
DO-292	Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band
DO-294C	Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft
DO-307	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance
DO-357	User Guide: Supplement to DO-160G
DO-363	Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft
DO-364	Minimum Aviation System Performance Standards (MASPS) for Aeronautical Information/ Meteorological Data Link Services
DO-363	Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft
DO-307A	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

SAE Standards http://www.sae.org/

Document Number	Title
ARP 5583A	Guide to Certification of Aircraft in a High Intensity Radiation (HIRF) Environment

Notes:

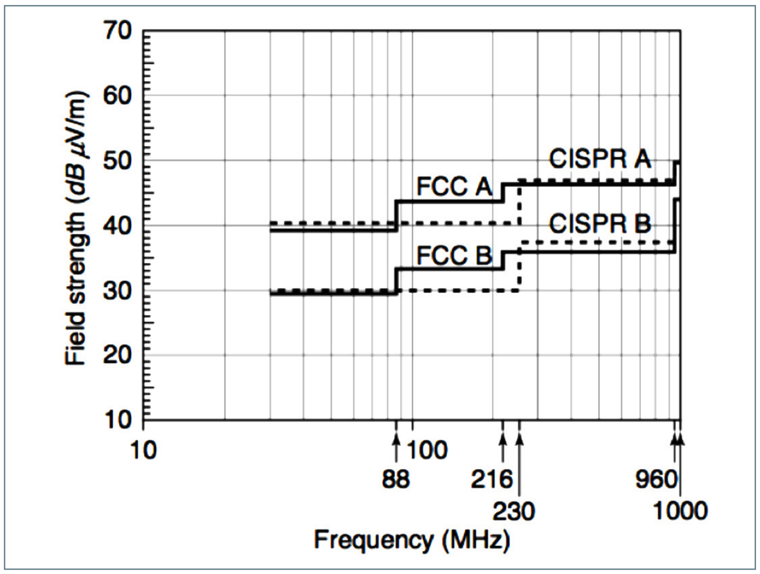
FCC and CISPR Radiated and Conducted Limits



CISPR conducted emission limits when measured using a LISN.

FCC Class A Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (μV)
0.45 - 1.6	1000
1.6 - 30.0	3000
FCC Class B Conducted EMI Limit	
Frequency of Emission (MHz)	Conducted Limit (μV)
0.455 - 1.6	250
1.6 - 30.0	250
FCC Class B 3-Meter Radiated EMI Limit	
Frequency of Emission (MHz)	Field Strength Limit (μV/m)
30 - 88	100
88 - 216	150
216 - 1000	200
above 1000	200
FCC Class A 10-Meter Radiated EMI Limit	
Frequency of Emission (MHz)	Field Strength Limit (μV/m)
30 - 88	90
88 - 216	150
216 - 960	210
above 960	300

FCC conducted and radiated emission test limits.



FCC and CISPR radiated emission limits at a 10m test distance. Note that the limits, if taken at 3m, would be 10 dB higher.

CISPR Class A Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBμV)	
	Quasi-peak	Average
0.15 - 0.50	79	66
0.50 - 30.0	73	60
CISPR Class B Conducted EMI Limit		
Frequency of Emission (MHz)	Conducted Limit (dBμV)	
	Quasi-peak	Average
0.15 - 0.50	66 to 56*	56 to 46*
0.50 - 5.00	56	46
5.00 - 30.0	60	50
CISPR Class A 10-Meter Radiated EMI Limit		
Frequency of Emission (MHz)	Field Strength Limit (dBμV/m)	
30 - 88	39	
88 - 216	43.5	
216 - 960	46.5	
above 960	49.5	
CISPR Class B 3-Meter Radiated EMI Limit		
Frequency of Emission (MHz)	Field Strength Limit (dBμV/m)	
30 - 88	40	
88 - 216	43.5	
216 - 960	46.0	
above 960	54.0	

*Decreases with the logarithm of the frequency.

CISPR conducted and radiated emission test limits.

EMC Standards Organizations

American National Standards Institute
www.ansi.org

ANSI Accredited C63
www.c63.org

Asia Pacific Laboratory Accreditation Cooperation
APLAC, www.aplac.org

BSMI (Taiwan)
http://www.bsmi.gov.tw/wSite/mp?mp=95

Canadian Standards Association
CSA, www.csa.ca

CISPR
http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID,FSP_LANG_ID:1298,25

CNCA (China)
http://www.cnca.gov.cn/cnca/cncatest/20040420/column/227.htm

Electromagnetic Compatibility Industry Association
UK, http://www.emcia.org

FDA Center for Devices & Radiological Health (CDRH)
https://www.fda.gov/MedicalDevices/default.htm

Federal Communications Commission
FCC, www.fcc.gov

Gosstandart (Russia)
http://gosstandart.gov.by/en-US/index.php

IEC
http://www.iec.ch/index.htm

IEEE Standards Association
www.standards.ieee.org

IEEE EMC Society Standards Development Committee (SDCOM)
http://standards.ieee.org/develop/project/electromagnetic_compatibility.html

Industry Canada (Certifications and Standards)
http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06165.html

ISO (International Organization for Standards)
http://www.iso.org/iso/home.html

RTCA
https://www.rtca.org

SAE EMC Standards Committee
www.sae.org

SAE EMC Standards
http://www.sae.org/servlets/works/committeeHome.do?comtID=TEVEES17

VCCI (Japan, Voluntary Control Council for Interference
http://www.vcci.jp/vcci_e/

Notes:

Advanced EMI/RFI Absorber Materials and Anechoic Chambers

From the formulation of advanced materials in our laboratory to the design and construction of test facilities in the field, we are one of the world leaders in technology development pertaining to anechoic chambers, microwave and EMC absorbers, dielectrics and suppression materials.

PPG Aerospace
Cuming Microwave

Pyramidal & Specialty Absorber Materials
T 508.521.6700
Avon, MA 02322
CumingMicrowave.com

PPG Aerospace
Cuming-Lehman Chambers

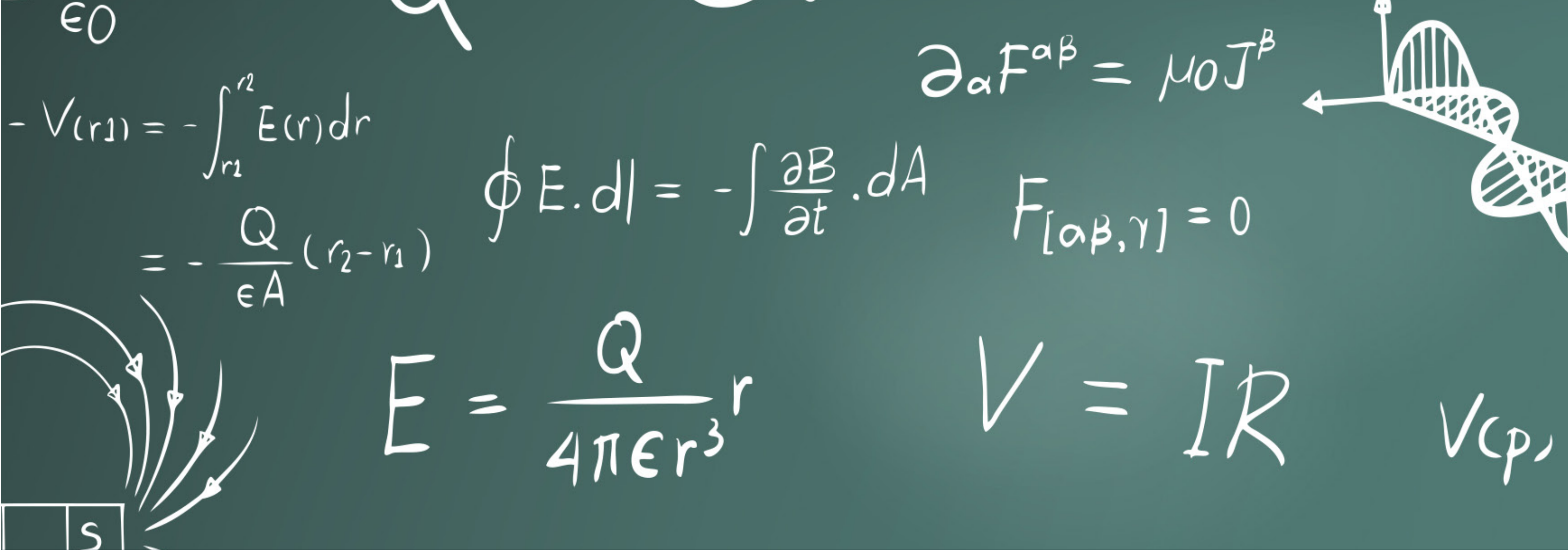
Anechoic Chamber Design, Engineering and Construction
T 717.263.4101
Chambersburg, PA 17202
CumingLehman.com

MASTER SPONSOR ROHDE&SCHWARZ

MISSED A PRESENTATION AT THE EMC+SIPI 2017 SYMPOSIUM?

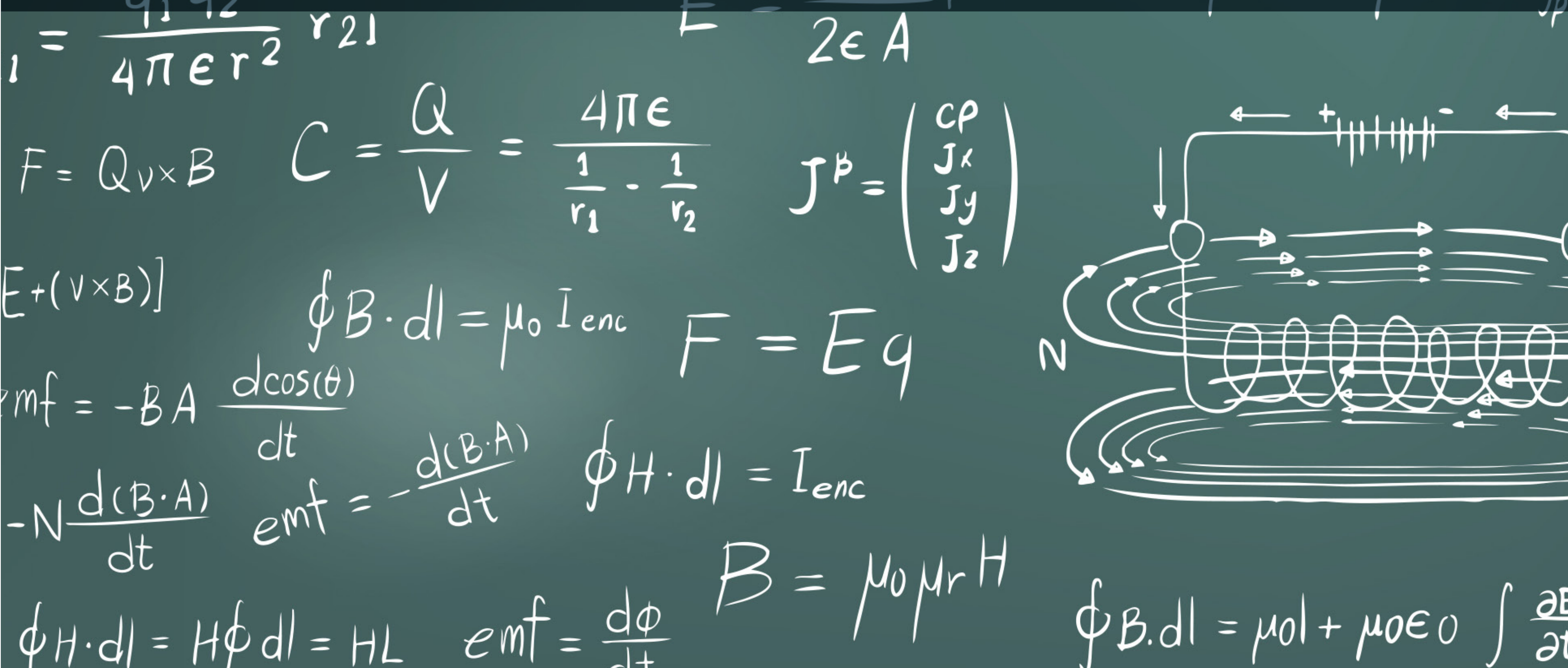
Many of the presentations have been recorded and can be watched on-demand on the EMC+SIPI 2017 Online Symposium website.

www.emc2017online.emcss.org

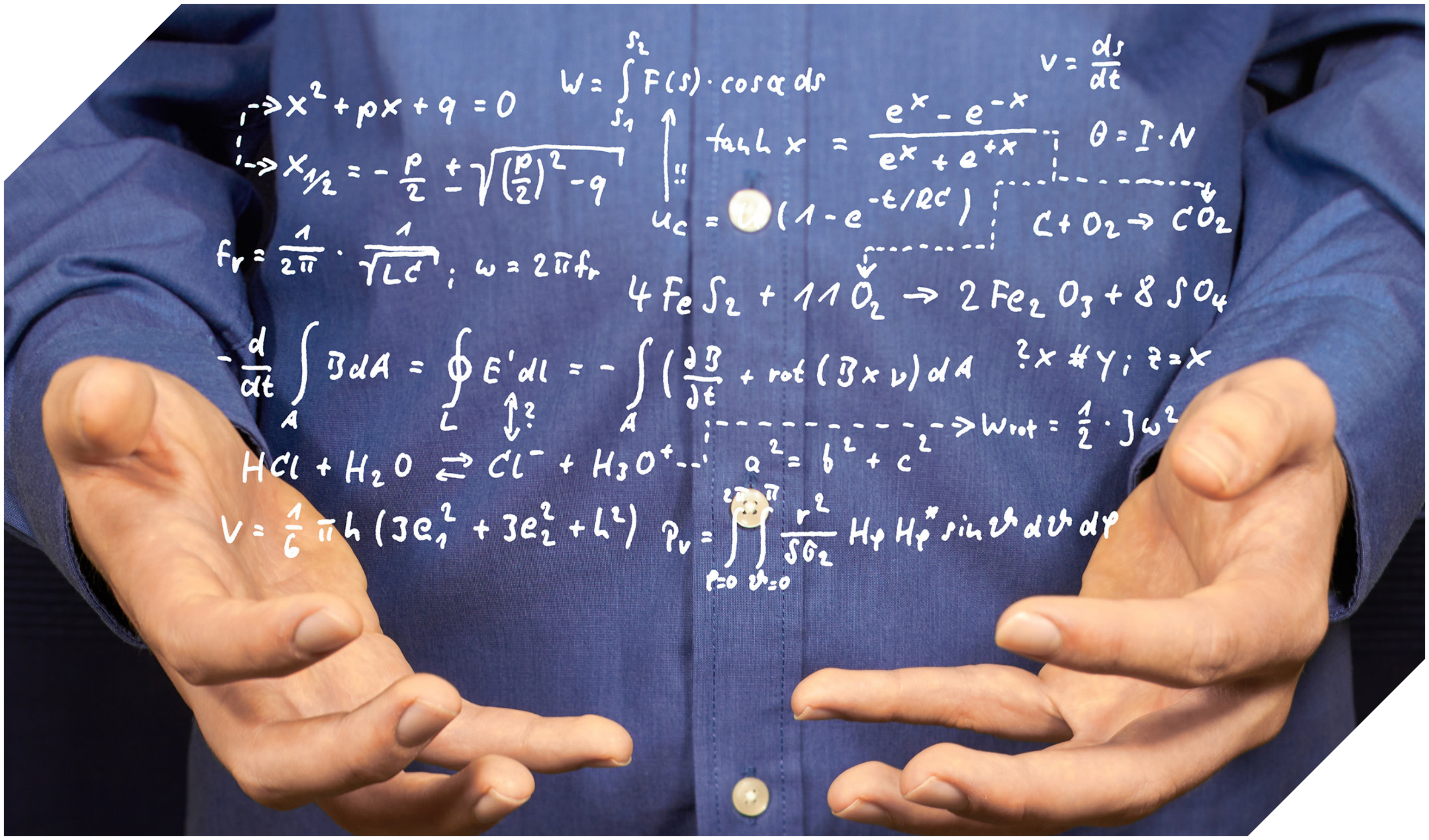


EMC Desk Reference

EQUATIONS

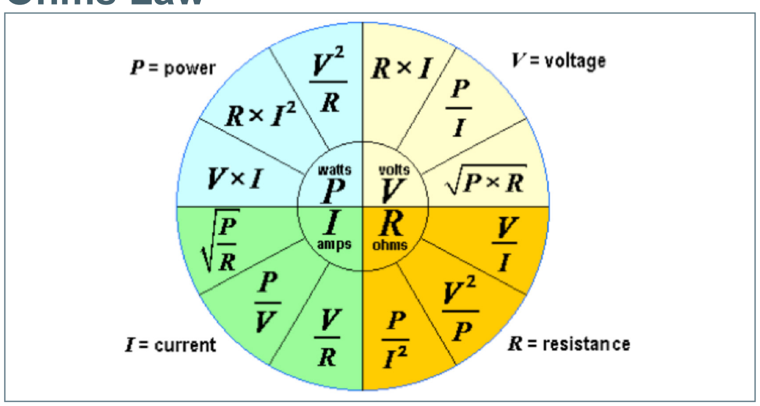


Notes:



Common EMC-Related Equations

Ohms Law



Ohms Law "formula wheel" for calculating resistance (R), voltage (V), current (I) or power (P), given at least two of the other values.

Bandwidth versus Rise Time

$$BW\ (GHz) = \frac{0.35}{RT\ (nsec)}$$

Empirically derived and applies for a square wave, with rise time measured at 10 and 90%. Example, for a rise time of 1 nsec, the bandwidth is 350 MHz.

Bandwidth versus Clock Frequency

$$BW_{Clock}(GHz) = 5\ X\ F_{Clock}(GHz)$$

Assuming the rise time of a clock is 7% of the period, we can approximate the bandwidth as shown.

Example, for a clock frequency of 100 MHz, the bandwidth is 500 MHz. That is, the highest significant sine-wave frequency component in a clock wave is the fifth harmonic.

Period versus Frequency

$$F_{Clock}(GHz) = \frac{1}{T_{Clock}\ (nsec)}$$

Partial Self-Inductance of a Round Wire (1mm)

25 nH/inch or 1 nH/mm

Example, a 1.5mm long via has a partial self-inductance of about 1.5 nH.

Impedance of a Wire

$$Z_{Wire}\ (Ohms) = 2\pi\, f\,(GHz) L(nH)$$

Example, a one-inch wire (25 nH) has an impedance of 16 Ohms at 100 MHz.

Speed of Signals

In air: 12 inches/nsec

In most PC board dielectrics: 6 inches/nsec

VSWR and Return Loss

VSWR given forward/reverse power $VSWR = \frac{1+\sqrt{P_{rev}/P_{fwd}}}{1-\sqrt{P_{rev}/P_{fwd}}}$

VSWR given reflection coefficient (ρ) $VSWR = \left|\frac{1+\rho}{1-\rho}\right|$

Reflection coefficient (ρ), given Z1,Z2 Ohms $\rho = \left|\frac{Z_1 - Z_2}{Z_1 + Z_2}\right|$

Reflection coefficient (ρ), given fwd/rev power $\rho = \sqrt{\frac{P_{rev}}{P_{fwd}}}$

Return Loss, given forward/reverse power

$$RL(dB) = -10\log(\frac{P_{OUT}}{P_{IN}})$$

Return Loss, given VSWR

$$RL(dB) = -20\log(\frac{VSWR-1}{VSWR+1})$$

Return Loss, given reflection coefficient (ρ)

$$RL(dB) = -20\log(\rho)$$

E-Field from Differential-Mode Current

$$|E_{D,max}| = 2.63 * 10^{-14}\frac{|I_D|f^2Ls}{d}$$

I_D = differential-mode current in loop (A)

f = frequency (Hz)

L = length of loop (m)

s = spacing of loop (m)

d = measurement distance (3m or 10m, typ.)

(Assumption that the loop is electrically small and measured over a reflecting surface)

E-Field from Common-Mode Current

$$|E_{C,max}| = 1.257 * 10^{-6}\frac{|I_C|fL}{d}$$

I_C = common-mode current in wire (A)

f = frequency (Hz)

L = length of wire (m)

d = measurement distance (3m or 10m, typ.) (Assumption that the wire is electrically short)

Antenna (Far Field) Relationships

Gain, dBi to numeric $Gain_{numeric} = 10^{dBi/10}$

Gain, numeric to dBi $dBi = 10\log(Gain_{numeric})$

Gain, dBi to Antenna Factor $AF = 20\log(MHz) - dBi - 29.79$

Antenna Factor to gain in dBi $dBi = 20\log(MHz) - AF - 29.79$

Field Strength given watts, numeric gain, distance in meters

$$V/m = \frac{\sqrt{30 * watts * Gain_{numeric}}}{meters}$$

Field Strength given watts, dBi gain, distance in meters

$$V/m = \frac{\sqrt{30 * watts * 10^{(dBi/10)}}}{meters}$$

Transmit power required, given desired V/m, antenna numeric gain, distance in meters

$$Watts = \frac{(V/m * meters)^2}{30 * Gain_{numeric}}$$

Transmit power required, given desired V/m, antenna dBi gain, distance in meters

$$Watts = \frac{(V/m * meters)^2}{30 * 10^{dBi/10}}$$

PC Board Equations

1 oz. copper = 1.4 mils = 0.036 mm
0.5 oz. copper = 0.7 mils = 0.018 mm
Convert mils to mm: multiply by 0.0254 mm/mil
Convert mm to mils: multiply by 39.4 mil/mm
Signal velocity in free space: approx. 12 in/ns
Signal velocity in FR-4: approx. 6 in/ns

Temperature Conversions

Celsius to Fahrenheit: °C = 5/9(°F - 32)
Fahrenheit to Celsius: °F = 9/5(°C) + 32

Working with dB

<u>The decibel is always a ratio</u>
Power Gain = Pout/Pin
Power Gain(dB) = 10log(Pout / Pin)
Voltage Gain(dB) = 20log(Vout/Vin)
Current Gain(dB) = 20log(Iout/Iin)

<u>We commonly work with:</u>
dBm (referenced to 1 mW)
dBµV (referenced to 1 µV)
dBµA (referenced to 1 µA)

Notes:

EQUATIONS

Notes:

<u>Power Ratios</u>
3 dB = double (or half) the power
10 dB = 10X (or /10) the power

<u>Voltage/Current Ratios</u>
6 dB = double (or half) the voltage/current 20 dB - 10X (or /10) the voltage/current

dBm, dBµV, dBµA (conversion)

Volts to dBV:	dBV = 20log(V)
Volts to dBµV:	dBµV = 20log(V) + 120
dBV to Volts:	$V = 10^{(dBV/20)}$
dBµV to Volts:	$V = 10^{((dBuV=120)/20)}$
dBV to dBµV:	dBµV = dBV +120
dBµV to dBV:	dBV = dBµV - 120

Note: For current relationships, substitute A for V

Field Strength Equations

dBµV/m to V/m:	$V/m = 10^{(((dBuV/m)-120)/20)}$
V/m to dBµV/m:	dBµV/m = 20log(V/m) + 120
dBµV/m to dBµA/m:	dBµA/m = dBµV/m - 51.5
dBµA/m to dBµV/m:	dBµV/m = dBµA/m + 51.5
dBµA/m to dBpT:	dBpT = dBµA/m + 2
dBpT to dBµA/m:	dBµA/m = dBpT - 2
µT to A/m:	A/m = µT/1.25
A/m to µT:	µT = 1.25 * A/m

dBm to dBuV Chart

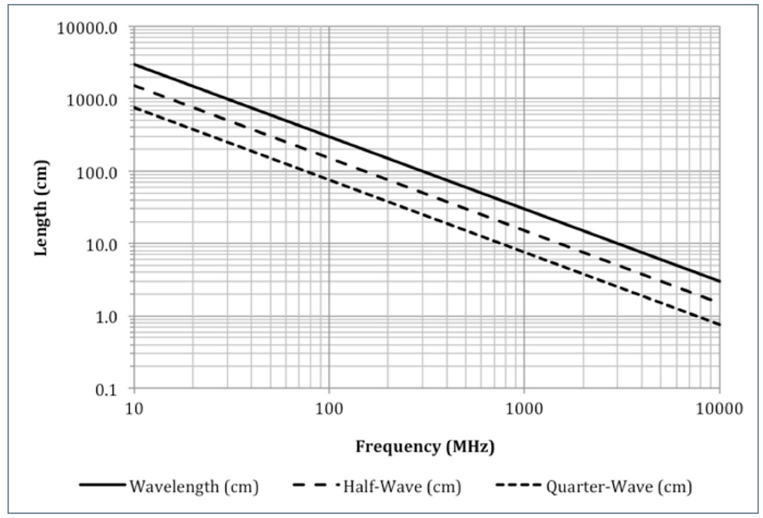
dBm	dBµV
20	127
10	117
0	107
-10	97
-20	87
-30	77
-40	67
-50	57
-60	47
-70	37
-80	27
-90	17
-100	7

A common formula for converting default spectrum analyzer amplitudes (dBm) to the limits as shown in the emissions standards (dBµV): dBm to dBµV, use: dBµV = dBm + 107

Wavelength Equations (free space)

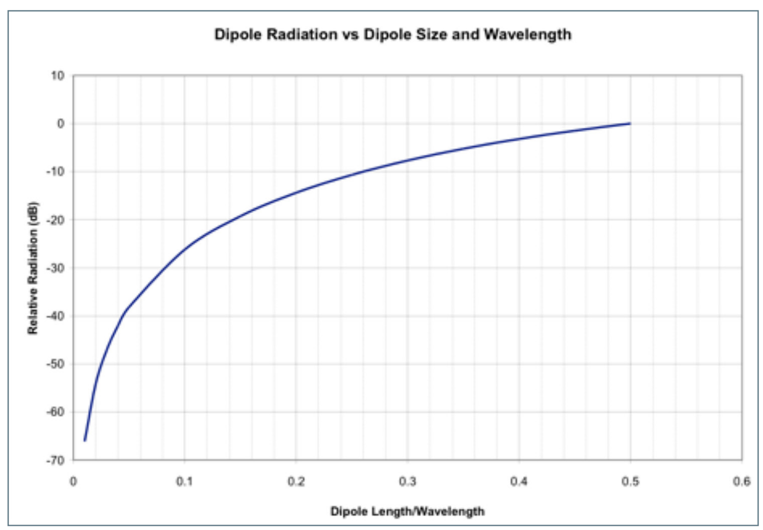
Wavelength(m) = 300/*f(MHz)*
Half wavelength(ft.) = 468/*f(MHz)*

Resonance of Structures



Use this handy chart for determining the resonant frequency versus cable or slot length in free space. Half-wavelength slots or cables simulate dipole antennas and are particularly troublesome. Figure, courtesy Patrick André.

Dipole Radiation versus Length



Use this chart to for determining the relative radiation versus size in wavelength. Figure, courtesy Bruce Archambeault.

For example, a wire or slot whose length is 0.2 wavelength at a particular frequency, would radiate about 15 dB down from the equivalent half-wavelength wire or slot.

Join the High Frequency/High Speed Revolution

EDICON is coming!
EDICON is coming!
EDICON is coming!

EDI CON 2017

Boston

Electronic Design Innovation Conference & Exhibition

September 11-13, 2017
HYNES CONVENTION CENTER • BOSTON, MA

Featuring:

- Exhibition of Industry-Leading Vendors
- Technical Sessions
- Workshops
- Panels
- Short Courses
- Keynotes and Plenary Session
- High-Speed Zone
- Frequency Matters Theater
- Demonstrations
- Networking
- Speed Training

REGISTER NOW
www.EDICONUSA.com

Organized by
horizon house®

Official Publications
Microwave Journal
Signal Integrity Journal

See us at IMS Booth 1202

BOOKS

Notes:

Recommended EMC 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 EMC test failures.

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

ARMSTRONG,
EMC Design Techniques For Electronic Engineers
Armstrong/Nutwood Publications, 2010. A comprehensive treatment of EMC theory and practical product design and measurement applications.

ARMSTRONG,
EMC For Printed Circuit Boards - Basic and Advanced Design and Layout Techniques
Armstrong/Nutwood Publications, 2010. A comprehensive treatment of PC board layout for EMC compliance.

ARRL,
The RFI Handbook
(3rd edition), 2010. Good practical book on radio frequency interference with mitigation techniques. Some EMC theory.

BOGATIN,
Signal & Power Integrity - Simplified
Prentice-Hall, 2009 (2nd Edition). Great coverage of signal and power integrity from a fields viewpoint.

BRANDER, ET AL,
Trilogy of Magnetics - Design Guide for EMI Filter Design, SMPS & RF Circuits
Würth Electronik, 2010. A comprehensive compilation of valuable design information and examples of filter, switch-mode power supply, and RF circuit design.

GOEDBLOED,
Electromagnetic Compatibility
Prentice-Hall, 1990. Good general text on EMC with practical experiments. May be out of print.

BOOKS

Notes:

KIMMEL AND GERKE,
Electromagnetic Compatibility in Medical Equipment
IEEE Press, 1995. Good general product design information.

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

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.

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

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

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

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.

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.

SLATTERY AND SKINNER,
Platform Interference in Wireless Systems - Models, Measurement, and Mitigation
Newnes Press, 2008. The first publication to publicize the issue of self-interference to on-board wireless systems.

SMITH,
High Frequency Measurements and Noise in Electronic Circuits
Springer, 1993. A classic book on high frequency measurements, probing techniques, and EMC troubleshooting measurements.

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, encompassing both commercial and military EMC.

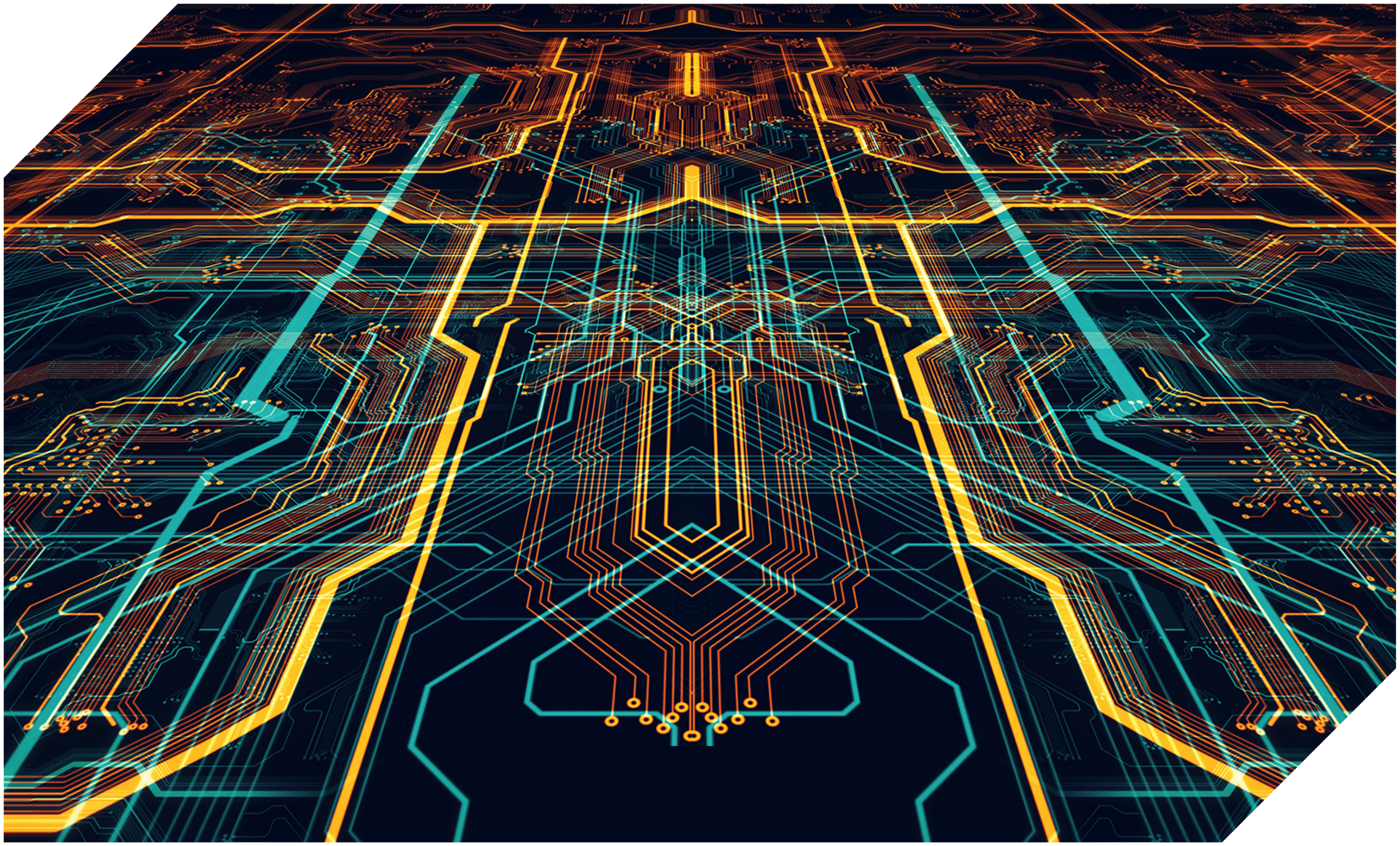
WITTE,
Spectrum and Network Measurements
(2nd edition), SciTech Publishing, 2014. The best text around explaining the theory and usage of spectrum and network analyzers.

WYATT AND JOST,
Electromagnetic Compatibility (EMC) Pocket Guide
SciTech Publishing, 2013. A handy pocket-sized reference guide to EMC.

WYATT AND GRUBER,
Radio Frequency (RFI) Pocket Guide
SciTech Publishing, 2015. A handy pocket-sized reference guide to radio frequency interference.

DESIGN GUIDES | MISCELLANEOUS
SYMBOLS & ACRONYMS

Notes:



Recommended Guides from Interference Technology

(Free downloads available on www.interferencetechnology.com)

2016 Automotive EMC Guide
http://learn.interferencetechnology.com/2016-automotive-emc-guide/

2017 EMC Precompliance Test Guide
http://learn.interferencetechnology.com/2017-emc-pre-compliance-test-guide/

2017 EMC Fundamentals Guide
http://learn.interferencetechnology.com/2017-emc-fundamentals-guide/

2017 EMC Testing Guide
http://learn.interferencetechnology.com/2017-emc-testing-guide/

2016 EMI Shielding Guide
http://learn.interferencetechnology.com/2016-emi-shielding-guide/

2017 EMC Filters Guide
http://learn.interferencetechnology.com/2017-emc-filters-guide/

2017 Medical EMC Guide
http://learn.interferencetechnology.com/2017-medical-emc-guide/

2017 Military and Aerospace EMC Guide
http://learn.interferencetechnology.com/2017-military-and-aerospace-emc-guide/

2016 Real-Time Spectrum Analyzers Guide
http://learn.interferencetechnology.com/2016-real-time-spectrum-analyzer-guide/

2017 Wireless Interference & RFI Guide
http://learn.interferencetechnology.com/2017-wireless-interference-rfi-guide/

Recommended Websites

Clemson University Vehicular Electronics Laboratory
http://www.cvel.clemson.edu/emc/index.html

Doug Smith
http://emcesd.com

EMC Information Centre (Archived)
http://www.compliance-club.com

Henry Ott
http://www.hottconsultants.com

Notes:

Recommended Websites Continued

In Compliance Magazine
http://incompliancemag.com

IEEE EMC Society
http://www.emcs.org

Interference Technology
https://interferencetechnology.com

Keith Armstrong
https://www.emcstandards.co.uk

Kenneth Wyatt
http://www.emc-seminars.com

Patrick André
http://andreconsulting.com

Silent Solutions
http://www.silent-solutions.com/index.htm

University of Missouri EMC Lab
https://emclab.mst.edu

University of Oklahoma EMC
http://www.ou.edu/engineering/emc/

Van Doren Company
http://www.emc-education.com

List of LinkedIn Groups

- Aircraft and Spacecraft ESD/EMI/EMC Issues
- Automotive EMC Troubleshooting Experts
- Electromagnetic Compatibility Automotive Group
- Electromagnetic Compatibility Forum
- Electromagnetics and Spectrum Engineering Group
- EMC - Electromagnetic Compatibility
- EMC Experts
- EMC Jobs
- EMC Testing and Compliance
- EMC Troubleshooters
- EMI and EMC Consultants
- ESD Experts
- iNARTE
- Military EMC Forum
- RTCA/DO-160 Experts
- Signal & Power Integrity Community

List of Conferences

IEEE CONFERENCES

2017 IEEE International Symposium on EMC&SIPI
August 7-11 Washington DC
Mike Violette, 240.401.1388

2018 Joint IEEE International Symposium on EMC and APEMC
May 14-17 Singapore
Liu Enxiao, liuex@ihpc.a-star.edu.sg Er Ping Li, erpingli@ieee.org

2018 IEEE Symposium on EMC&SIPI
July 30-August 3 Long Beach, California
Ray Adams, r.k.adams@ieee.org

2019 IEEE International Symposium on EMC&SIPI
July 22-26 New Orleans, Louisiana
Dennis Lewis, dennis.m.lewis@boeing.com

2020 IEEE International Symposium on EMC&SIPI
July 27-31 Reno, Nevada
Darryl Ray, darrylr16@yahoo.com

EUROPEAN EMC (and related) CONFERENCES (2017)

Automotive Testing Expo (includes EMC)
June 20-22, 2017 Stuttgart, Germany
http://www.testing-expo.com/europe/english/

EMC Compo - Workshop on the Electromagnetic Compatibility of Integrated Circuits
July 4-8, 2017 St. Petersburg, Russia
http://www.emccompo2017.eltech.ru

EMC Europe 2017
September 4-8, 2017 Angers, France
http://emceurope2017.org

European Microwave Conference
October 8-13, 2017 Nuremberg, Germany
http://www.eumweek.com

Notes:

Common Symbols

A	Amperes, unit of electrical current
AC	Alternating Current
AM	Amplitude modulated
dBm	dB with reference to 1 mW
dBµA	dB with reference to 1 µA
dBµV	dB with reference to 1 µV
DC	Direct Current
E	"E" is the electric field component of an electromagnetic field.
E/M	Ratio of the electric field (E) to the magnetic field (H), in the far-field this is the characteristic impedance of free space, approximately 377 Ω
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMI	Electromagnetic Interference
FM	Frequency modulated
GHz	Gigahertz, one billion Hertz (1,000,000,000 Hertz)
H	"H" is the magnetic field component of an electromagnetic field.
Hz	Hertz, unit of measurement for frequency
I	Electric current
kHz	Kilohertz, one thousand Hertz (1000 Hertz)
λ	Lambda, symbol for wavelength
MHz	Megahertz, one million Hertz (1,000,000 Hertz)
mil	Unit of length, one thousandth of an inch
mW	Milliwatt (0.001 Watt)
mW/cm2	Milliwatts per square centimeter, a unit for power density
Pd	Power density, unit of measurement of power per unit area (W/m^2 or mW/cm^2)
R	Resistance
RF	Radio Frequency
RFI	Radio Frequency Interference
V	Volts, unit of electric voltage potential
V/m	Volts per meter, unit of electric field strength
W/m2	Watts per square meter, a unit for power density, one W/m^2 equals 0.1 mw/cm^2
Ω	Ohms, unit of resistance

Ref: ANSI/IEEE 100-1984, IEEE Standard Dictionary of Electrical and Electronics Terms, 1984.

Common Acronyms

AF	(Antenna Factor) - The ratio of the received field strength to the voltage at the terminals of a receiving antenna. Units are 1/m.
ALC	(Absorber-Lined Chamber) - A shielded room with RF-absorbing material on the walls and ceiling. In many cases, the floor is reflective.
AM	(Amplitude Modulation) - A technique for putting information on a sinusoidal carrier signal by varying the amplitude of the carrier.
BCI	(Bulk Current Injection) - An EMC test where common-mode currents are coupled onto the power and communications cables of an EUT.
CE	(Conducted Emissions) - The RF energy generated by electronic equipment, which is conducted on power cables.
CE Marking	The marking signifying a product meets the required European Directives.
CENELEC	French acronym for the “European Committee for Electrotechnical Standardization”.
CI	(Conducted Immunity) - A measure of the immunity to RF energy coupled onto cables and wires of an electronic product.
CISPR	French acronym for “Special International Committee on Radio Interference”.
Conducted	Energy transmitted via cables or PC board connections.
Coupling Path	A structure or medium that transmits energy from a noise source to a victim circuit or system.
CS	(Conducted Susceptibility) - RF energy or electrical noise coupled onto I/O cables and power wiring that can disrupt electronic equipment.
CW	(Continuous Wave) - A sinusoidal waveform with a constant amplitude and frequency.
EMC	(Electromagnetic Compatibility) - The ability of a product to coexist in its intended electromagnetic environment without causing or suffering disruption or damage.

Common Acronyms Continued

EMI	(Electromagnetic Interference) - When electromagnetic energy is transmitted from an electronic device to a victim circuit or system via radiated or conducted paths (or both) and which causes circuit upset in the victim.
EMP	(Electromagnetic Pulse) - Strong electromagnetic transients such as those created by lightning or nuclear blasts.
ESD	(Electrostatic Discharge) - A sudden surge in current (positive or negative) due to an electric spark or secondary discharge causing circuit disruption or component damage. Typically characterized by rise times less than 1 ns and total pulse widths on the order of microseconds.
ESL	(Equivalent Series Inductance) - Generally refers to the parasitic series inductance of a capacitor or inductor. It could also include the extra series inductance of any connecting traces or vias on a PC board.
ESR	(Equivalent Series Resistance) - Generally refers to the parasitic series resistance of a capacitor or inductor.
EU	European Union.
EUT	(Equipment Under Test) - The device being evaluated.
Far Field	When you get far enough from a radiating source the radiated field can be considered planar (or plane waves).
FCC	U.S. Federal Communications Commission.
FM	(Frequency Modulation) - A technique for putting information on a sinusoidal "carrier" signal by varying the frequency of the carrier.
IEC	International Electrotechnical Commission
ISM	(Industrial, Scientific and Medical equipment) - A class of electronic equipment including industrial controllers, test & measurement equipment, medical products and other scientific equipment.
ITE	(Information Technology Equipment) - A class of electronic devices covering a broad range of equipment including computers, printers and external peripherals; also includes, telecommunications equipment, and multi-media devices.
LISN	(Line Impedance Stabilization Network) - Used to match the 50-Ohm impedance of measuring receivers to the power line.
MLCC	(Multi-Layer Ceramic Capacitor) - A surface mount capacitor type often used as decoupling or energy storage capacitors in a power distribution network.
Near Field	When you are close enough to a radiating source that its field is considered spherical rather than planar.
Noise Source	A source that generates an electromagnetic perturbation or disruption to other circuits or systems.
OATS	(Open Area Test Site) - An outdoor EMC test site free of reflecting objects except a ground plane.
PDN	(Power Distribution Network) - The wiring and circuit traces from the power source to the electronic circuitry. This includes the parasitic components (R, L, C) of the circuit board, traces, bypass capacitance and any series inductances.
PLT	(Power Line Transient) - A sudden positive or negative surge in the voltage on a power supply input (DC source or AC line).
PI	(Power Integrity) - Refers to the quality of the energy transfer along the power supply circuitry from the voltage regulator module (VRM) to the die of the ICs. High switching noise or oscillations mean a low PI.
Radiated	Energy transmitted through the air via antenna or loops.
RFI	Radio Frequency Interference) - The disruption of an electronic device or system due to electromagnetic emissions at radio frequencies (usually a few kHz to a few GHz). Also EMI.
RE	(Radiated Emissions) - The energy generated by a circuit or equipment, which is radiated directly from the circuits, chassis and/or cables of equipment.
RI	Radiated Immunity) - The ability of circuits or systems to be immune from radiated energy coupled to the chassis, circuit boards and/or cables. Also Radiated Susceptibility (RS).
RF	(Radio Frequency) - A frequency at which electromagnetic radiation of energy is useful for communications.
RS	(Radiated Susceptibility) - The ability of equipment or circuits to withstand or reject nearby radiated RF sources. Also Radiated Immunity (RI).
SSCG	Spread Spectrum Clock Generation) - This technique takes the energy from a CW clock signal and spreads it out wider, which results in a lower effective amplitude for the fundamental and high-order harmonics. Used to achieve improved radiated or conducted emission margin to the limits.
SI	(Signal Integrity) - A set of measures of the quality of an electrical signal.
SSN	(Simultaneous Switching Noise) - Fast pulses that occur on the power bus due to switching transient currents drawn by the digital circuitry.
TEM	(Transverse Electromagnetic) - An electromagnetic plane wave where the electric and magnetic fields are perpendicular to each other everywhere and both fields are perpendicular to the direction of propagation. TEM cells are often used to generate TEM waves for radiated emissions (RE) or radiated immunity (RI) testing.
Victim	An electronic device, component or system that receives an electromagnetic disturbance, which causes circuit upset.
VRM	(Voltage Regulator Module) - A linear or switch-mode voltage regulator. Generally, there will be several of these mounted to a PC board in order to supply different levels of required voltages.
VSWR	(Voltage Standing Wave Ratio) - A measure of how well the load is impedance matched to its transmission line. This is calculated by dividing the voltage at the peak of a standing wave by the voltage at the null in the standing wave. A good match is less than 1.2:1.
XTALK	(Crosstalk) - A measure of the electromagnetic coupling from one circuit to another. This is a common problem between one circuit trace and another.

Notes:

Advertisers Index

A.H. Systems, Inc.
9710 Cozycroft Ave,
Chatsworth, CA 91311

page: 17
t: (818) 998-0223
e: sales@ahsystems.com
w: www.ahsystems.com

AR RF/Microwave Instrumentation
160 School House Rd.
Souderton PA 18964-9990

page: Inside Back Cover
t: (215) 723-8181
e: info@arworld.us
w: www.arworld.us

ATEC
10401 Roselle Street
San Diego, CA 92121

page: 128
t: (800) 404-2832
e: sales@atecorp.com
w: www.atecorp.com

CST of America®, Inc.
US Headquarters
492 Old Connecticut Path,
Suite 500 Framingham, MA 01701

page: 4
t: (508) 665-4400
e: info@cst.com
w: www.cst.com

Delta
Americas Headquarters
46101 Fremont Blvd,
Fremont, CA 94538, U.S.A.

page: 24
t: (510) 668-5100
e: ESPSales.US@deltaww.com
w: delta-americas.com

EDI Con Boston 2017
Septebmer 11-13
Hynes Convention Center

page: 47
t: (781) 619-1930
e: aconnell@mwjournal.com
w: www.ediconusa.com

EMC+SIPI 2017 Online Symposium
Online Event
August 7-11, 2017

page: 42
e: emc2017online@Item.media
w: www.emc2017online.emcss.org

ITEM Media
1000 Germantown Pike
Plymouth Meeting, PA 19462

page: 19
t: (484) 688-0300
e: info@item.media
w: item.media

Master Bond, Inc.
154 Hobart Street
Hackensack, NJ 07601 USA

page: 16
t: (201) 343-8983
e: main@masterbond.com
w: www.masterbond.com

Montrose Compliance Services, Inc
2353 Mission Glen Drive
Santa Clara, Ca 95051 USA

page: 16
t: (408) 247-5715
e: mark@montrosecompliance.com
w: www.montrosecompliance.com

PPG Aerospace
Cuming Microwave Corporation
264 Bodwell Street
Avon, MA 02322

page: 41
t: (508) 521-6700
w: www.CumingMicrowave.com

Retlif Testing Laboratories
795 Marconi Avenue,
Ronkonkoma, NY 11779 USA

page: 22
t: (631) 737-1500
w: www.retlif.com

Rhode & Schwarz
Muehldorfstrasse 15
81671 Munich, Germany

page: Inside Front Cover
t: Germany: +49 (0) 89 4129 12345
United States: (410) 910-7800
w: www.rohde-schwarz.com
www.rohde-schwarz-usa.com

Wyatt Technical Services, LLC
56 Aspen Dr.
Woodland Park, CO 80863

page: 16
t: (719) 310-5418
e: ken@emc-seminars.com
w: www.emc-seminars.com


ITEM MEDIA
Engineered Marketing For The Electronics Industry
Understand your customers' digital footprints to better understand their journey.
Lead Qualification
Lead Generation
Audience Development
Online Events
Content Creation
Technology Implementation
Big Data Translation
...and MORE!
Start your journey today!
please visit
item.media
Additional ITEM Media Brands: Interference Technology | Electronics Cooling | Environmental Test & Design

INTERFERENCE TECHNOLOGY®

EMC DESK REFERENCE

Interference Technology | ITEM Media
1000 Germantown Pike, Plymouth Meeting, PA 19462
Copyright © 2017 ITEM Media. All Rights Reserved.