PRESENTED BY

INTERFERENCE TECHNOLOGY®

2017 EMC FUNDAMENTALS GUIDE

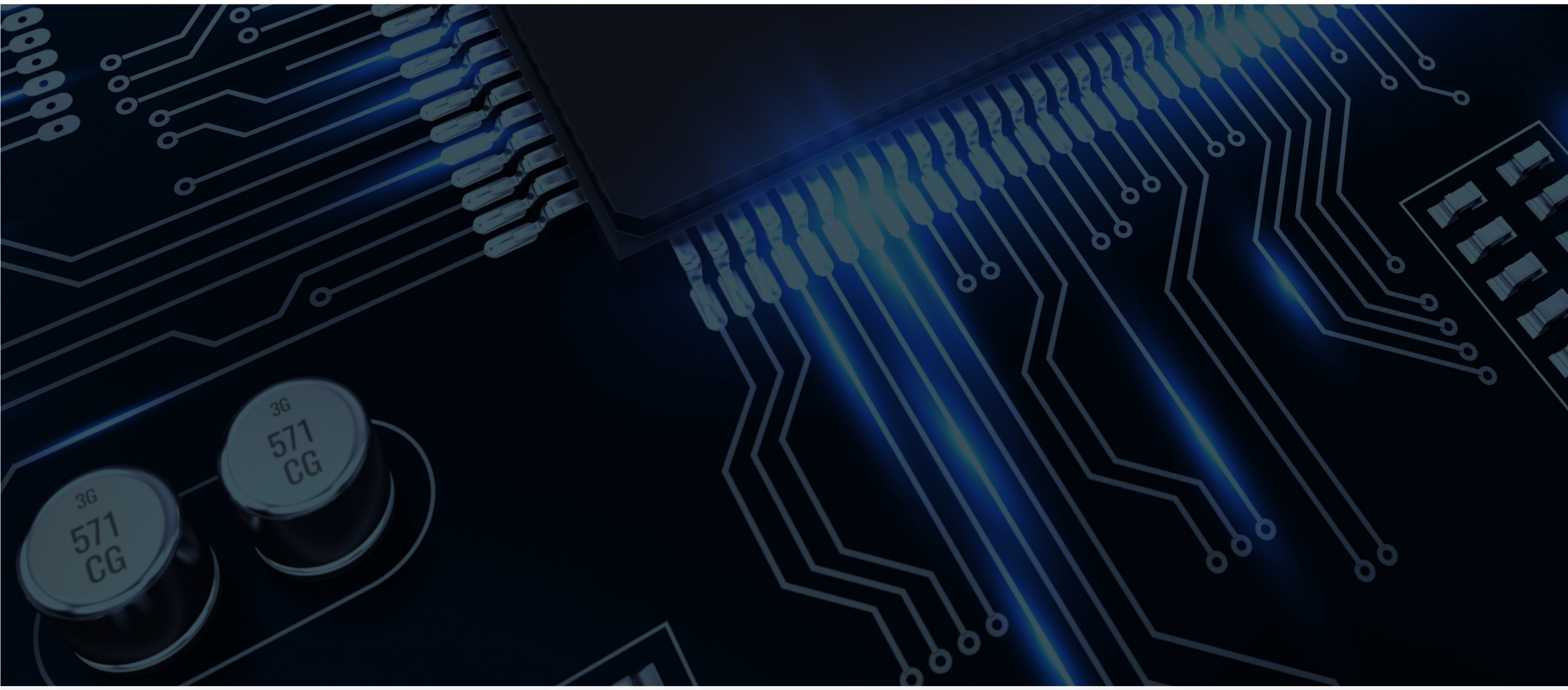


TABLE OF CONTENTS

INTRODUCTION

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

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 cost.

The purpose of this short guide is to help product designers learn enough of the basics of EMC and EMI so that the usual design failures are addressed early, when costs and design is minimized. Achieving EMC/EMI is easy once the basics are understood.

Today, with 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. Most countries now impose some sort of EMC standards to which products must be tested.

Basic Definitions
Let's start with some basic definitions, 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 more concerned 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 from 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 emission. 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*.

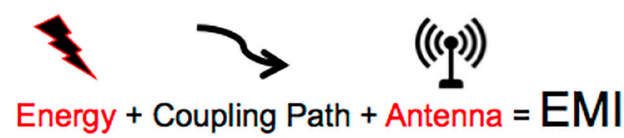


Figure 1 - A simple model for radiated emissions. Take away any of the three elements and you have no EMI.

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.

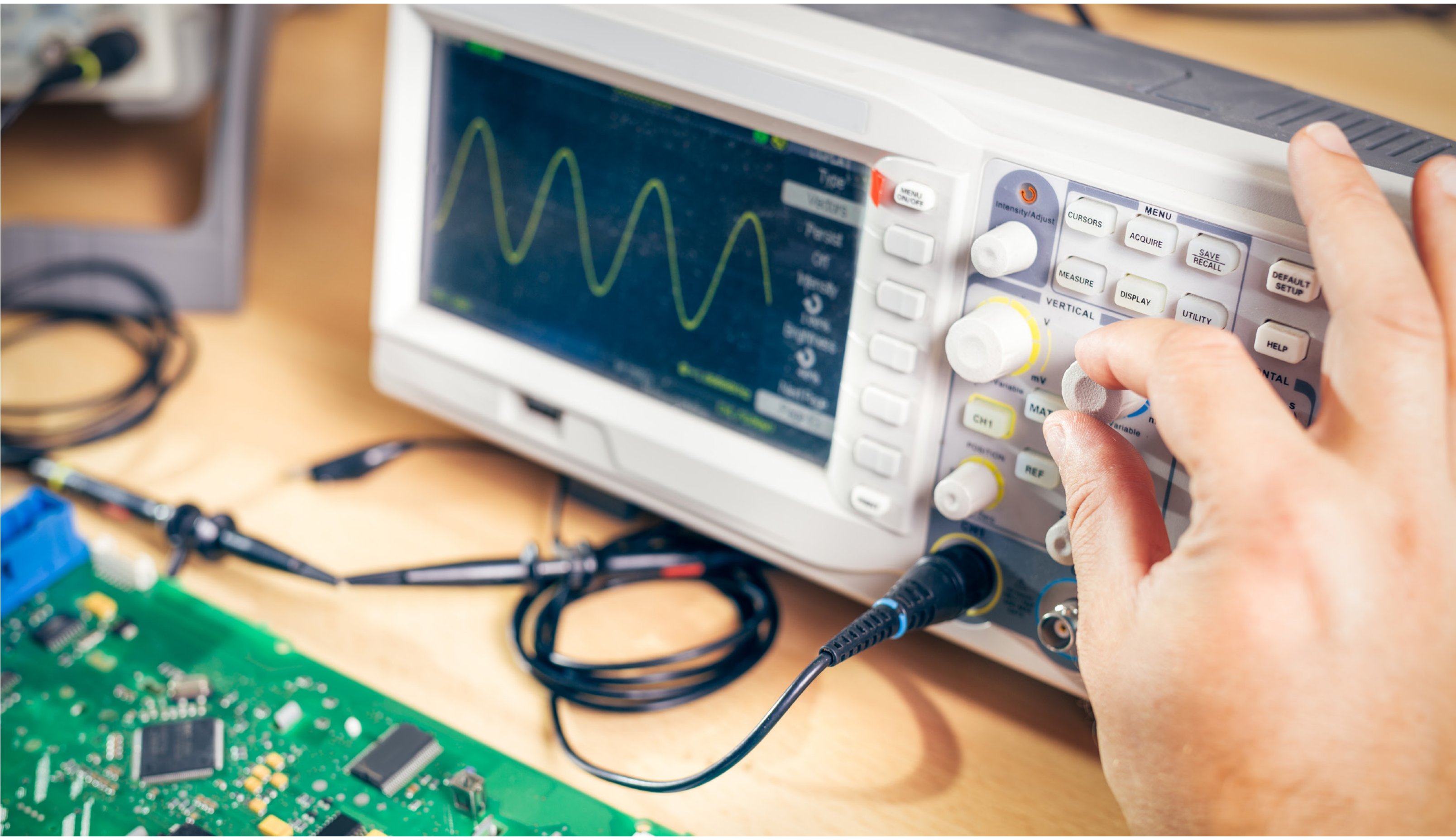
The three top product failures I see all the time as a consultant are (1) radiated emissions, (2) radiated susceptibility, and (3) electrostatic discharge. We'll discuss these and more in this EMC Fundamentals Guide.

We'll start off with some very basic EMC theory, describe some common product design issues, and wrap up with a host of additional reference material, such as lists of common EMC standards, additional reference articles, books, and many other charts and tools.

EMC EQUIPMENT MANUFACTURERS

Introduction

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



EMC Equipment Manufacturers		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	http://www.atecorp.com	X	X	X	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
Electro Rent	http://www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	http://www.emtest.com/home.php									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/en/					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/main/home.jspx?cc=US&lc=eng			X		X		X			X			X
Microlease	https://www.microlease.com/us/home		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/narda/default_en.asp	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/us/home_48230.html	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	http://siglentamerica.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/en/index.php		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/us/en/home.html						X			X				
Thurlby Thandar (AIM-TTi)	http://www.aimtti.us					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.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	http://vectawave.com		X											
Windfreak Technologies	https://windfreaktech.com													X

emi filtering

The broadest line of standard products and custom passive component solutions.

Spectrum Control Brand Products

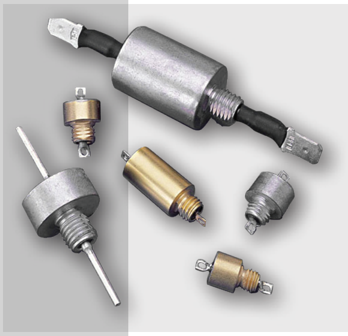
Ceramic Capacitors
Exhibit low parasitic capacitance and superior EMI filtering capabilities

Coaxial Filters & Interconnects
Delivering a broad range of custom and off-the-shelf options to meet your design requirements

Magnetics
Broad range of custom, application-specific solutions

Power Filters
Ideal to filter the AC or DC power entering your system to prevent radiated or conducted EMI

Specialty Connectors
Custom connectors can be designed to meet RTCA/DO-160 Section 22 Lighting Strike



Innovative solutions from components to complex assemblies.

Standard configurable and fully customizable electromagnetic integrated solutions.

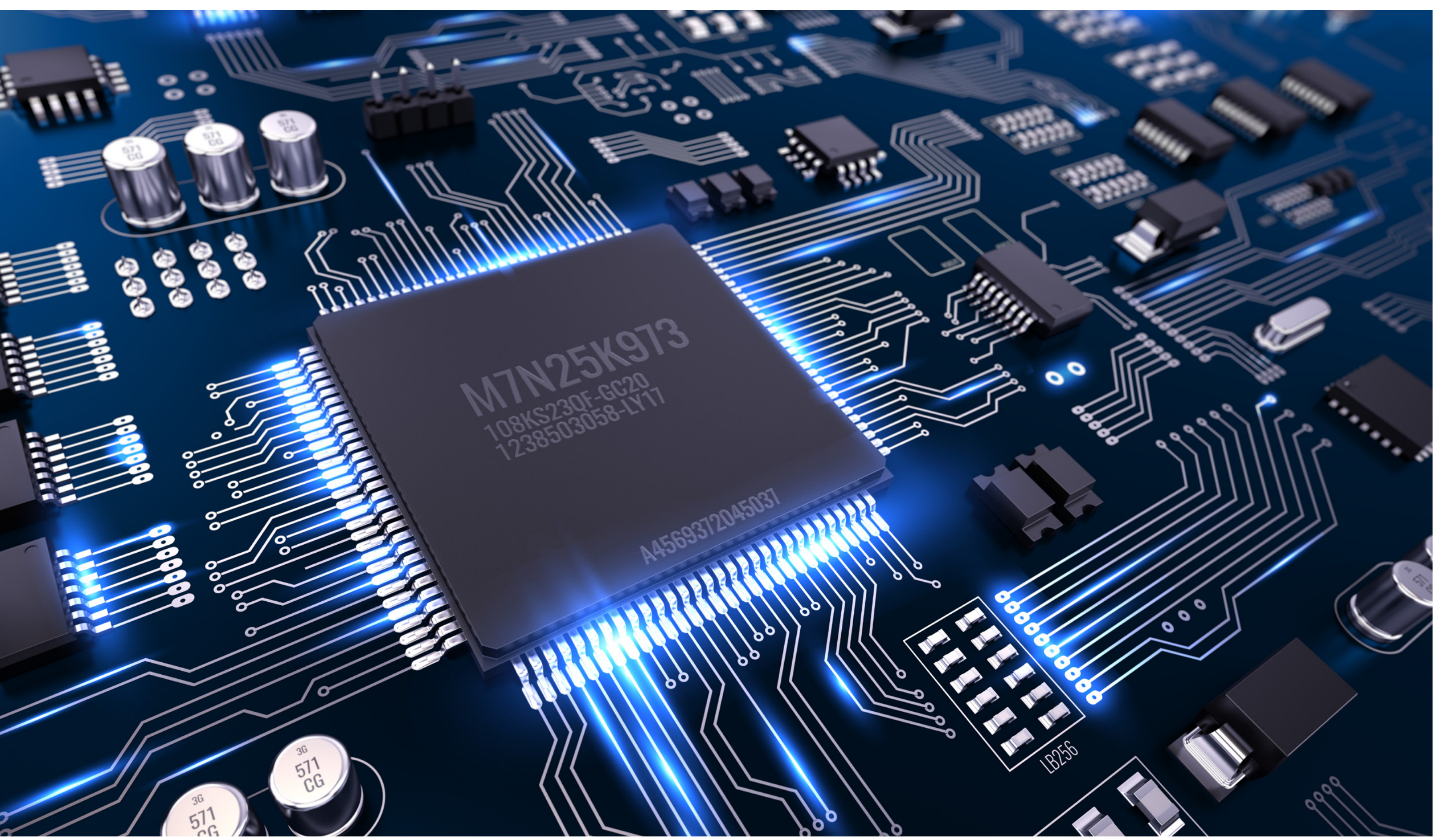
api technologies corp.

Email: eisSales@apitech.com
Phone: 1 (855) 294-3800

eis.apitech.com

BASIC EMC CONCEPTS

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



INTRODUCTION

Understanding EMC 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.

Currents Flow In Loops

These two concepts are closely related and coupled to one another. The problem we circuit designers miss is defining the return path 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).

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* return signals get comingled with I/O circuit return currents or sensitive analog return currents. We'll discuss PC board design in the next article. 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 1*, 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 for capacitors and Maxwell called this effect "displacement current".

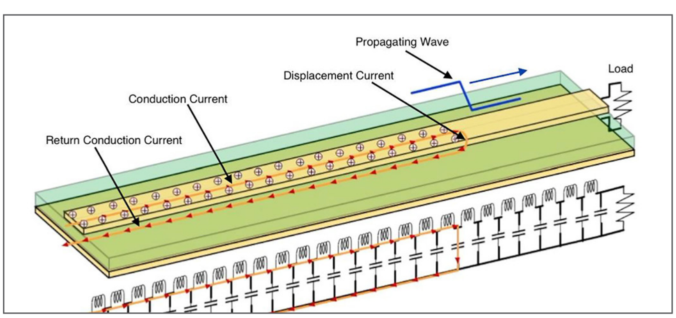


Figure 1 - A digital signal propagating along a microstrip with currents shown.

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. Refer to *References 1, 2*, and *3* for further details.

The important thing is that this combination of conduction and displacement current must have an uninterrupted path back to the source. If it is interrupted in any way, the propagating electromagnetic wave will "leak" all around inside the PC board layers and cause "common mode" currents to form, which then couple to other signals (cross-coupling) or to "antenna-like structures", such as I/O cables or slots/apertures in shielded enclosures.

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.

It is very important to note that all power distribution networks (PDNs) and high frequency signal traces are transmission lines and the energy is transferred as electromagnetic waves at about half the speed of light in normal FR4-type board dielectrics. We'll show what happens when the return path or return plane is interrupted by a gap in the next article. More on PDN design may be found in *Reference 4, 5,* and *6*.

Differential Mode versus Common Mode Currents

Referring to *Figure 2*, the differential mode current (in blue) is the digital signal itself (in this case, shown in 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.

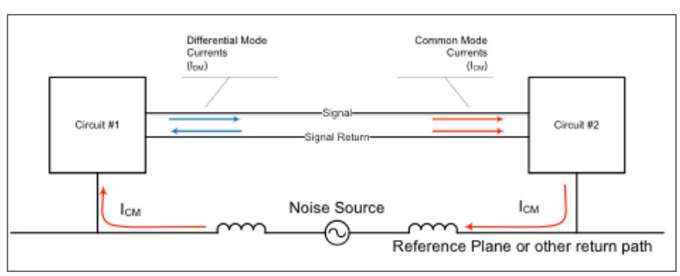


Figure 2 - An example of differential and common mode currents.

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. 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.

Summary

To summarize product design for EMI compliance, a properly designed PC board with adjacent return planes to all signals and PDNs, properly bonded I/O cable shields, well bonded shielded enclosures with minimal slots or gaps, and common mode filtering on all I/O and power cables for unshielded products is generally required for best EMI performance. Paying attention to these factors early in the design greatly reduces the risk of EMC and EMI compliance failures.

References

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

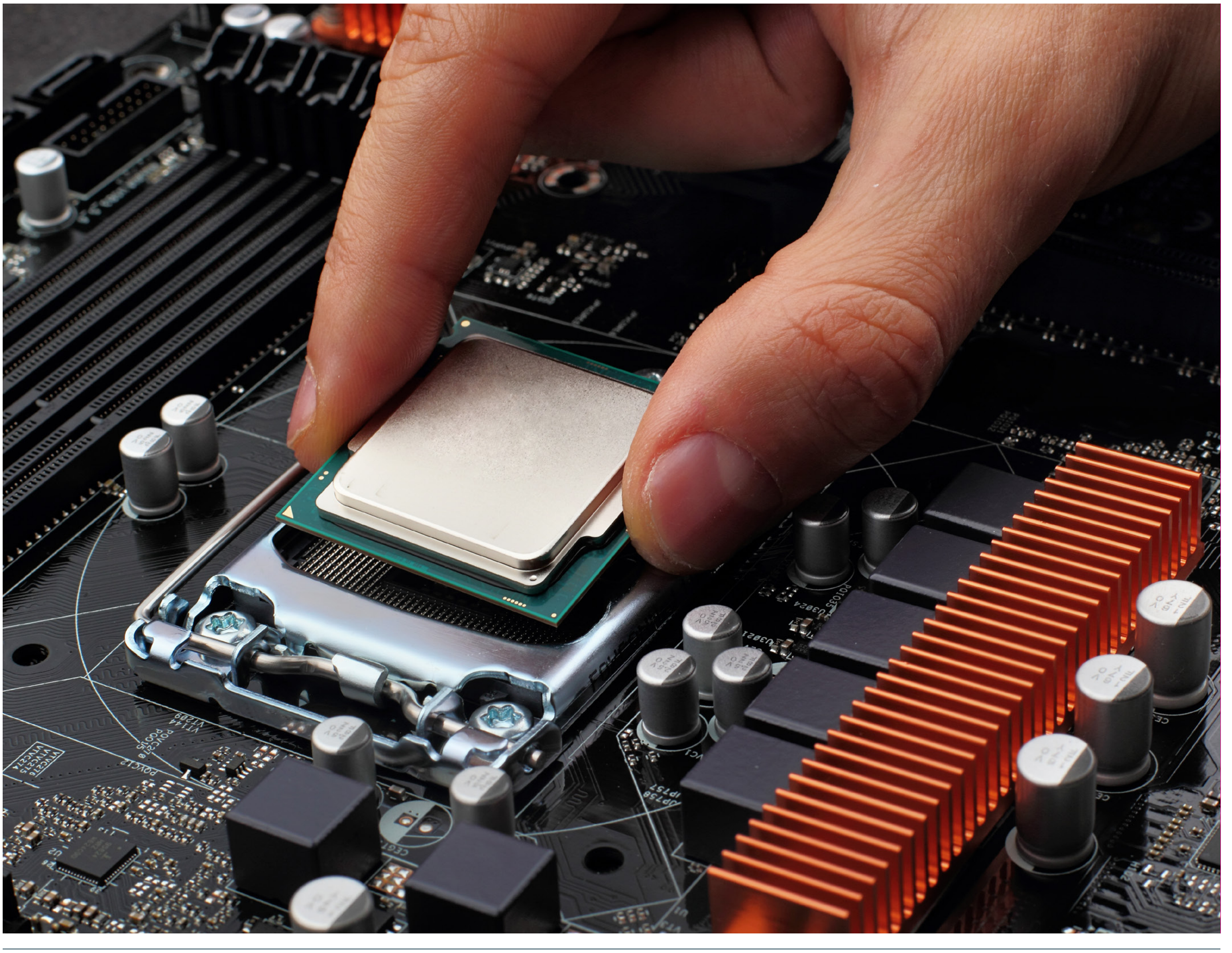
2. Morrison, Grounding and Shielding - Circuits and Interference, Wiley, 2016.

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

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.



DESIGN FOR EMC COMPLIANCE ESSENTIALS

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

Introduction

While unrealistic to discuss all aspects of product design in a single article, I'll try to describe the most common design issues I find in the hundreds of client products I've had a chance to work on. These issues generally include PC board design, cables, shielding, and filtering. More detailed information may be found in the Reference section below.

As previously mentioned, the top three product failures I run into include (1) radiated emissions, (2) radiated susceptibility, and (3) electrostatic discharge. Other failures can include things like conducted emissions, electrically fast transient, conducted susceptibility, and electrical surge. Most of these last items are also the result of the same poor product designs, which cause the top three failures.

NOTE: I prefer to avoid the word "ground" in this article or in my consulting practice. The reason is that there are too many misinterpretations, which can also lead to EMC failures. It's much more clear to use power and power return, and signal and signal return - or just "return plane" or reference plane. Finally, cable shields or shielded enclosures are "bonded" together - not "grounded". The only exception is the so called "safety ground" or earth ground. But these have nothing at all to do with proper EMC design - just personal safety against electrical shock. I suppose the one exception would be the earth ground connection on a three-wire power line filter. Also, occasionally, there will be an earth ground on a PC board - especially for power supplies, but again, connecting a product or system to earth ground will not improve EMI, due to the very high inductance (length) of the wire.

DESIGN FOR EMC COMPLIANCE ESSENTIALS

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.

The previous article introduced the concept of the circuit theory and field theory viewpoints. A successful PC board design accounts for both viewpoints. 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. Breaks or gaps in the return path are major causes of radiated emissions, radiated susceptibility, and ESD failures.

Correspondingly, electric fields on PC boards exist between two pieces of metal, such as a microstrip over a return plane (or trace). If the return path is broken, the electric field will "latch on" to the next closest metal and 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, as well as cause cross-coupling of clocks or other high speed signals to dozens of other circuit traces within that same dielectric.

Figure 1 shows a propagating wave within the dielectric between the signal trace and return plane (or trace). This shows both the conduction current flowing in the signal trace and back on the return plane (or trace) and the displacement current "through" the dielectric. The signal wave front travels at some fraction of the speed of light as determined by the dielectric constant. In air, signals travel at about 12 inches per nanosecond. In the typical FR4 dielectric, the speed is about half that at 6 inches per nanosecond. Refer to *Reference 1, 2,* and *3* for more information on the physics of signal propagation through PC boards.

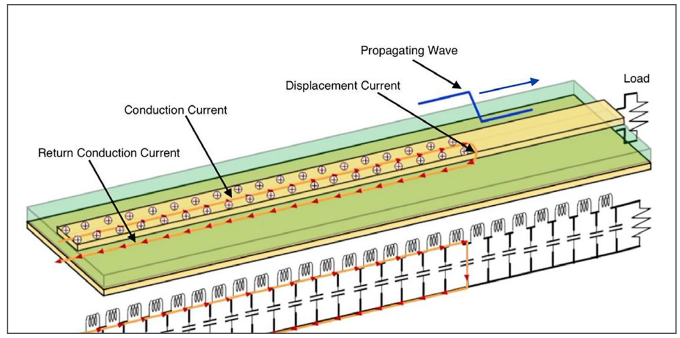


Figure 1 - A propagating wave along a microstrip with reference plane. Figure, courtesy Eric Bogatin.

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. PDN design also requires both bulk and decoupling "energy storage" capacitors. 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 - and most importantly, with minimal trace length connecting these from the power pins to signal return plane. Ideally, all decoupling capacitors should be mounted right over (or close to) the connecting vias and multiple vias should be used for each capacitor to reduce series inductance.

Signal or power routed referenced to a single plane will always have a defined return path back to the source. *Figure 2* shows how the electromagnetic field stays within the dielectric on both sides of the return plane. The dielectric is not shown for clarity.

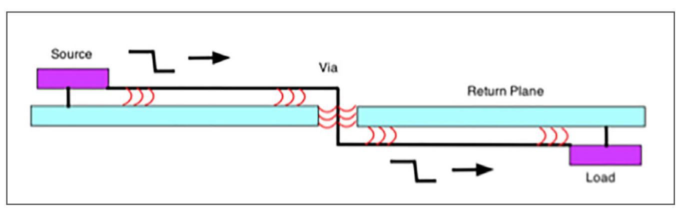


Figure 2 - A signal trace passing through a single reference plane.

On the other hand, referring to *Figure 3*, 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.

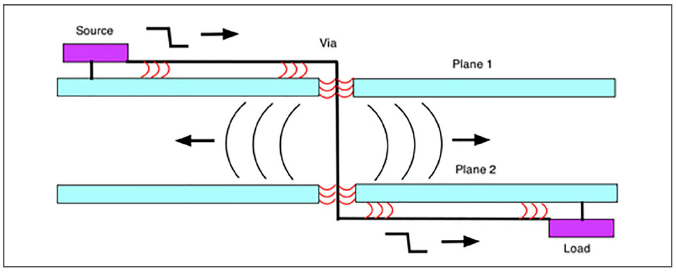


Figure 3 - A signal trace passing through two reference planes. If the reference planes are the same potential (signal or power returns, for example), then stitching vias next to the signal via should be sufficient. However, if the planes are different potentials (power and return, for example), then 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. See *Figure 4*.

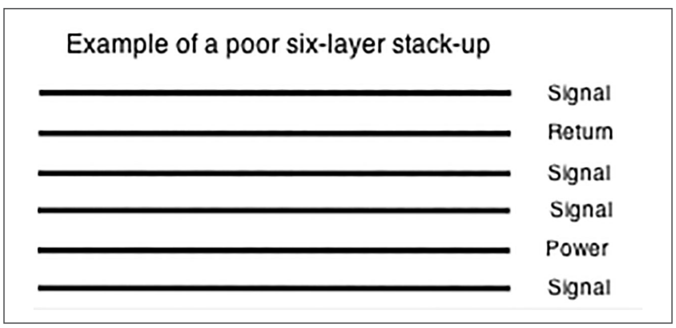


Figure 4 - A six-layer board stack-up with very poor EMI performance.

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.

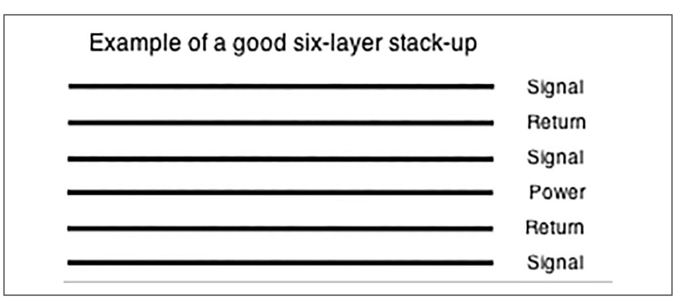


Figure 5 - A six-layer board stack-up with good EMI performance. Each signal layer has an adjacent return plane and the power and power return planes are adjacent.

A better design is shown in *Figure 5*. 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.

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.

Gaps in Return Plane - I'd like to come back to the 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 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 6* and *Reference 4*.

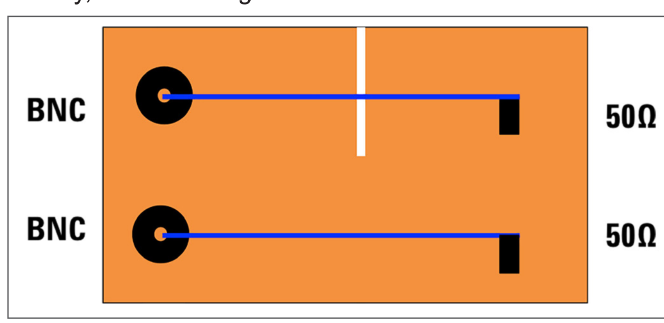


Figure 6 - shows a demonstration test board with transmission lines terminated in 50 Ohms. One transmission line has a gap in the return plane and the other doesn't. A 2 ns pulse generator is connected to one of the two BNC connectors in turn and the harmonic currents in a wire clipped to the return plane are measured with a current probe.

The difference between the gapped and un-gapped traces is shown in *Figure 7*. 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.

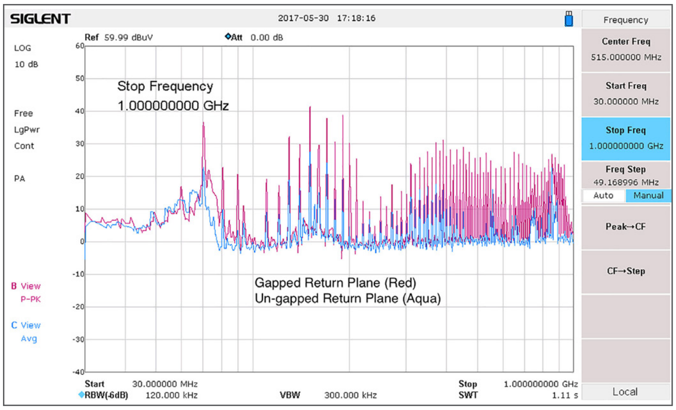


Figure 7 - The resulting common mode currents on an attached wire as measured with a current probe. The trace in aqua is the un-gapped return path and the trace in red, the gapped return path. The difference is 10 to 15 dB higher for the gapped return path. These harmonic currents will tend to radiate and will likely cause radiated emissions failures.

Shielding

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. Slots or apertures in shielded enclosures become issues when the longest dimension approaches a half wavelength. *Figure 8* shows a handy chart for determining the 20 dB attenuation of a given slot length. See *Reference 5* and *6* for more detail on shielding. Interference Technology also has a free downloadable 2016 EMI Shielding Guide with excellent information (*Reference 7*).

Figure 9 is a chart of wavelength versus frequency. For example a 6-inch (15 cm) slot has a half wave resonance at 1000 MHz. If a product design requires at least a 20 dB shielding effectiveness, then the longest slot length can be just one-half inch.

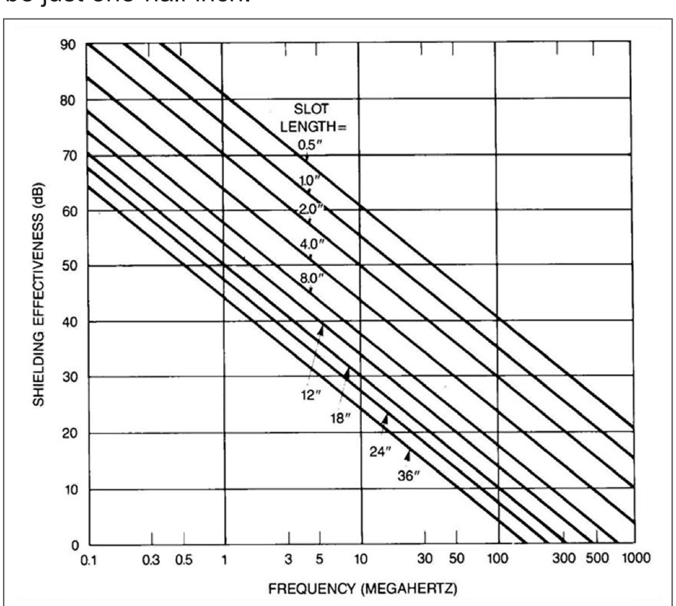


Figure 8 - A chart of attenuation versus slot length. Figure, courtesy Henry Ott.

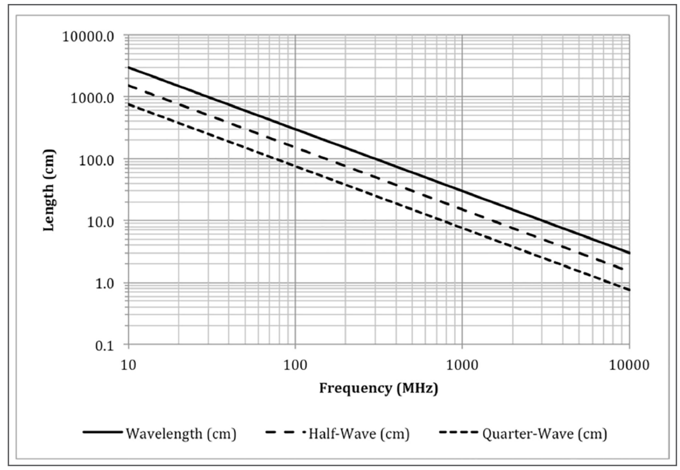


Figure 9 - A handy chart for determining resonant frequency versus cable or slot length in free space. Half-wavelength slots simulate dipole antennas and are particularly troublesome. Figure, courtesy Patrick André.

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 10* and *11*). 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.

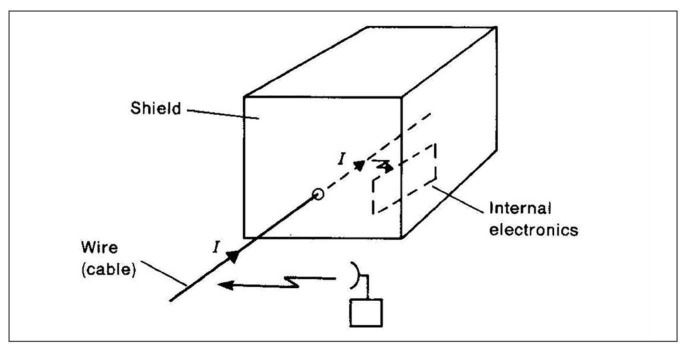


Figure 10 - Penetrating the shield with a cable defeats the shield. This example shows how external energy sources can induce noise currents in I/O cables, which can potentially disrupt internal circuitry. The reverse is also true, where internal noise currents can flow out the cable and cause emissions 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 must be added at the point of penetration or at the I/O connector of the PC board. *Figure 11* shows the usual result when connectors simply poke through a shielded enclosure.

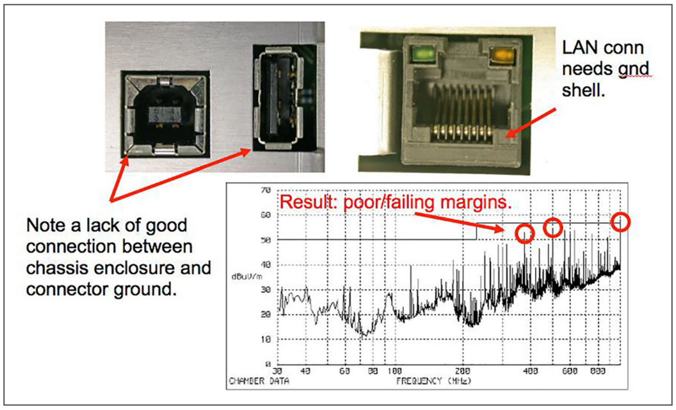


Figure 11 - Result of a penetrating cable through a shielded enclosure, because of un-bonded I/O connectors to the shielded enclosure.

Cable Shield Terminations - Another potential issue is if the I/O cable uses a "pigtail" connection to the connector shell. 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. 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.

Filtering

I won't go into very much detail here, because Interference Technology has an excellent EMI Filter Guide free for the downloading (see *Reference 8*). Suffice to say, filters, as well as transient protection, are important at power and I/O connectors. Typically, these will be common mode topologies, as shown in *Figure 12*. Most signal-level common mode chokes may be obtained in surface mount packaging. Power chokes are much larger to handle the current and may be obtained as either surface mount or through-hole mount, depending on the current rating. Many Ethernet connectors have built-in common mode filtering.

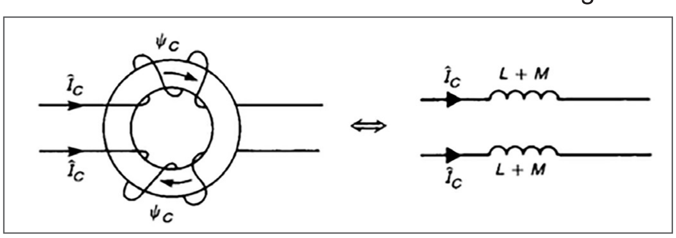


Figure 12 - A typical common mode filter used for I/O filtering. The two windings are wound in opposite directions and so tend to cancel the common mode currents.

Power supply input filters are generally designed to suppress both differential and common mode currents. A typical topology is shown in *Figure 13*. The "X" capacitor is designed to filter differential mode, while the CM choke and "Y" capacitors are designed to filter common mode. The resistor shown is usually 100 kOhm and the purpose is merely to bleed off the line voltage stored on the capacitors to a safe level.

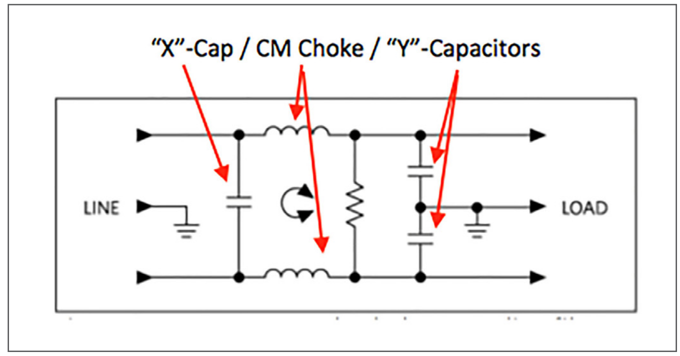


Figure 13 - A general purpose filter typically used for power supply input filtering.

For general purpose filtering of signals, the handy chart of possible filter topologies may be found in *Reference 9* and is reproduced here in *Figure 14*. The appropriate topology depends on the source and load impedances. If these impedances are not known, then either the "PI" or "T" topology may be used (#3 or #5 on the chart, respectively).

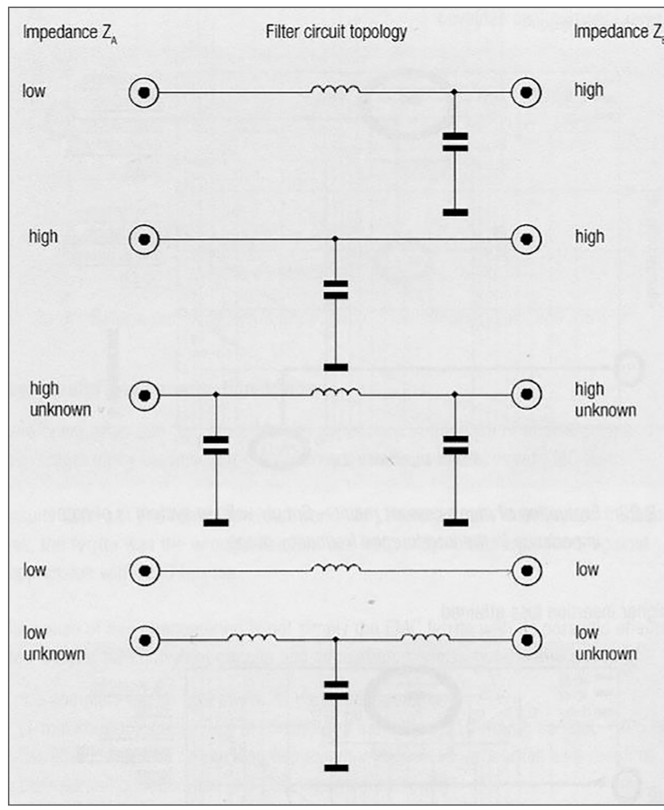


Figure 14 - Five common filter topologies, depending on the source and load impedances. Figure, courtesy Würth Electronik.

Ferrite or inductive components should not be used in series with the power pins of ICs, as this will only reduce the ability of the local decoupling capacitors to supply required energy during simultaneous switching of the IC output stages with the resulting higher power supply noise.

Ferrite Chokes - One common filter element usually added to I/O cables is the ferrite choke. Ferrite chokes come in either the clamp-on types or solid cores meant to be assembled along with the cable assembly. Often, these are used as a last resort to reduce cable emissions or susceptibility.

Most ferrite chokes have an associated impedance versus frequency characteristic, often peaking around 100 to 300 MHz. Some materials are designed to peak below 100 MHz for lower frequency applications. Maximum impedances can range from 25 to 1000 Ohms, depending on the ferrite material used and style of choke.

Sometimes, clipping a ferrite choke onto a cable has no effect. This is usually due to the fact the choke has the same, or lower, effective impedance than the cable itself.

The attenuation of a ferrite choke is easily calculated.

$$\text{Attenuation (dB)} = 20 * \log((Zin + Zferrite + Zload) / (Zin + Zload))$$

For example, if we add a 100 Ohm ferrite choke to a power supply cable with system impedance of 10 Ohms, the attenuation would be:

$$\text{Attenuation} = 20 * \log((10 + 100 + 10) / (10 + 10)) = 15.5 \text{ dB}$$

Refer to *Reference 9* for much additional detail on ferrite chokes and general filter design.

Transient Protection

In order to protect internal circuitry from electrical transients, such as ESD, electrically fast transient (EFT), or power line surge, due to lightning, transient protective devices should be installed at all power and I/O ports. These devices sense the transient and “clamp” the transient pulse to a specified clamp voltage.

Transient protectors in signal lines must generally have a very low parallel capacitance (0.2 to 1 pF, typical) to the return plane, depending on the data rate in order to maintain signal integrity. These silicon-based devices may be purchased in very small surface mount packaging.

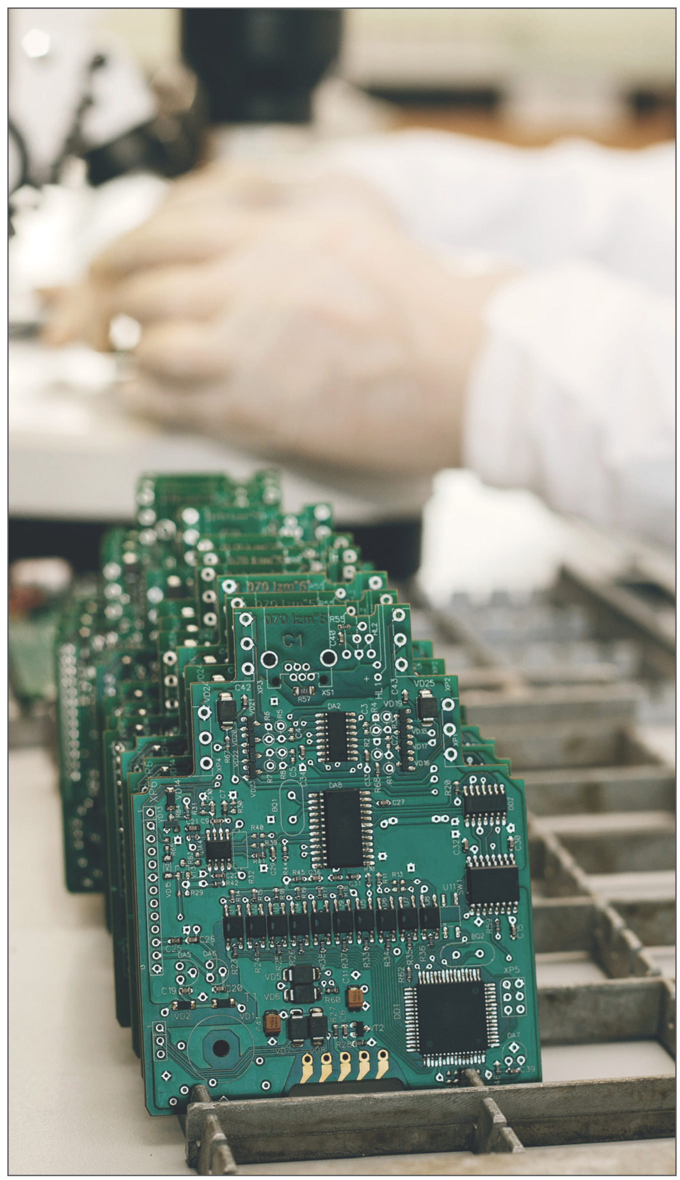
Power line surge protection usually requires much larger transient protection devices and they can come in a variety of types. Gas discharge or metal oxide varistors are the most common, but larger silicon-based devices are also available. More information on the design of surge protection may be found in *Reference 4*.

Summary

Most EMC/EMI failures are due to poor shielding, penetration of cables through shields, poor cable shield termination, poor filtering, and above all, poor PC board layout and stack-up. Paying attention to these common design faults will pay off with a lower risk of compliance failures and result in lower project costs and schedule slippage.

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.
4. Wyatt, Gaps in Return Planes - Bad News for EMI (with video demo), https://interferencetechnology.com/gaps-return-planes-bad-news-emi/
5. Ott, Electromagnetic Compatibility Engineering, Wiley, 2009.
6. André and Wyatt, EMI Troubleshooting Cookbook for Product Designers, SciTech, 2014.
7. ITEM, 2016 EMI Shielding Guide, http://learn.interferencetechnology.com/2016-emi-shielding-guide/
8. ITEM, 2017 EMC Filters Guide, http://learn.interferencetechnology.com/2017-emc-filters-guide/
9. Würth Electronik, Trilogy of Magnetics, 2010.



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

COMMON COMMERCIAL EMC STANDARDS

Commercial Electromagnetic Compatibility (EMC) Standards

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

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

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

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

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

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

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

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

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

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

CISPR	
Document Number	Title
CISPR 11	Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
CISPR 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 (continued)	
Document Number	Title
CISPR 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement
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

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.

MIL-HDBK-235-1C Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010.

MIL-HDBK-237D Electromagnetic Environmental Effects and Spectrum Certification Guidance for the Acquisition Process, 20 May 2005.

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

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

MIL-HDBK-274A Electrical Grounding for Aircraft Safety, 14 Nov 2011.

MIL-HDBK-335 Management and Design Guidance Electromagnetic Radiation Hardness for Air Launched Ordnance Systems, Notice 4, 08 Jul 2008.

MIL-HDBK-419A Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, 29 Dec 1987.

MIL-HDBK-454B General Guidelines for Electronic Equipment, 15 Apr 2007.

MIL-HDBK-1004-6 Lightning Protection, 30 May 1988.

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

MIL-HDBK-1512 Electroexplosive Subsystems, Electrically Initiated, Design Requirements and Test Methods, 30 Sep 1997.

MIL-HDBK-1857 Grounding, Bonding and Shielding Design Practices, 27 Mar 1998.

MIL-STD-188-124B Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications-Electronics Facilities and Equipment, 18 Dec 2000.

MIL-STD-188-125-1 High-Altitude Electromagnetic Pulse (HEMP) Protection for Ground-Based C41 Facilities Performing Critical, Time-Urgent Missions Part 1 Fixed Facilities, 17 Jul 1998.

MIL-STD-220C Test Method Standard Method of Insertion Loss Measurement, 14 May 2009.

MIL-STD-331C Fuze and Fuze Components, Environmental and Performance Tests for, 22 Jun 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.

MIL-STD-464C Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010.

MIL-STD-704E Aircraft Electric Power Characteristics, 12 Mar 2004.

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

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

MIL-STD-1399 Section 300B Interface Standard for Shipboard Systems, Electric Power, Alternating Current, 24 Apr 2008.

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-1605 Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009.

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

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

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

DoDI 3222.03 DoD Electromagnetic Environmental Effects (E3) Program, 24 Aug 2014.

DoDD 4650.01 Policy and Procedures for Management and Use of the Electromagnetic Spectrum, 09 Jan 2009.

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

AEROSPACE STANDARDS

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

S-121-2009, Electromagnetic Compatibility Requirements for Space Equipment and Systems

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

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-307A, 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/

ARP 5583 – Guide to Certification of Aircraft in a High Intensity Radiation (HIRF) Environment http://standards.sae.org/arp5583/

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY (EMC) STANDARDS

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

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

CISPR (Automotive Emissions Requirements)	
Document Number	Title
CISPR 12	Vehicles, boats, and internal combustion engine driven devices – Radio disturbance characteristics – Limits and methods of measurement for the protection of receivers except those installed in the vehicle/boat/device itself or in adjacent vehicles/boats/devices
CISPR 25	Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices – Limits and methods of measurement

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

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

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

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

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

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

DaimlerChrysler	
Document Number	Title
DC-10614	EMC Performance Requirements – Components
DC-10615	Electrical System Performance Requirements for Electrical and Electronic Components
DC-11224	EMC Performance Requirements – Components
DC-11225	EMC Supplemental Information and Alternative Component Requirements
DC-11223	EMC Performance Requirements – Vehicle

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

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

MEDICAL ELECTRICAL EQUIPMENT AND SYSTEMS STANDARDS

Darryl P. Ray
Darryl Ray EMC Consulting, LLC
Darryl.ray@Dray-emc.com

Tables 1 and 2 below list the collateral (vertical) and particular (product specific) standards within the IEC/ISO 60601 family[1]. Requirements in the particular standards take precedence over those in the General Safety Standard (IEC 60601-1) or the Collateral Standards (IEC 60601-1-X). Table 3 list several other relevant standards. Refer the standard for the exact title.

Table 1. Collateral Standards

Document	Description
IEC 60601-1-1	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	Usability
IEC 60601-1-8	Alarm systems
IEC 60601-1-9	Requirements for environmentally conscious design
IEC 60601-1-10	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 intended for use in the emergency medical services environment

Table 2. Particular Standards

Document	Description
IEC 60601-2-1	Electron accelerators in the range 1 MeV to 50 MeV
IEC 60601-2-2	High frequency surgical equipment and high frequency surgical accessories
IEC 60601-2-3	Short-wave therapy equipment
IEC 60601-2-4	Cardiac defibrillators
IEC 60601-2-5	Ultrasonic physiotherapy equipment
IEC 60601-2-6	Microwave therapy equipment
IEC 60601-2-7	High-voltage generators of diagnostic X-ray generators
IEC 60601-2-8	(replaced by IEC 60601-2-63 and IEC 60601-2-65)
IEC 60601-2-9	Therapeutic X-ray equipment operating in the range 10 kV to 1 MV
IEC 60601-2-10	Patient contact dosemeters used in radiotherapy
IEC 60601-2-11	Nerve and muscle stimulators
ISO 80601-2-12	Gamma beam therapy equipment
ISO 80601-2-13	Critical care ventilators
IEC 60601-2-14	Anaesthetic workstations

Table 2. Particular Standards (continued)

Document	Description
IEC 60601-2-15	Capacitor discharge X-ray generators (withdrawn)
IEC 60601-2-16	Haemodialysis, haemodiafiltration and haemofiltration equipment
IEC 60601-2-17	Automatically-controlled brachytherapy afterloading equipment
IEC 60601-2-18	Endoscopic equipment
IEC 60601-2-19	Infant incubators
IEC 60601-2-20	Infant transport incubators
IEC 60601-2-21	Infant radiant warmers
IEC 60601-2-22	Surgical, cosmetic, therapeutic and diagnostic laser equipment
IEC 60601-2-23	Transcutaneous partial pressure monitoring equipment
IEC 60601-2-24	Infusion pumps and controllers
IEC 60601-2-25	Electrocardiographs
IEC 60601-2-26	Electroencephalographs
IEC 60601-2-27	Electrocardiographic monitoring equipment
IEC 60601-2-28	X-ray tube assemblies for medical diagnosis
IEC 60601-2-29	Radiotherapy simulators
IEC 80601-2-30	Automated non-invasive sphygmomanometers
IEC 60601-2-31	External cardiac pacemakers with internal power source
IEC 60601-2-32	Associated equipment of X-ray equipment (withdrawn)
IEC 60601-2-33	Magnetic resonance equipment for medical diagnosis
IEC 60601-2-34	Invasive blood pressure monitoring equipment
IEC 80601-2-35	Heating devices using blankets, pads or mattresses
IEC 60601-2-36	Equipment for extracorporeally induced lithotripsy
IEC 60601-2-37	Ultrasonic medical diagnostic and monitoring equipment
IEC 60601-2-38	Electrically operated hospital beds
IEC 60601-2-39	Eritoneal dialysis equipment (withdrawn)
IEC 60601-2-40	Electromyographs and evoked response equipment

MEDICAL ELECTRICAL EQUIPMENT AND SYSTEMS STANDARDS

CONTINUED

Table 2. Particular Standards (continued)

Document	Description
IEC 60601-2-41	Surgical luminaires and luminaires for diagnosis
IEC 60601-2-42	N/A
IEC 60601-2-43	X-ray equipment for interventional procedures
IEC 60601-2-44	X-ray equipment for computed tomography
IEC 60601-2-45	Mammographic X-ray equipment and mammographic stereotactic devices
IEC 60601-2-46	Operating tables
IEC 60601-2-47	Ambulatory electrocardiographic systems
IEC 60601-2-48	N/A
IEC 60601-2-49	Multifunction patient monitoring equipment
IEC 60601-2-50	Infant phototherapy equipment
IEC 60601-2-51	Recording and analysing single channel and multichannel electrocardiographs (withdrawn)
IEC 60601-2-52	Medical beds
IEC 60601-2-53	N/A
IEC 60601-2-54	X-ray equipment for radiography and radioscopy
ISO 80601-2-55	Respiratory gas monitors
ISO 80601-2-56	Clinical thermometers for body temperature measurement
IEC 60601-2-57	Non-laser light source equipment intended for therapeutic, diagnostic, monitoring and cosmetic/aesthetic use
IEC 80601-2-58	Lens removal devices and vitrectomy devices for ophthalmic surgery and associated accessories
IEC 80601-2-59	Screening thermographs for human febrile temperature screening
IEC 80601-2-60	Dental equipment
ISO 80601-2-61	Pulse oximeter equipment
IEC 60601-2-62	High intensity therapeutic ultrasound (HITU) equipment
IEC 60601-2-63	Dental extra-oral X-ray equipment
IEC 60601-2-64	Light ion beam medical electrical equipment
IEC 60601-2-65	Dental intra-oral X-ray equipment
IEC 60601-2-66	Hearing instruments and hearing instrument systems
ISO 80601-2-67	Oxygen-conserving equipment
IEC 60601-2-68	X-ray-based image-guided radiotherapy equipment for use with electron accelerators, light ion beam therapy equipment and radionuclide beam therapy equipment

Table 2. Particular Standards (continued)

Document	Description
ISO 80601-2-69	Oxygen concentrator equipment
ISO 80601-2-70	Sleep apnoea breathing therapy equipment
IEC 80601-2-71	Functional near-infrared spectroscopy (NIRS) equipment
ISO 80601-2-72	Home healthcare environment ventilators for ventilator-dependent patients

Table 3. Other Relevant Standards

Document	Description
CISPR 11	Emissions requirements for ISM equipment
IEC 60601-1	General Safety Standard
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
ISO 14708	Active implantable medical devices
ISO 14117	EMC test protocols for implantable cardiac pacemakers, implantable cardioverter defibrillators and cardiac resynchronization devices

[1] Some of the part 2 standards are listed within the IEC or ISO 80601 family.

REFERENCES
(ARTICLE LINKS, BOOKS, MINI GUIDES, WEBSITES, & LINKEDIN GROUPS)

LINKS TO LONGER ARTICLES

DiBiase, 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/

RECOMMENDED BOOKS

EMI Troubleshooting Cookbook for Product Designers
André and Wyatt
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.

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

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

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

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

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

Grounds For Grounding
Joffe and Lock
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.

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

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

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

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

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

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

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

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

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

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

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

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

RECOMMENDED MINI-GUIDES FROM INTERFERENCE TECHNOLOGY (FREE DOWNLOADS)

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 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

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 Forum

Electromagnetics and Spectrum Engineering Group

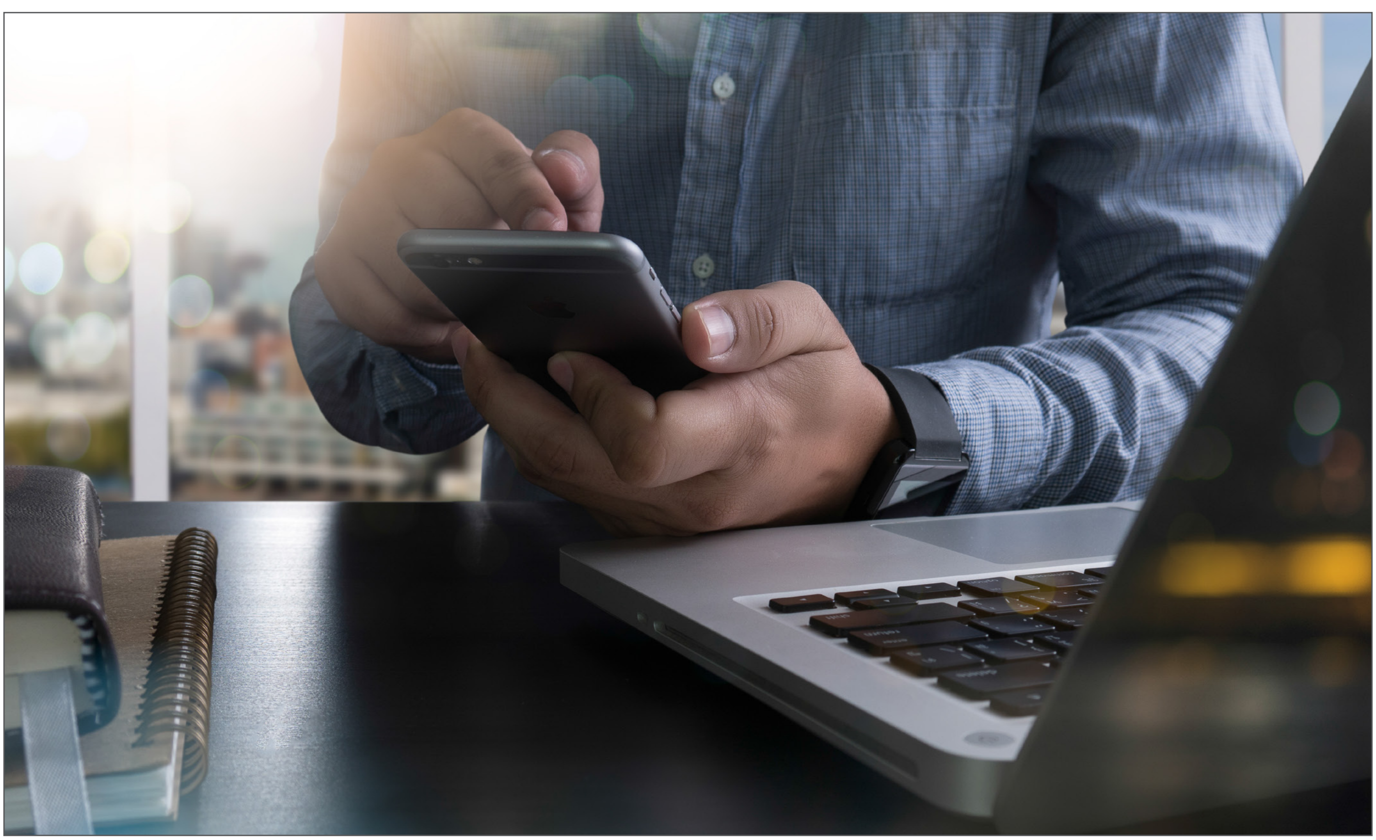
EMC - Electromagnetic Compatibility

EMC Experts

EMC Troubleshooters

ESD Experts

Signal & Power Integrity Community



2017 EMC CONFERENCES

IEEE CONFERENCES

2017 IEEE International Symposium on EMC, SI & PI
August 7-11
Washington DC
Mike Violette, (240) 401-1388
www.emc2017.emcss.org

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, SI & PI
July 30-August 3
Long Beach, California
Ray Adams, r.k.adams@ieee.org

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

2020 IEEE International Symposium on EMC, SI & PI
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

INDEX OF ADVERTISERS

API Technologies Corp.
8061 Avonia Road
Fairview, PA 16415

page: 8
t: (855) 294-3800
e: aisSales@apitech.com
w: eis.apitech.com

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

page: 5
t: (215) 723-8181
e: info@arworld.us
w: www.arworld.us

EMC+SIPI 2018
2018 IEEE Symposium on Electromagnetic Compatibility, Signal and Power Integrity

Long Beach, CA & Online
July 30-August 3, 2018

page: 12
w: www.emc2018usa.emcss.org

ITEM Media
1000 Germantown Pike
Plymouth Meeting, PA 19462

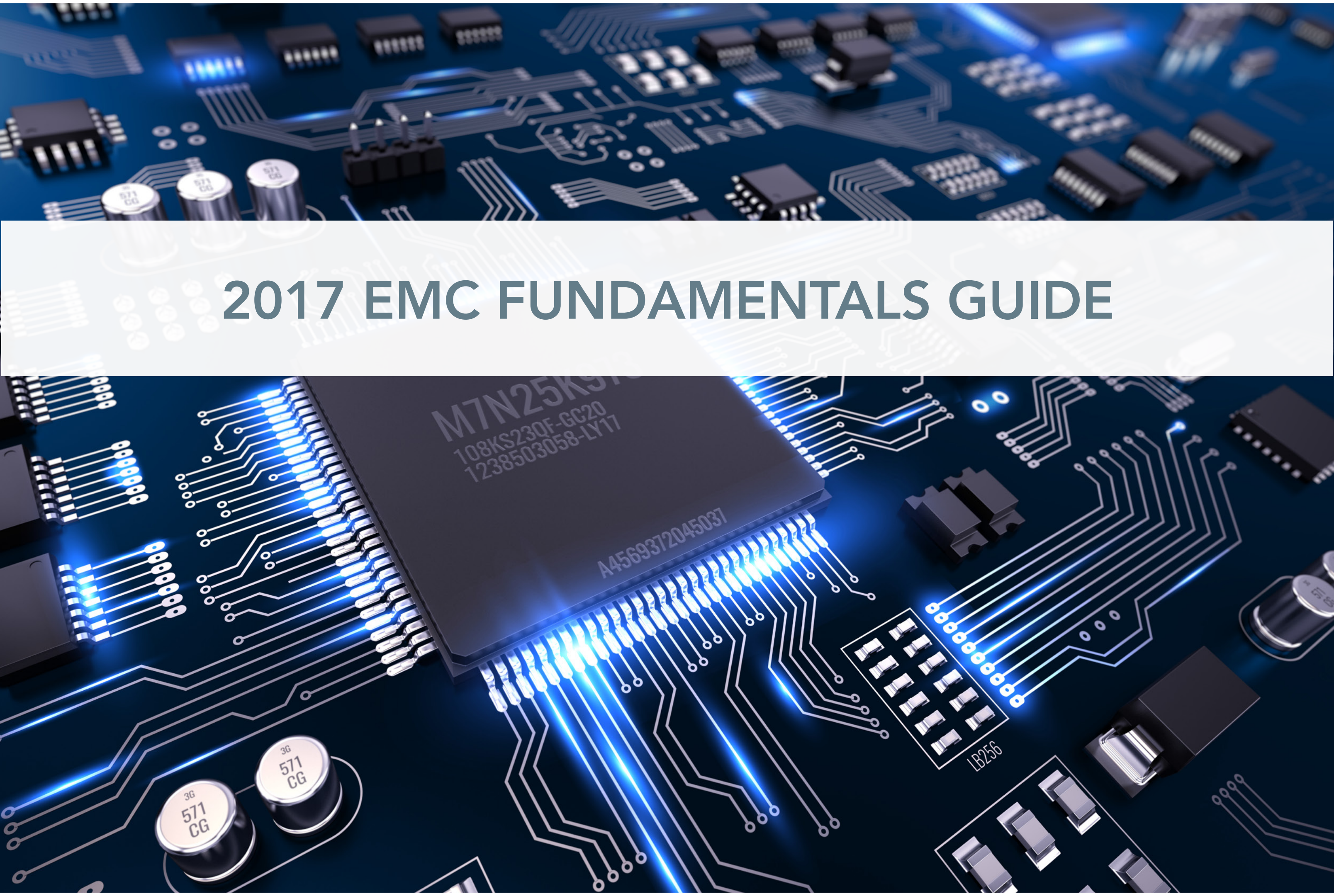
page: 19
t: (484) 688-0300
e: info@item.media
w: item.media

MiCOM Labs
575 Boulder Court
Pleasanton, CA 94566

t: (925) 462-0304
e: sales@micomlabs.com
w: www.micomlabs.com

Rhode & Schwarz
Muehldorfstrasse 15
81671 Munich, Germany

page: 2
t: Germany: +49 (0) 89 4129 12345
United States: (410) 910-7800
e: email address
w: www.rohde-schwarz.com
www.rohde-schwarz-usa.com



2017 EMC FUNDAMENTALS GUIDE

INTERFERENCE TECHNOLOGY
INTERFERENCE TECHNOLOGY GUIDE SERIES
www.interferencetechnology.com