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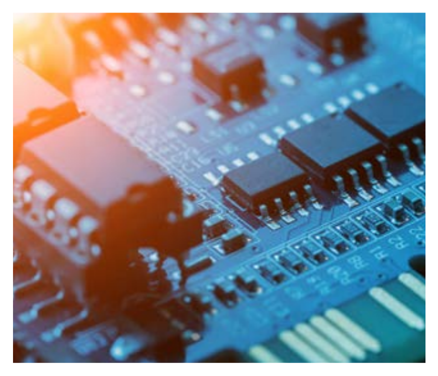

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INTRODUCTION

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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 or EMC engineers 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. The content has been updated with the latest information and two new articles have been added - one on ESD design and the other featuring special issues with DC-DC power converters.

Today, with all the myriad of electronic products, including wireless and mobile devices, compatibility between devices is becoming even more important. Products must not interfere with one another (radiated or conducted emissions) and they must be designed to be immune to external energy sources. 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 implies both emissions and immunity in close environments. This usually applies to military and aerospace products and systems, as well as automotive environments.

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, industrial, 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*.

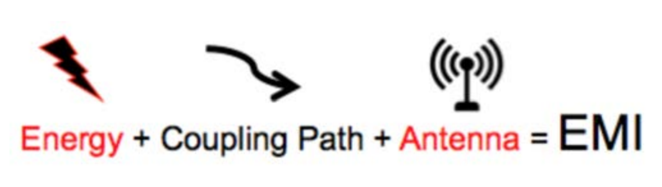


Figure 1 - A simple model for radiated emissions. Take away any of the three elements and you have no EMI.

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 compliance 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 or terminated I/O cable and allowing the resulting high transient current to disrupt (or destroy) sensitive circuitry.

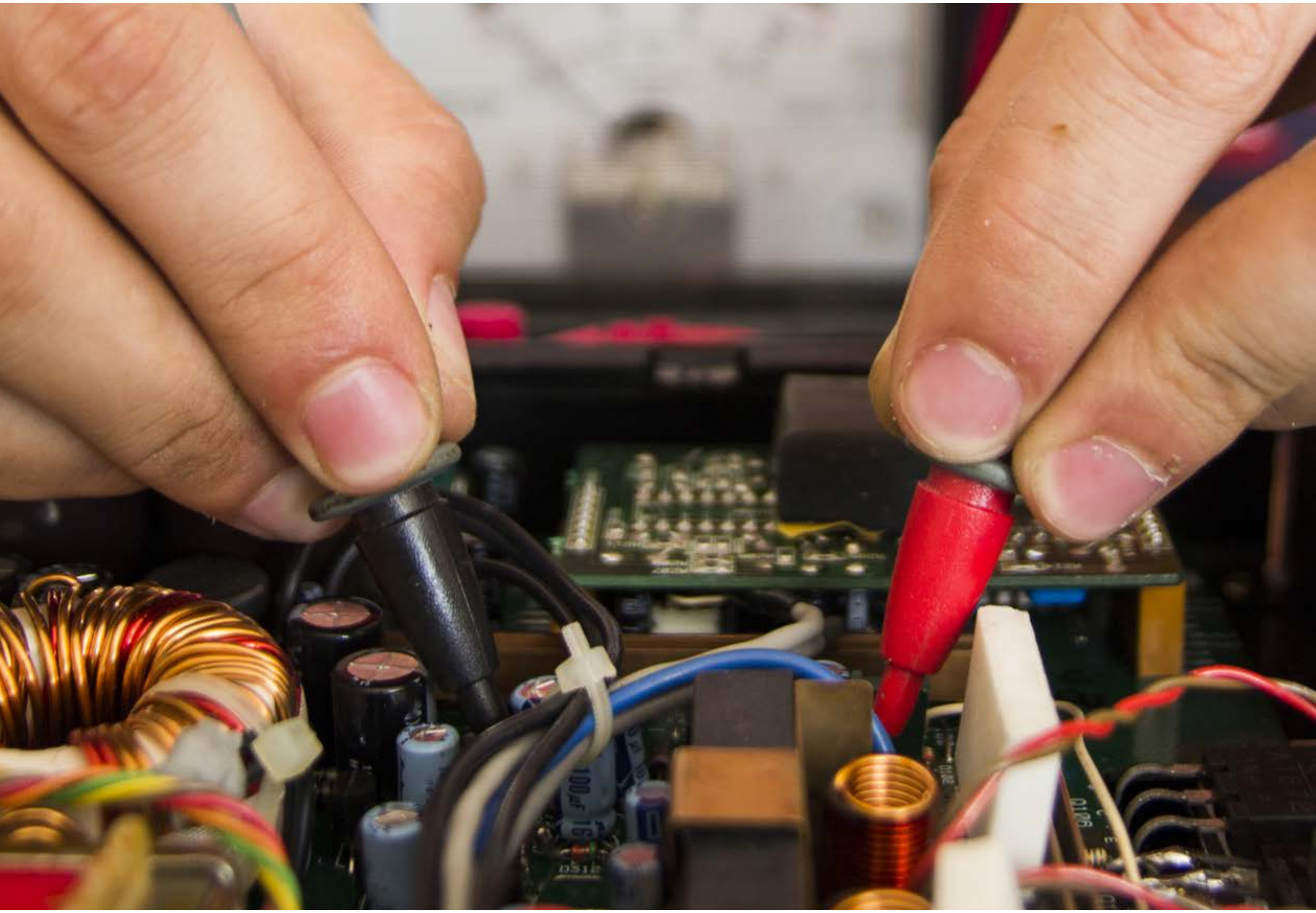
The three top product failures I see all the time as a consultant are (1) radiated emissions, (2) radiated susceptibility, and (3) electrostatic discharge. In many cases, these failures are due to poorly-designed PC boards. We'll discuss these and more in this EMC Fundamentals Guide.

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	www.ahsystems.com	X	X		X						X			
Aaronia AG	www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	www.atecorp.com	X	X	X	X	X	X	X	X	X	X	X	X	X
Amplifier Research (AR)	www.arworld.us	X	X			X		X	X	X	X			X
Anritsu	www.anritsu.com					X					X			X
Electro Rent	www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	www.emtest.com/home.php									X	X	X		
EMC Partner	www.emc-partner.com						X			X				
Empower RF Systems	www.empowerrf.com		X						X					
Fischer Custom Communications	www.fischercc.com			X	X			X			X			
Gauss Instruments	www.gauss-instruments.com/en/					X								
Haefley-Hippotronics	www.haefely-hipotronics.com						X			X				
Instrument Rental Labs	www.testequip.com		X			X	X	X	X	X	X		X	X
Keysight Technologies	www.keysight.com/main/home.jspx?cc=US&lc=eng			X		X		X			X			X
Microlease	www.microlease.com/us/home		X			X	X	X	X	X	X		X	X
Milmega	www.milmega.co.uk		X						X	X				
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X			X		X	X	X	X			
Noiseken	www.noiseken.com						X			X	X			
Ophir RF	www.ophirrf.com		X							X				
Pearson Electronics	www.pearsonelectronics.com				X									
Rigol Technologies	www.rigolna.com		X	X	X	X					X			X
Rohde & Schwarz GmbH & Co. KG	www.rohde-schwarz.com	X	X	X	X	X		X	X	X	X			X
Rohde & Schwarz USA, Inc.	www.rohde-schwarz.com	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	www.siglentamerica.com			X		X					X			X
Signal Hound	www.signalhound.com			X		X					X			X
TekBox Technologies	www.tekbox.net		X	X				X			X	X		
Tektronix	www.tek.com			X		X					X			
Teseq	www.teseq.com/en/index.php		X		X		X		X	X	X	X		
Test Equity	www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thurlby Thandar (AIM-TTi)	www.aimtti.us					X					X			X
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	www.rf-consultant.com													X
Transient Specialists	www.transientspecialists.com								X	X		X		
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	www.vectawave.com		X											
Windfreak Technologies	www.windfreaktech.com													X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BASIC EMI CONCEPTS

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BASIC EMI CONCEPTS

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 and the field energy travels through the dielectric. The two concepts are related because they are intertwined together. Digital signals create the propagating field, which induces the convection current to flow in the copper traces/planes.

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 (keeping them separate) on your board is so important.

HOW SIGNALS MOVE

At frequencies greater than DC, digital signals start to propagate as electromagnetic waves in transmission lines. As shown in *Figure 1*, a high frequency signal propagates along a microstrip 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".

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.

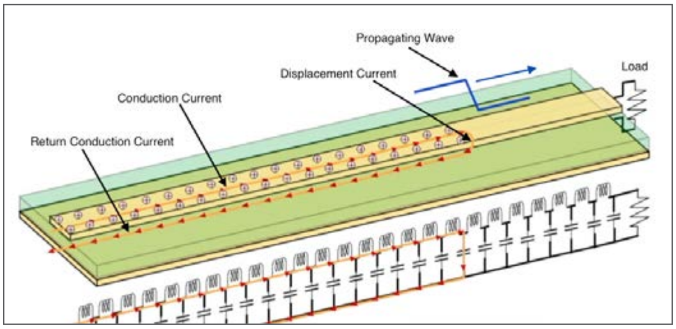

Figure 1 - A digital signal propagating along a microstrip with currents shown.

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 dielectric layers and cause electromagnetic coupling and "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 (power and signal traces 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.

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.

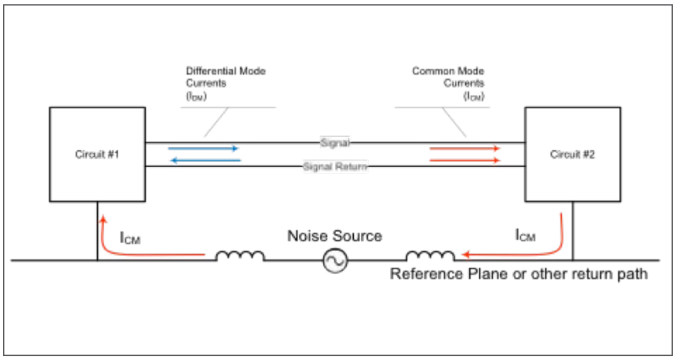

Figure 2 - An example of differential and common mode currents.

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.

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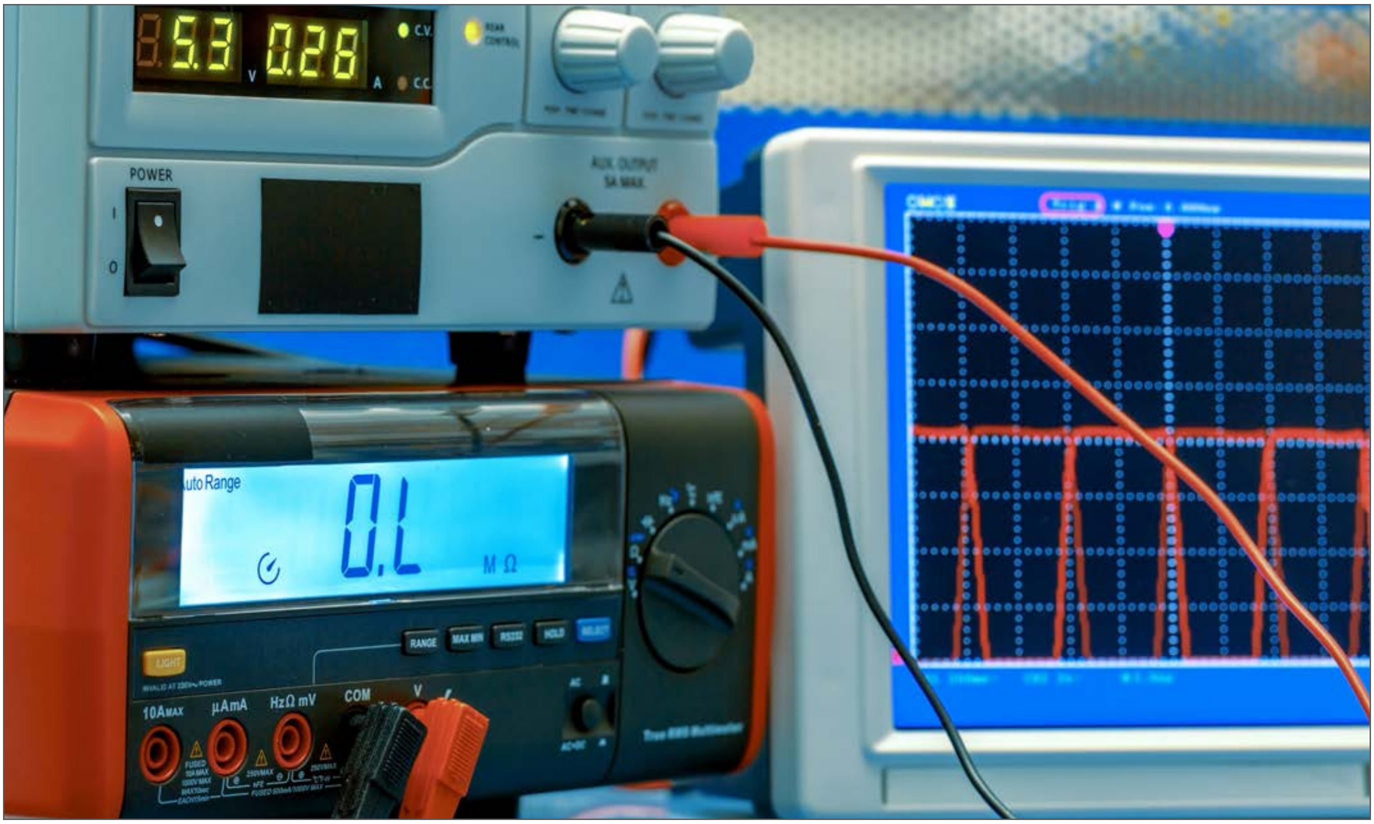

DESIGN FOR COMPLIANCE ESSENTIALS

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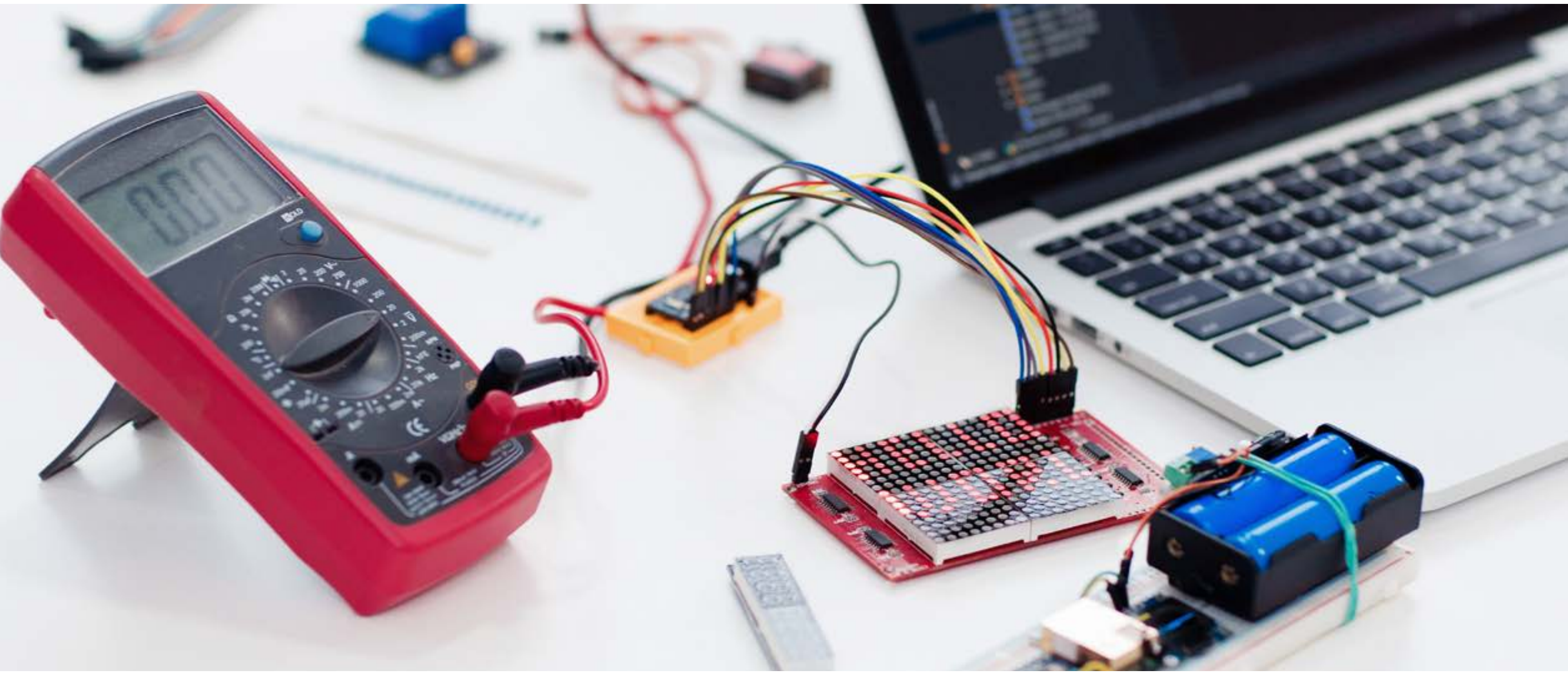
Introduction

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 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.

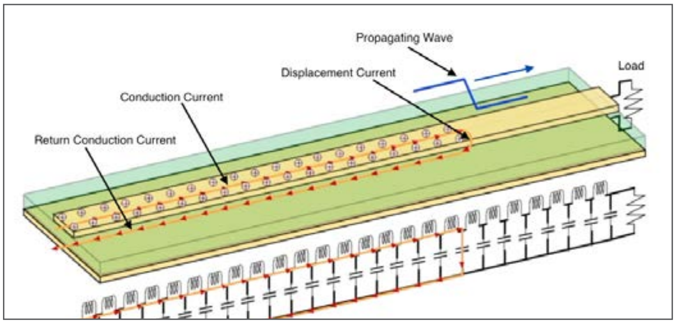


Figure 1 - A propagating wave along a microstrip with reference plane. Figure, courtesy Eric Bogatin.

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.

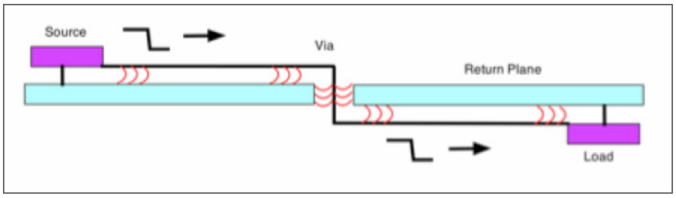


Figure 2 - A signal trace passing through a single reference plane.

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.

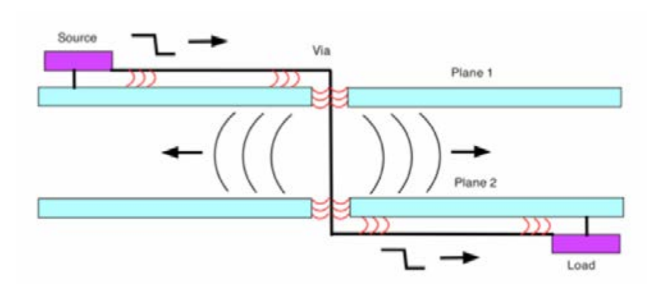


Figure 3 - A signal trace passing through two reference planes. If the reference planes are the same potential (signal or power returns, for example), then stitching vias next to the signal via should be sufficient. However, if the planes are different potentials (power and return, for example), then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

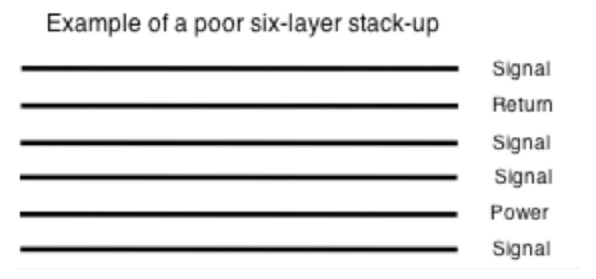


Figure 4 - A six-layer board stack-up with very poor EMI performance.

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, only signal layers 1 and 3 have an adjacent return plane. Signal layers 4 and 6 are referenced to power, rather than signal return, therefore, the propagating wave return path will jump all over to whatever is the closest metal on the way back to the source, which is referenced to signal return. Again, this will tend to couple clock and other digital noise throughout the board.

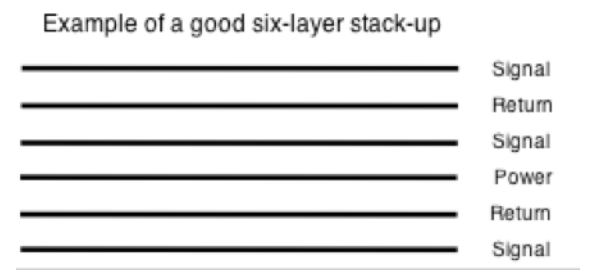


Figure 5 - A six-layer board stack-up with good EMI performance. Each signal layer has an adjacent return plane and the power and power return planes are adjacent.

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 still 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 in the return plane.

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 I/O or power 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*.

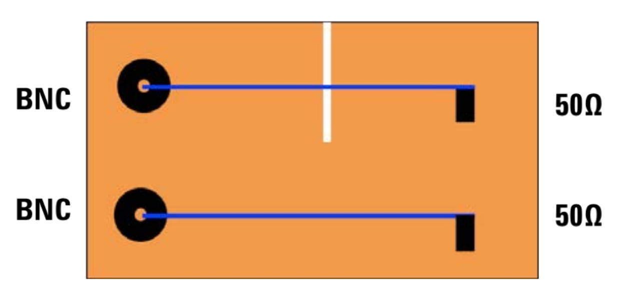


Figure 6 - shows a demonstration test board with transmission lines terminated in 50 Ohms. One transmission line has a gap in the return plane and the other doesn't. A harmonic comb generator (2 ns pulse) is connected to one of the two BNC connectors in turn and the harmonic currents in a wire taped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

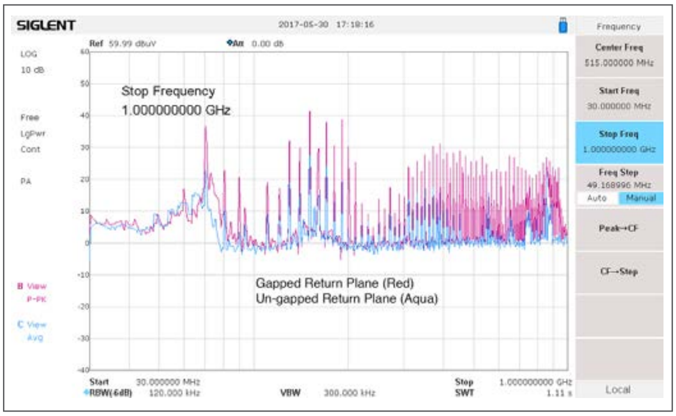


Figure 7 - The resulting common mode currents on an attached wire (to the return plane) as measured with a current probe. The trace in aqua is the un-gapped return path and the trace in red, the gapped return path. The difference is 10 to 15 dB higher for the gapped return path. These harmonic currents 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.

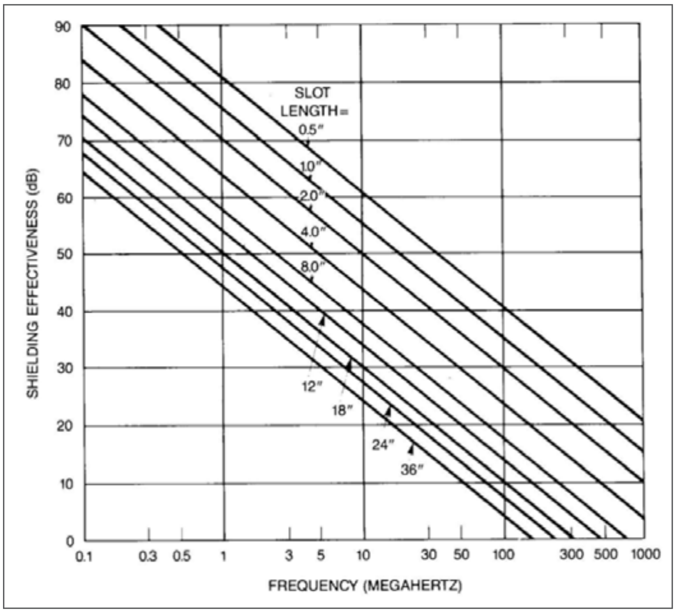


Figure 8 - A chart of attenuation versus slot length. Figure, courtesy Henry Ott.

Figure 8 shows a handy chart for determining the 20 dB attenuation of a given slot length. For example, if a product design requires at least a 20 dB shielding effectiveness, then the longest slot length can be just one-half inch. See *Reference 5* and *6* for more detail on shielding. Interference Technology also has a free downloadable 2017 EMI Shielding Guide with excellent information (*Reference 7*).

Figure 9 is a chart of wavelength versa half wave resonance at 1000 MHz. This is a handy tool for determining how efficient a cable or slot will act as an antenna.

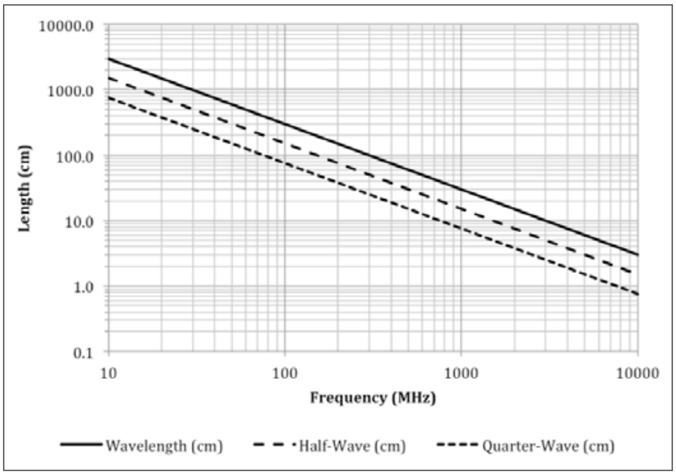


Figure 9 - A handy chart for determining resonant frequency versus cable or slot length in free space. Half-wavelength slots simulate dipole antennas and are particularly troublesome. Figure, courtesy Patrick André.

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 today 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.

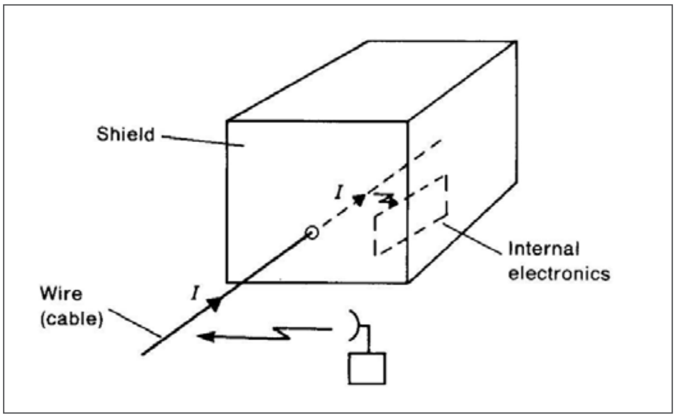


Figure 10 - Penetrating the shield with a cable defeats the shield. This example shows how external energy sources can induce noise currents in I/O cables, which can potentially disrupt internal circuitry. The reverse is also true, where internal noise currents can flow out the cable and cause emissions 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.

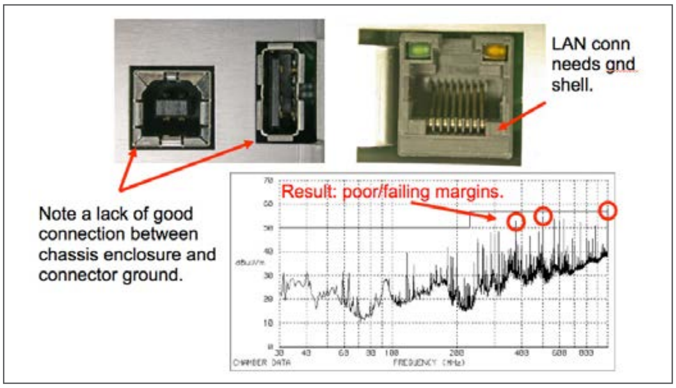


Figure 11 - Result of a penetrating cable through a shielded enclosure, because of un-bonded I/O connectors to the shielded enclosure.

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) originally failed to specify the method for terminating the cable shield to the connector. This may have been corrected in the latest edition of the standard released in 2017.

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 also have built-in common mode filtering.

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.

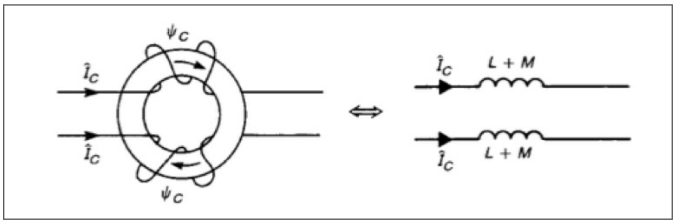


Figure 12 - A typical common mode filter used for I/O filtering. The two windings are wound in opposite directions and so tend to cancel the common mode currents.

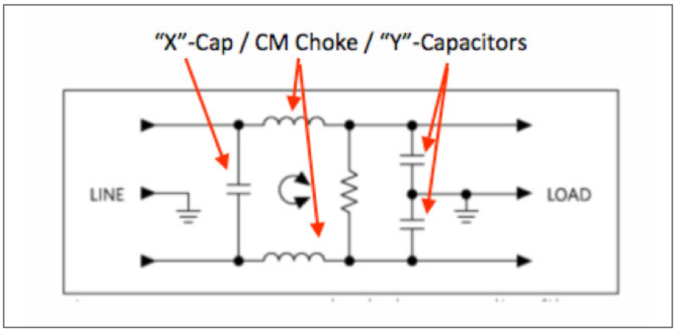


Figure 13 - A general purpose filter typically used for power supply input filtering.

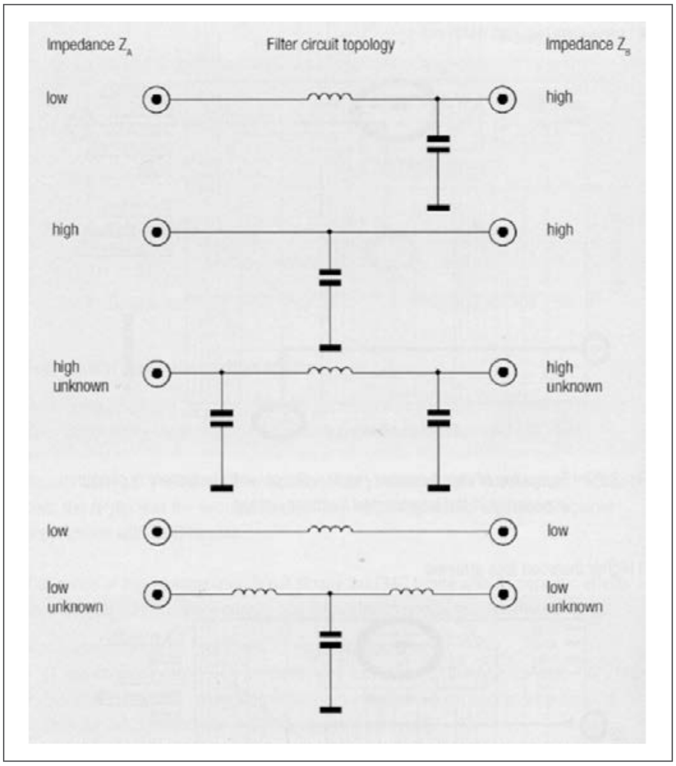


Figure 14 - Five common filter topologies, depending on the source and load impedances. Figure, courtesy Würth Electronik.

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).

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. If used, they should be inserted “upstream” from the bulk capacitor.

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.

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.

You may have noticed that clipping a ferrite choke onto a cable sometimes has no effect. This is usually due to the fact the choke has the same, or lower, effective impedance than the source and load impedances. The attenuation of a ferrite choke is easily calculated.

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 (source and load), the attenuation would be:

Attenuation = 20 * log((10 + 100 + 10) / (10 + 10)) = 15.5 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 (or earth ground), 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 9*.

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.

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ROHDE&SCHWARZ
Meas BW
Att
Input
1 Bargraph
Max Peak
24.70 dBµV
3 IF Analysis
CF 770.8933 kHz
2 Scan
Limit Check
Start 150.0 kHz
POWER
SYSTEM

DIY NEAR FIELD PROBES & PREAMPLIFIERS

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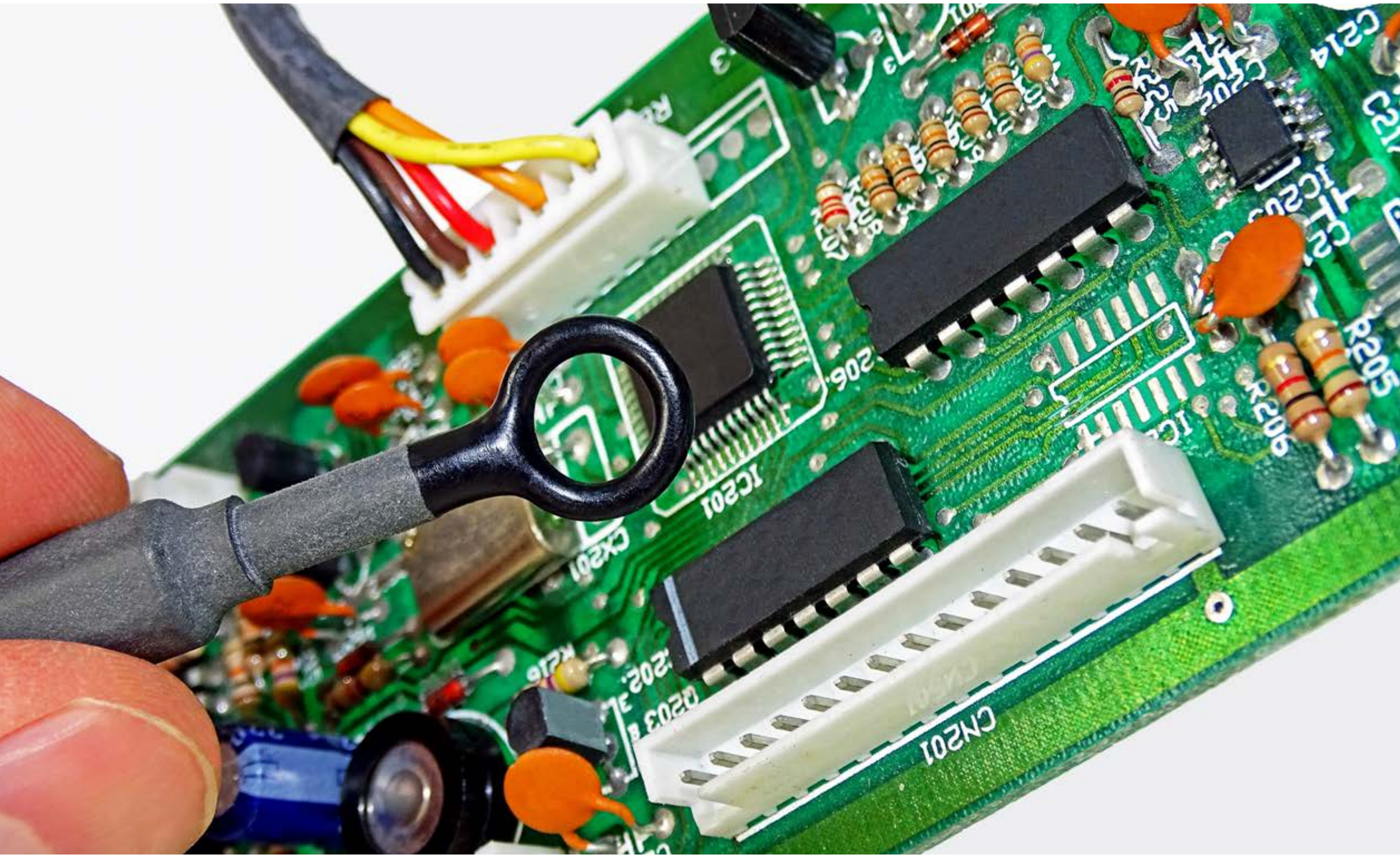
Introduction

A very useful tool for troubleshooting EMC issues is the near field probe. Due to its small size (compared against antennas) the most common use of these tools is to aid in detection of the source of a particular signal (emission), or as a local field-generating source (immunity), helping you to find weak spots in your device under test. There are several options available costing from hundreds up to thousands of dollars. In this article, I will show you how to build your own set of near field probes for a few bucks and a cheap pre-amplifier enabling you to get started troubleshooting EMC issues.



DIY NEAR FIELD PROBES & PREAMPLIFIERS

MY PROBES

I have been making my own EMC gear for a while, so last year I built two H-field probes (red ones on *Figure 1*). I also have an extra probe (unshielded) which was a gift from a lab technician. He built it in a fashion to comply with a certain standard that I am not aware of (so I am probably not making the best use of it!). It has a lot of external interference for emissions (due to poor shielding) but it is quite effective for immunity testing.

Figure 1 – H-field probes. At right details of the ones that I made myself.

I followed the article “Probing the magnetic probe” from Roy Ediss [1] to make what he calls a “King type with central gap” probe. The basic idea is to create a closed loop on a coax cable and cut a single slot in the outer sheath (gap). You can find other designs in his article that are even easier to make and the main difference between them is their self-resonating frequency, which will vary according to the parasitic capacitances and inductances of the probe, which depends on how you build it (among other things).

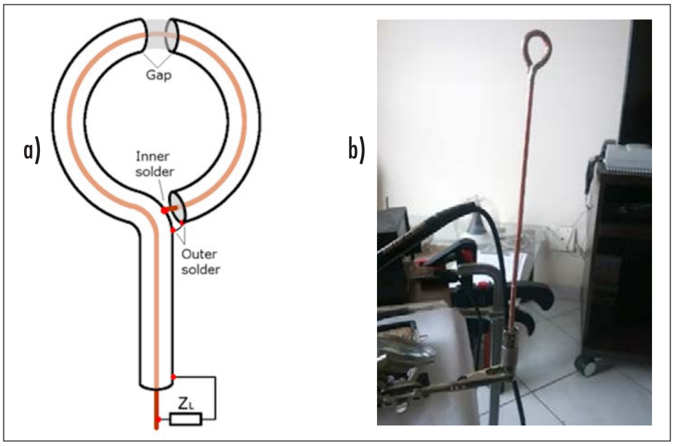


Figure 2 – a) H-field probe based on Roy Ediss’ design b) Making my own probe at home.

To make the probe I got a regular 50Ω coax cable with rigid center conductor that I had on hand, removed the outer jacket, the foil and braided shield, and wrapped a copper tape around the dielectric to replace the braid. I am not sure if this would significantly change the probe characteristic impedance but replacing the braid by the copper tape made it very easy to solder, cut the small gap and keep it rigid. It may be a good idea to replace the flexible coax cable by a semi-rigid one, but they are not so easy to find.

To build the loop you have to solder the inner conductor in the tip to the outer sheath (inner solder on *Figure 2*) and then the outer sheath in the tip to itself (outer solder on *Figure 2*). Cut a slice of the outer sheath to make the gap in the center of the loop. It is important to keep the gap small (around millimeter). After that, I soldered the inner conductor on the base to one end of a BNC adapter (double female), two 100Ω SMD resistors between BNC adapter’s inner and outer conductors diametrically opposed and finally the shielding copper tape to the outside of the BNC. Then I acquired a can of red liquid electrical tape and applied some coats of it to the entire thing until I got a thick wall and an even finish. For the smaller one I could simply dip the tip into the can. Finally, I placed a shrinkable sleeve between probe and BNC connector. As an alternative, you can skip the outer solder and the gap cutting, leaving only the inner solder done and you will have another probe design (not the “King type with central gap”).

On one occasion, I had access to a Beehive Electronics’ probe set (very nice stuff if you can afford it) and did some quick comparison between them and my probes and, for my surprise, they have a quite similar sensitivity. Of course, my test setup was not reproducible enough to compare the readings numerically, but at least I could see similar emission patterns as shown on *Figure 3*.

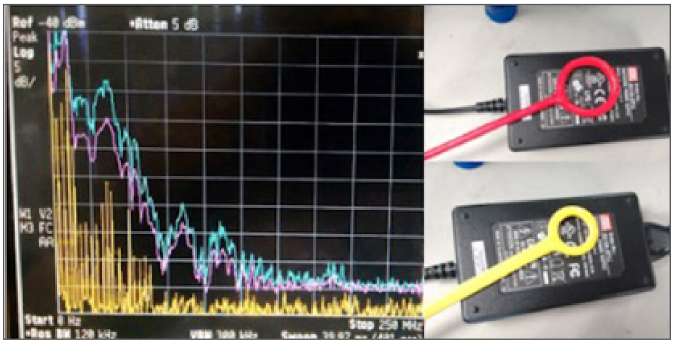


Figure 3 – Comparison between mine (pink trace) and Beehive’s probe (green trace)

MAKING A TINY PROBE

Since I often use near field probes for finding a source of magnetic field, it is helpful to have a probe that can find exactly the trace generating the unwanted emission. To achieve this resolution, you will need a probe with a tiny tip. I will show you how to build one based on Kenneth Wyatt’s course “EMC Troubleshooting and Pre-Compliance Testing for Product Designers” available on Fast Pass Online Training Hub [2].

To do my own tiny probe, I got a spare Wi-Fi antenna used for an old project, which has a thin wire (probably RG316) and an SMA connector. I took the antenna apart and made three levels of cut to the coax cable like shown on *Figure 4* (1st cut: expose braid; 2nd cut: expose dielectric; 3rd cut: expose inner wire).

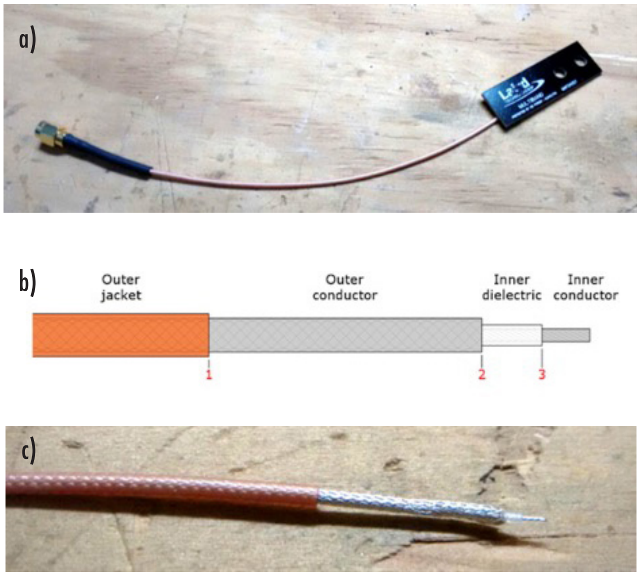


Figure 4 – a) Spare Wi-Fi antenna; b) Layers diagram; c) Coax with exposed layers

I put a little drop of solder to the end of the braid to hold it together for the next steps. After that, I soldered the inner wire to the braid creating a loop. The loop shape is around 5x2mm and it is not perfectly round because the braid solder made it rigid.

I thought it would be nicer if the cable was not too flexible for the probe to reach the inside of an equipment without bending, so I came out with an idea: I got a pair of 0.8mm steel wires and twisted them tight together with a drilling machine to get a nice straight rod. After that, I placed the rod along with the coax cable and squeezed all together with a shrinkable sleeve from the outside.

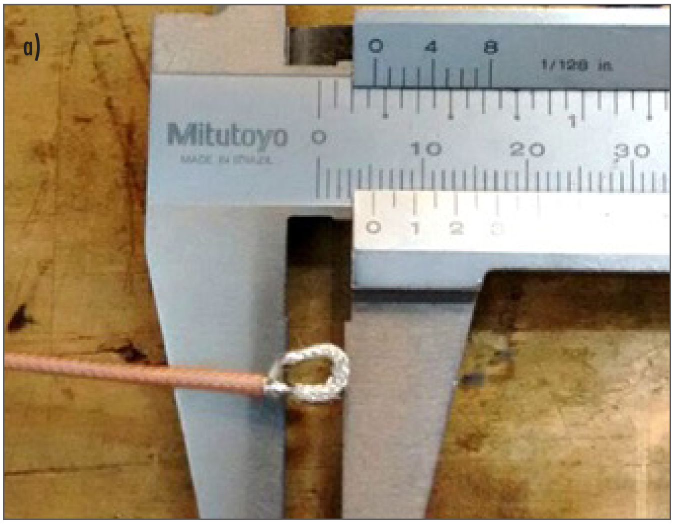


Figure 5 – a) Inner conductor soldered to braid forming a loop; b) Shrinkable sleeve, probe and twisted rod

After heating the sleeve, I dipped the tip into the can of liquid electrical tape. I really liked the finishing and, of course, I like the fact that the probe works just fine! One day after and the coating was completely dry and shrunk a little, exposing details of the inner shape.

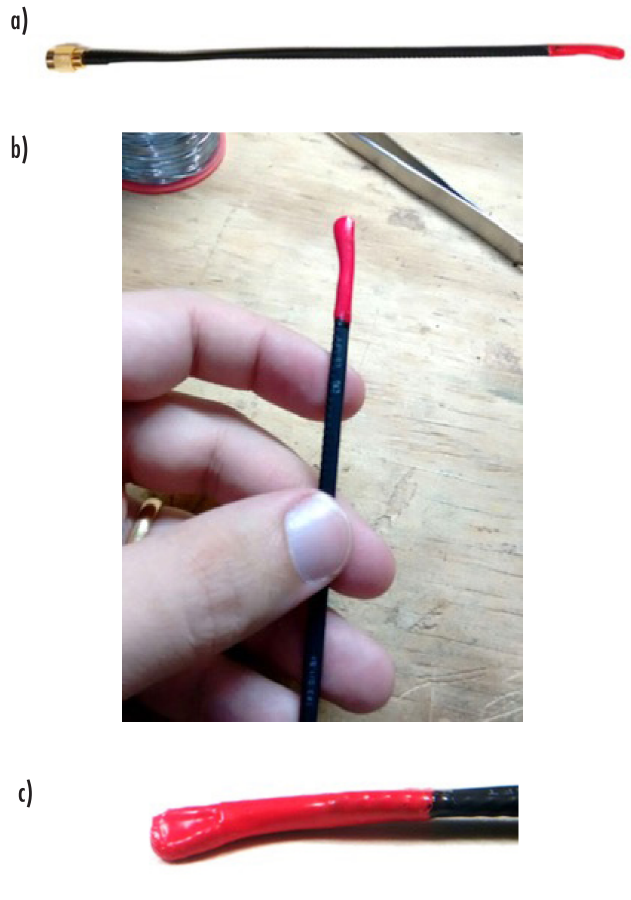


Figure 6 – a) Finished probe; b) Right after applying insulation coating; c) Coating in the day after

LOW NOISE PREAMPLIFIER

It is handy to have a preamplifier to amplify the signal of your freshly made H-field probes. I have a low noise amplifier (LNA) module from Mini-Circuits model ZX60-3018G+ [3] that is very helpful in finding small signals (especially if you are using the tiny probe). I like to build stuff, so I've got a chunk of aluminum and made myself a shiny

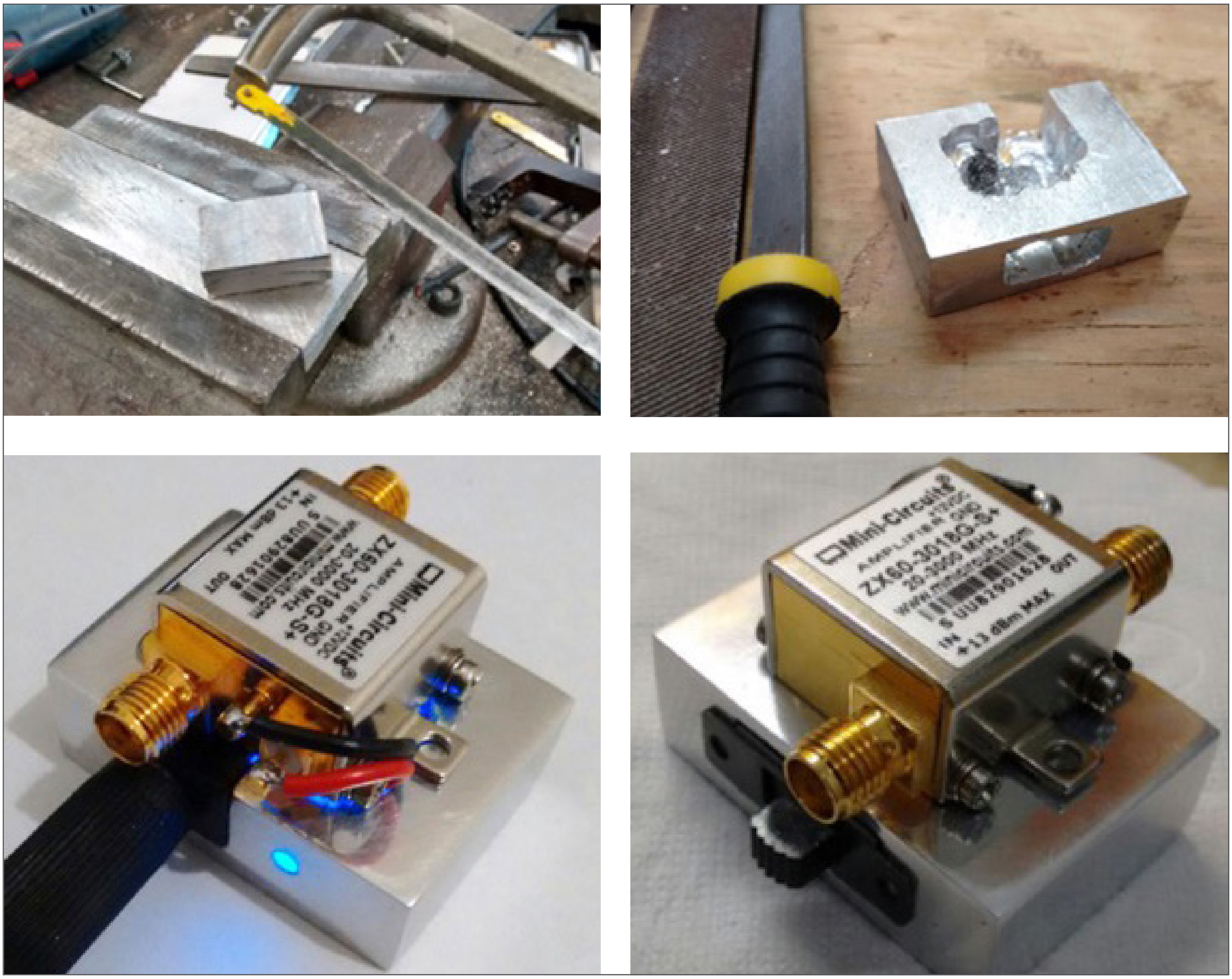


Figure 7 – Making the amplifier: from the aluminum chunk to the shiny assembly

base to place a connector, switch and LED to seat my amplifier on (after a lot of filing and sanding). Despite being a simple project, I am very proud on how it came out. The amplifier can be powered by battery or any DC supply through the power jack.

Another cheap solution that I tested (and works very well) is the LNA4ALL from 9A4QV based on Mini-Circuits part number PSA4-5043+ [4]. Even CATV amplifiers can do a good boost to your signals but it will be a little noisier. A good practice is to know your environment when using near field probes outside a shielded room or when using a noisy amplifier: always check if the emission spikes you are looking at remain visible when you move the probes away from the device under test.

SUMMARY

If you, just like myself, don't have a large budget or live in a place where it is difficult to buy equipment for troubleshooting your EMC issues, you would only need a couple bucks or maybe recycle parts from old projects and a few hours to make your own near field probes. Even if you already have a set of probes, learning how to make near field probes can be useful to create custom probes if you need. You should now be able to get yourself a spectrum analyzer (or even a good oscilloscope), a bunch of wires and go outside exploring equipment RF emissions and troubleshooting some (or maybe most) EMC test issues!

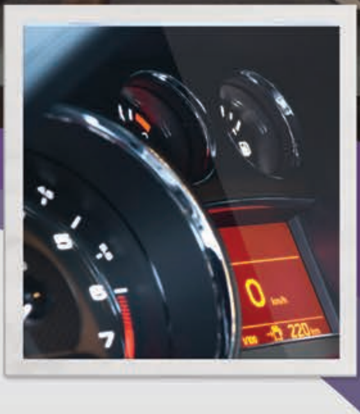
REFERENCES

[1] Probing the magnetic field probe by Roy Ediss http://www.ediss-electric.com/general_pdf/Probing_the_mag_field_probe.pdf

[2] Access the online course EMC Troubleshooting and Pre-Compliance Testing for Product Designers at https://emcfastpass.com/training/index.php/course/emc-troubleshooting/

[3] Find this amplifier and more RF circuits at https://www.minicircuits.com/

[4] Purchase LNA4ALL and find more information at http://lna4all.blogspot.com



WHAT YOU SEE WITH NEAR FIELD PROBES

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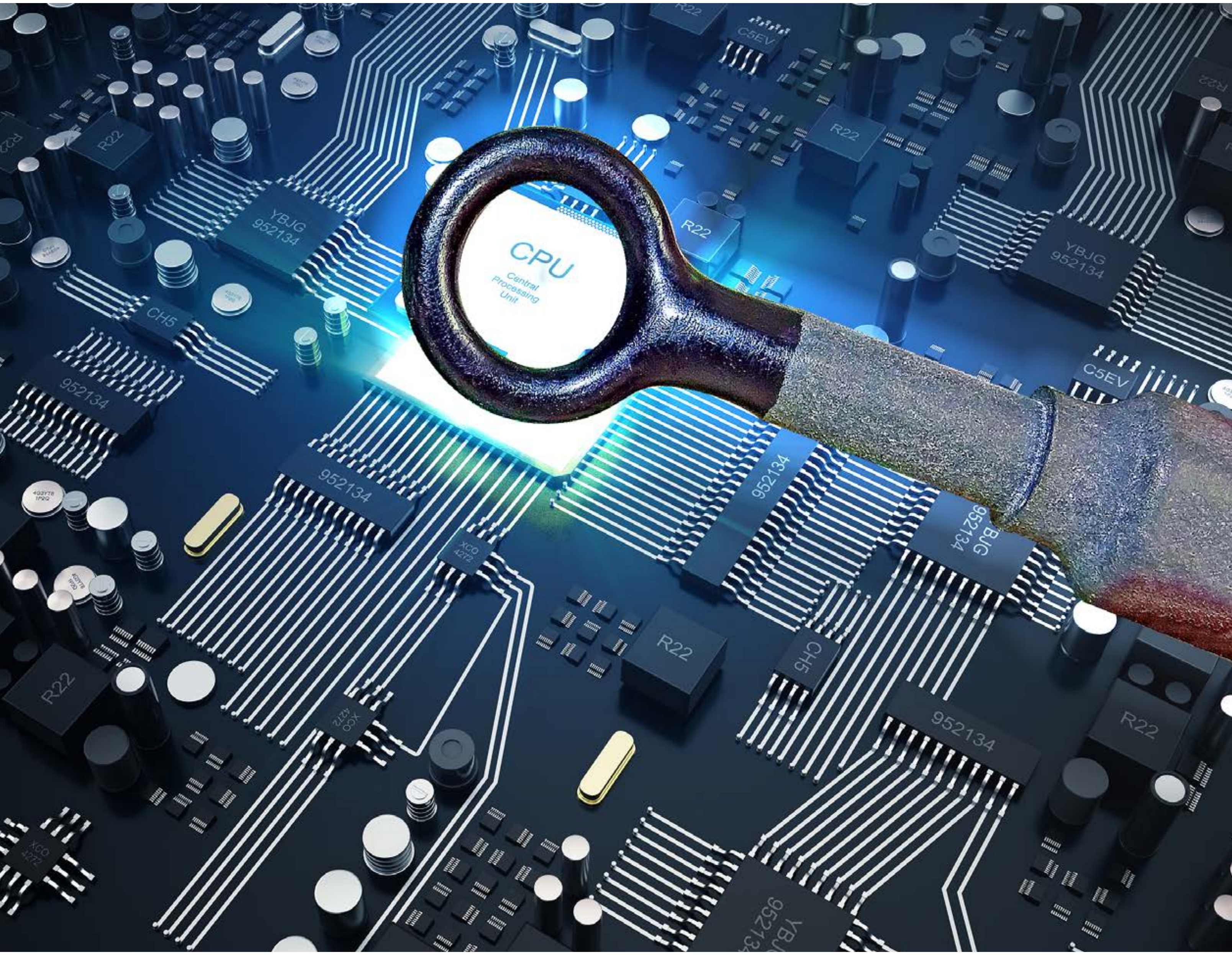


WHAT YOU SEE WITH NEAR FIELD PROBES

In EMI/EMC troubleshooting, near field probes (NFPs) are great tools. Let's review how to understand what you really see at the screen of your instrument with a magnetic near field probe.

EMI/EMC problems (radiated and conducted emissions) are usually related with current in your circuits: high frequency currents (i.e. high di/dt currents) are responsible of radiation from PCBs, cables, slots and apertures, ground noise, crosstalk, etc.

That is because a magnetic field probe (loop) is a great help to identify where the culprit signal is being created (ringing, parasitic oscillations, harmonics, etc.).

And it is common to use near field probes with spectrum analyzers. In this way, you see the spectrum of the signals close to the probe and it is easy to measure the frequencies involved in the test. Sometimes no more info is needed.

But, have you ever thought about what you have in the screen of your instrument? Is magnetic field? Is current in your circuit? Is voltage in your circuit? ... Think.

Near field probes give us a voltage applied to the input impedance of the instrument (50 ohm or 1 Mohm, typ.) so, what is exactly that voltage?

I will try to explain the idea with a very basic experiment as in *Fig.1.*

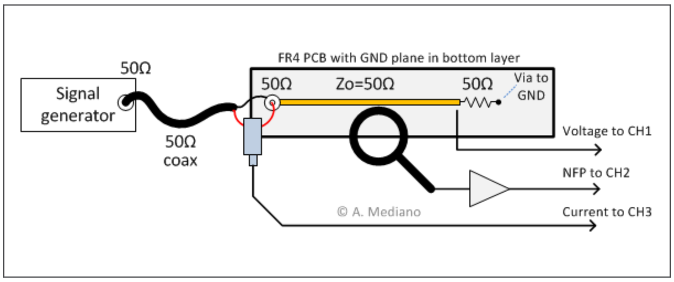


Fig. 1. The setup of our experiment.

The signal from a signal generator with 50 ohm output impedance is applied to a 50 ohm trace in a two layer PCB. The line is terminated with 50 Ohms.

A square wave signal with 20 MHz frequency is applied to the circuit with our signal generator and our magnetic near field (ROUND) probe is located close to the signal and connected to channel 2 of the oscilloscope (Agilent InfiniVision DSO 7104B) using a low noise and linear amplifier.

The FFT of the signal (or you can use your spectrum analyzer) is observed in the screen in channel 2, CH2 (*Fig. 2*):

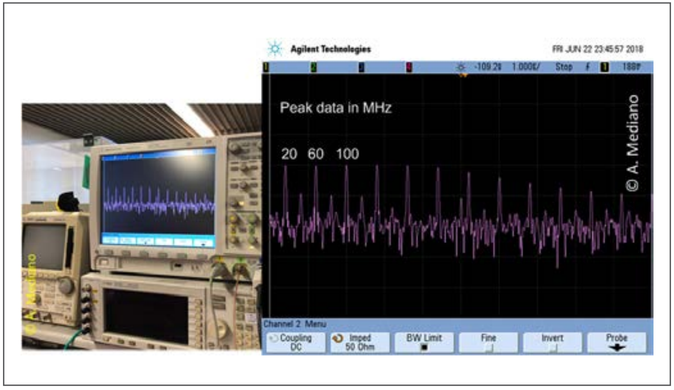


Fig. 2. The frequency domain for the output of our near field probe.

What we see on the screen is the FFT of a VOLTAGE (the output voltage of the near field probe on the input impedance of the scope). How is that voltage related with currents and voltages in the circuit?

Remember with the probe we capture magnetic field lines (the probe is shielded for electric fields) and we can identify the harmonics of our 20 MHz "clock". Note odd harmonics are bigger than even harmonics.

Let us add two additional probes to our experiment: the voltage in the load resistor will be measured in channel 1 (CH1) with a passive (x10) probe and the current in the circuit will be measured in channel 3 (CH3) as explained in *Fig. 1* and in *Fig. 3:*

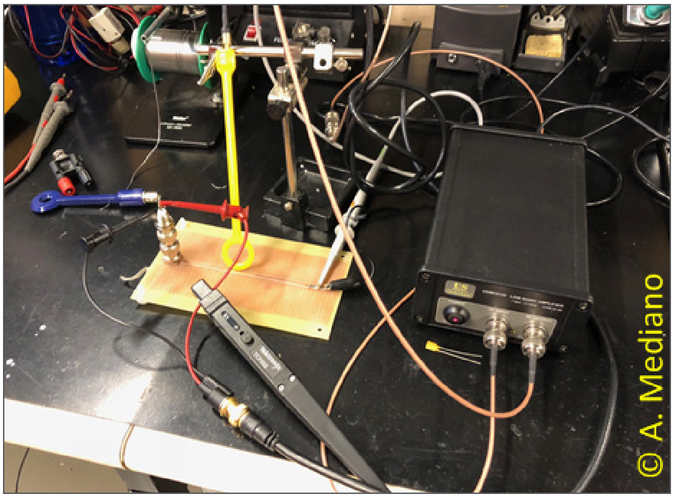


Fig. 3. Detail of the experiment.

In *Fig. 3* you can see the PCB board, the near field probe (from Beehive), the Tektronix TCP202 current probe, and my US Microwave Laboratories USMC0125 Low Noise Amplifier (a really useful tool for any EMI/RF lab).

We configure the output of the signal generator to SINUSOIDAL waveform (20 MHz frequency). In *Fig. 4* we see the screen of our instrument.

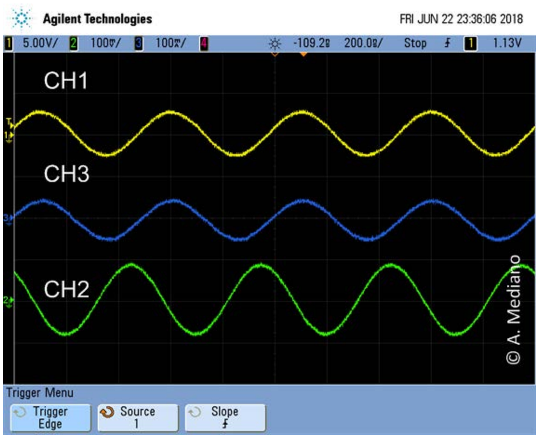


Fig. 4. Measurements for the second experiment: voltage in load resistor (CH1), current in the circuit (CH3), and near field probe output (CH2).

Note CH1 and CH3 are in phase (resistive load for the signal generator).

If you see CH2 in spectrum analyzer, FFT or time domain (without seeing CH1/CH3) perhaps you will not appreciate that CH2 and CH3 are related but they are not the same signal. The near field probe is measuring magnetic field so the output voltage is proportional to magnetic field. You can see that CH3 and CH2 are 90º approx. in phase difference.

Sometimes in the spectrum point of view this is not a problem if you are interested in measuring the frequency (i.e. measuring some ringing) but in other situations while troubleshooting serious problems is important to consider the difference.

Now, change the output of the signal generator to SQUARE waveform again (20 MHz frequency). In *Fig. 5* we see the screen of our instrument.

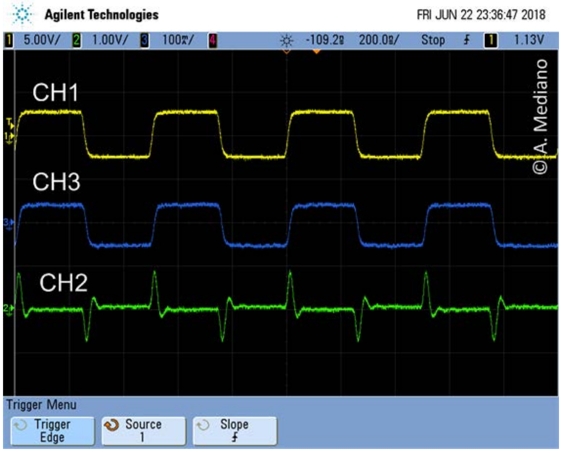


Fig. 5. Signals with square waveform in signal generator.

Now, the waveform is changed to square and you can appreciate CH3 and CH2 are fully different.

The reason for this behavior is the near field probe close to your circuit trace (or wire) is picking-up magnetic field lines and we can represent the coupling effect like a transformer with a primary (your circuit with current i) and a secondary (the near field probe). The output of the secondary is exactly M·di/dt (where M is mutual inductance or coupling factor between the circuits) so, it is proportional to the derivative of current in your circuit!

Again with *Fig. 5* we see clearly that the output of the near field probe (CH2) is proportional to di/dt (blue trace in CH3).

If you rotate the near field probe 180º the screen changes as in *Fig. 6*.

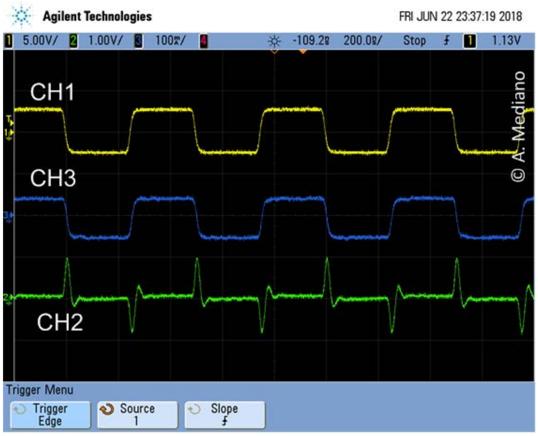


Fig. 6. Signals with square waveform in signal generator rotating the near field probe 180º.

Another interesting plot is the FFT for the current probe and for the NFP output for comparison (*Fig.7*).

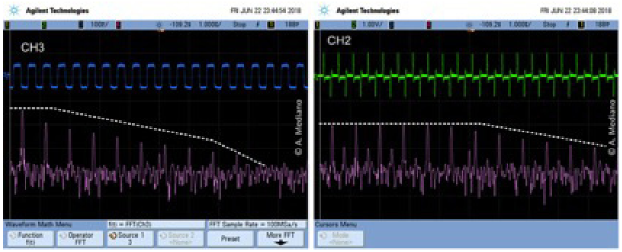


Fig. 7. The spectrum of current (CH3) and near field probes (CH2).

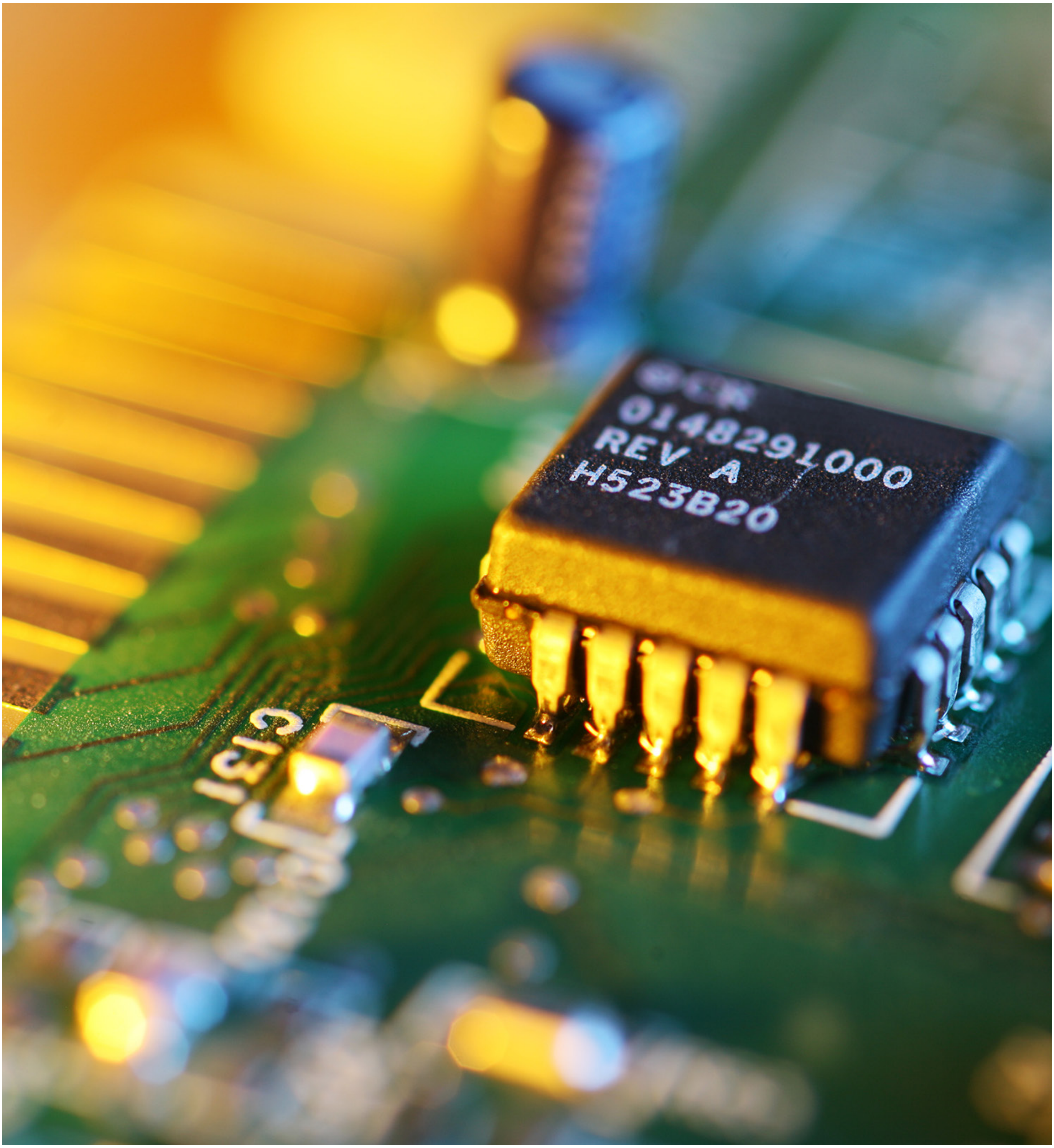
The spectrum of CH3 is the spectrum of a square wave signal, reducing harmonic amplitudes at -20 dB/decade and -40 dB/decade.

For the NFP (CH2) the low frequency components are with constant amplitude up to medium frequencies because the very small duty cycle of the waveform (remember the comb generator signals or the spectrum of impulsive signals).

So, remember: when using a ROUND magnetic near field probe, you will see in the screen of your instrument the time or frequency domain of the derivative of the current in your circuit.

Tip: with lower frequencies perhaps you can integrate with your scope to see the current in your screen.

In a future article I will try to explain what happens with a SQUARE near field probe.

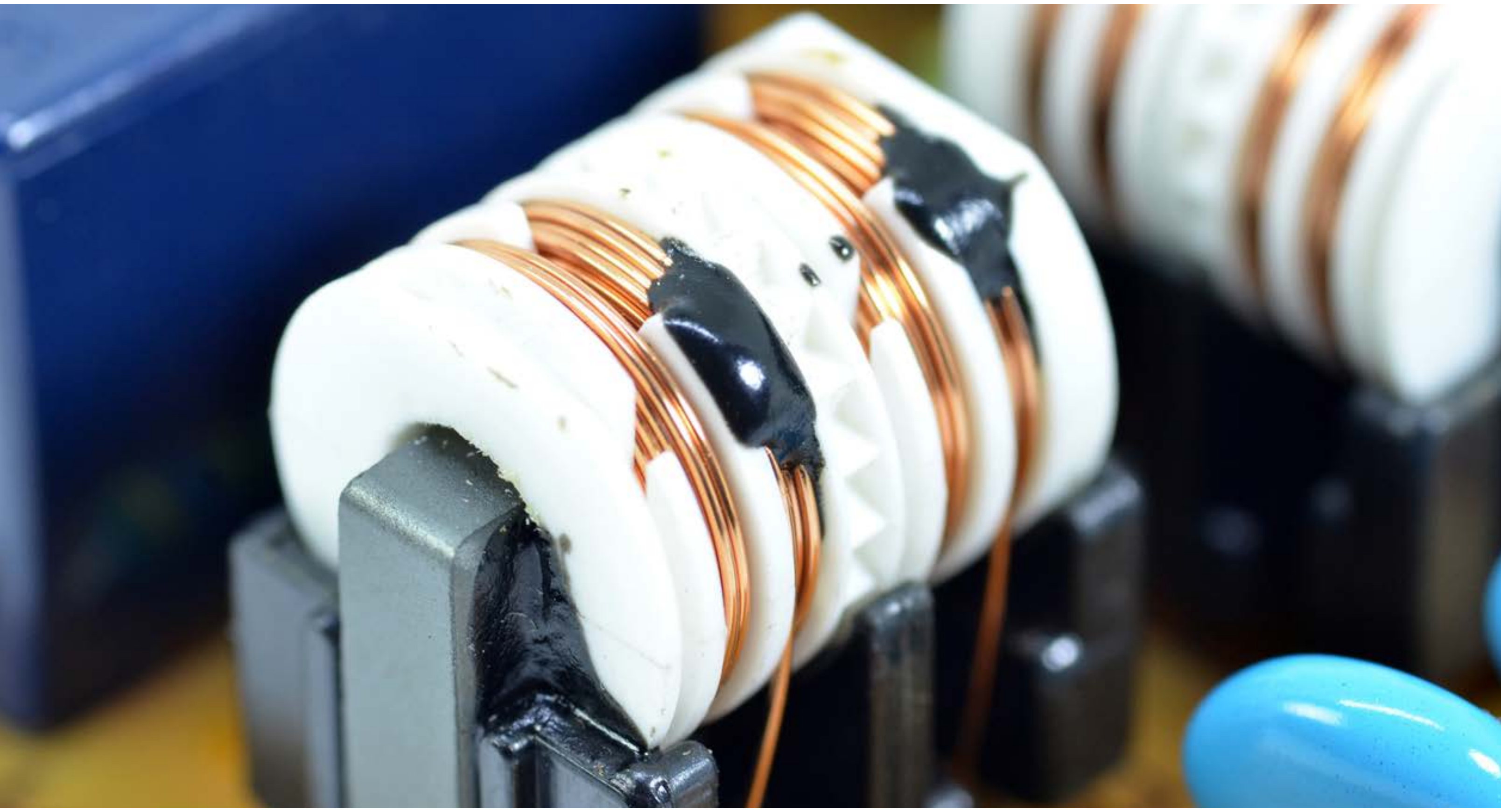


INPUT FILTERS — THE KEY TO SUCCESSFUL EMC VALIDATION

Ranjith Bramanpalli | Steffen Schulze
Würth Elektronik

Introduction

Input filters are today as ever a requisite factor for successful EMC validation of switching controllers, irrespective of the size of the AC component involved. Switching controllers create conducted EMC interferences due to AC components in their lines, independent of their individual topology and application. Certain component manufacturers have therefore optimized their power modules for a low line-bound and radiated emission of interferences. These types of modules' residual ripple generally exhibits a negligibly low value, meaning that an output filter can be dispensed within most applications. Since the input current at the step-down converter is pulsating, this may generate radio-frequency interferences in the application. Depending on the specific application, the hardware developer decides whether an input filter is necessary directly before the power module or in another position in the switch. The design process of input filters for optimized power modules and the measurement techniques that are used is discussed in this article.



INPUT FILTERS – THE KEY TO SUCCESSFUL EMC VALIDATION

As a starting point it is useful to illustrate how differential mode noises develop in the first place. Differential mode noises are interference signals in a system with a symmetrical current back and forth between the source and the load in the lines of a switching controller.

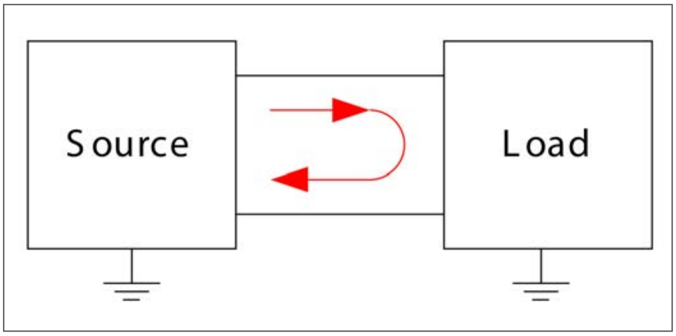


Figure 1 – Symmetrical system

In the input circuit, the clock frequency of the power module includes an AC component superimposed over the useful current and is similar in its configuration to the current through the storage inductance of the power module. The input current flows into the input capacitor Cin. Real capacitors possess a resistive component, the ESR, and an inductive component, the ESL as shown in *Figure 2*.

Due to the ESR of the input capacitor and the impedances of the lines of the power module, the AC component produces an undesirable voltage drop.

In this form, the noise voltage shows up as a differential-mode signal. The amplitude of the interference voltage occurring at the input capacitor is essentially dependent on the ESR of the capacitor used. Electrolytic capacitors have a relatively high ESR, the value of which can range between just a few milliohms up to several ohms. As a consequence, the interference voltage can vary between a few millivolts up to several volts. Ceramic capacitors, on the other hand, have a very small ESR of just a few milliohms and thus result in a noise voltage of a few millivolts. In addition, the circuit-board design of the power module exerts a great effect on the interference voltage.

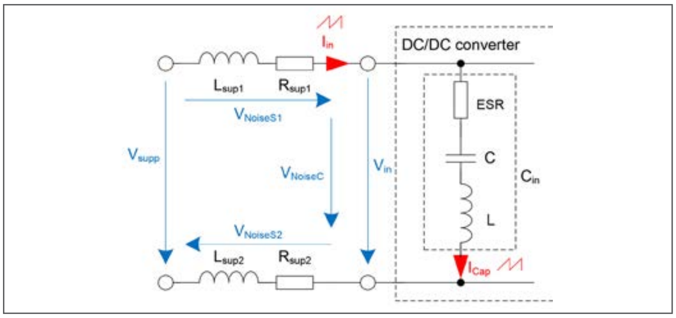


Figure 2 – Development of the noise voltage

To reduce differential mode noises, at least one simple LC filter must be fitted at the input of the converter as a measure to minimize the AC component in the line. In high-impedance systems, such an input filter can theoretically produce a voltage attenuation of 40 dB/decade in the stopband. In practice, a lower degree of attenuation is achieved since the terminating impedances are low-ohm in their nature and also because the components themselves exhibit losses. In dimensioning the LC filter a corner frequency f_c is selected that is below the switching frequency f_{sw} of the power module. If the factor is one tenth, theoretically an insertion loss of 40 dB is achieved at the switching frequency at which the highest spectral amplitude occurs.

$$f_C = \frac{f_{SW}}{10} \tag{1}$$

The corner frequency of an LC filter is generally:

$$f_C = \frac{1}{2\pi \cdot \sqrt{L_f \cdot C_f}} \tag{2}$$

As an example for the calculation of the filter, an inductance of 10 µH is selected and *Equation (2)* is transformed to:

$$C_f = \frac{1}{(2\pi \cdot 0.1 \cdot f_{sw})^2 \cdot L_f} \tag{3}$$

In arranging the filter components, as shown in *Figure 3,* the filter capacitor can be positioned on the side of the voltage source or on the input side of the power module. The decisive factor for the attenuation of the pulsating current drawn from the voltage source is the inductance of the filter inductor.

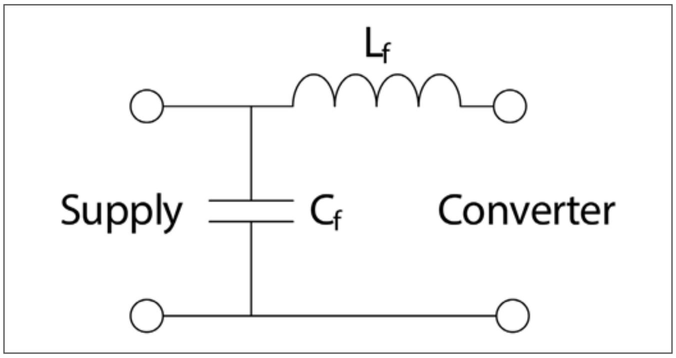


Figure 3 – Arrangement of the components of the input filter

When the quality of the filter resonance is too high, oscillations may occur in the event of changes in the input voltage that must be regulated. The stability criterion that applies here is that the output impedance of the input filter $Z_{out,filter}$ within a broad frequency spectrum has to be lower than the input impedance of the power module $Z_{in,converter}$:

$$|Z_{out,filter}| < |Z_{in,converter}| \tag{4}$$

In addition, the corner frequency f_c of the input filter should lie far below the crossover frequency f_{co} of the power module.

$$f_{c,filter} \ll f_{co,converter} \tag{5}$$

Figure 4 shows how this is done by placing an attenuating branch parallel to the power module input.

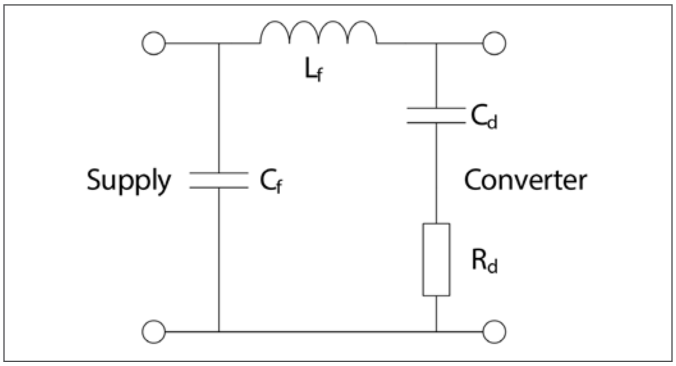


Figure 4 – Attenuation of the input filter

The attenuator reduces the quality of the input filter and consequently its output impedance at the resonance frequency. *Equation (6)* can be applied to calculate the attenuation resistance Rd for a filter quality of Qf=1:

$$R_d = \sqrt{\frac{L_f}{C_f}} \tag{6}$$

A value that has established itself in practice as an indicator of the capacity of the attenuation capacitor C_d is the five-to-ten-fold measure of the filter-capacitor capacitance:

$$(5 \cdot C_f) < C_d < (10 \cdot C_f) \tag{7}$$

As an alternative, the filter can be attenuated by selecting an electrolytic capacitor that is switched parallel to the filter output instead of the attenuator. As a rule, the value of the ESR of the electrolyte capacitor is sufficient to attenuate the filter.

SELECTING THE LC FILTER COMPONENTS

Both capacitors and coils show capacitive as well as inductive properties in reality. Filter inductors have their highest filter effect at their self-resonant frequency (SRF). In coils, the SRF is strongly dependent on the inductance and the capacitive coupling between the winding turns. In capacitors, the SRF is strongly dependent on the capacitance and the length of their terminations. When selecting the filter components, it is hence advisable to make sure that the SRF is at the upper end of the frequency range in which the RFI voltage is at its maximum or, respectively, in which the filter is to be active.

The decisive factor for the reduction of the differential-mode noise is the filter inductor, since this is the component that counteracts the rapid rise and drop in the current in the input circuit. *Figure 5* shows the impedance curves of three rod core chokes based on an example of the Würth Electronics WE-SD product family.

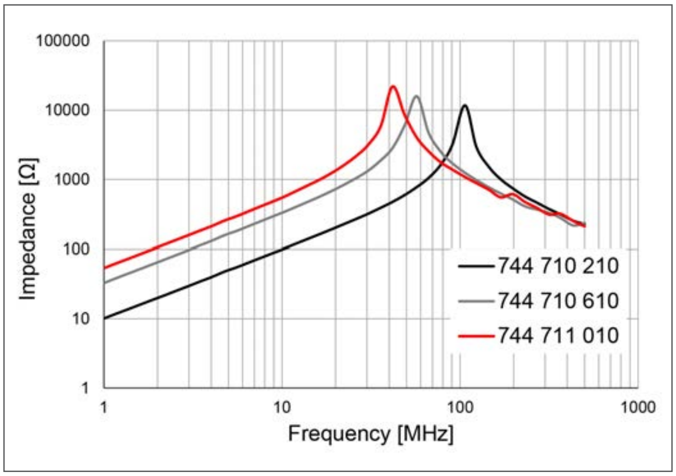


Figure 5 – Example of Impedance of one manufacturer's SD rod core chokes

The higher the inductance, the smaller the SRF. It is recommend-ed to select an inductor with an inductance whose numeric value is lower than the capacitance of the filter capacitor. In practice, a filter inductance with a maximum value of 10 µH is selected, since – depending on the design – such an inductance has a self-resonant frequency of approximately 30 MHz.

Exceeding the rated current of the filter inductor may result in damage to the wire winding. Taking the efficiency of the switching controller as a basis, it is possible to calculate the effective input current of the power module using *Equation (8)*.

$$I_{in} = \frac{V_{out} \cdot I_{out}}{V_{in} \cdot \eta} \tag{8}$$

For safety reasons, a larger value should be selected as the rated current of the filter coil.

The filter capacitor may take the form of a liquid electrolyte capacitor, a polymer capacitor, or even a ceramic capacitor. The only aspect that must be considered is that the filter quality at the corner frequency is sufficiently low.

Further measures must be considered when dimensioning a Π filter. In the optimal case, an input filter should be placed as close as possible to the input of the power module. For the case that the in-put filter is placed further away due to geometric circumstances, the traces may act as an antenna between the input filter and the power module at higher frequencies. The trace inductance can, however, also be used together with a ceramic capacitor to establish an additional LC filter with a higher cut-off frequency (see *Figure 6*). Due to its negligibly low ESR, a ceramic capacitor can swiftly short-circuit high-frequency voltages to ground with low impedance.

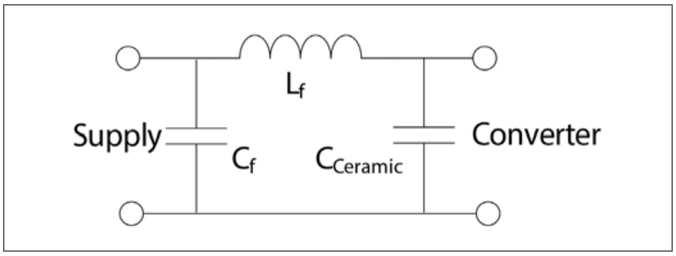


Figure 6 – Π input filter

The SRF of the capacitor should roughly lie within the spectrum of the switching frequency of the power module. To illustrate this point, *Figure 7* shows impedance curves of Würth Elektronik WCAP-CSGP ceramic capacitors in the 0805 size.

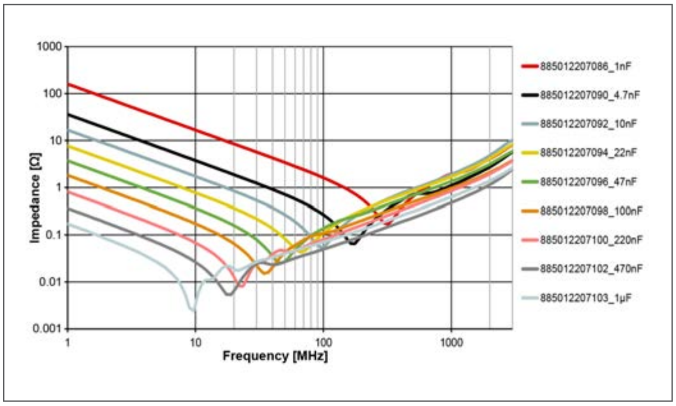


Figure 7 – Impedance of ceramic capacitors

Of the components shown in *Figure 7,* at a clock frequency of 2 MHz, for example, a capacitor with 1 µF would be suitable (resonant frequency marked in red). Even a 100 nF ceramic capacitor (resonant frequency marked in blue), which is used as a blocking capacitor in numerous electronic circuits, would be a suitable candidate at these values; it should be mentioned, however, that com-pared with the 1 µF version the 100 nF capacitor has an ESR higher by a factor of nine.

DIMENSIONING AN OUTPUT FILTER

Some power modules on the market, such as Würth Elektronik MagI³C power modules, exhibit a negligibly low residual ripple at the output, which is why an output filter is not absolutely necessary. For the case that components supplied by the switching controller decouple interference signals via interfaces (e.g. sensor switches, analog switching circuits), it may be necessary to include an output filter to filter the output voltage.

The circuit schematic shown in *Figure 6* images an output filter as an option comparable to that shown here in *Figure 8.* It is not generally possible to make a definitive statement on the necessity for and effectiveness of such an output filter, since this must be dimensioned individually for each specific application. It may be possible to use an output filter to reduce the residual ripple of the power module to an absolute minimum, or otherwise to suppress undesirable subharmonic oscillations. The filter can be dimensioned as already described. Attenuation of the filter resonance is not necessary in this case.

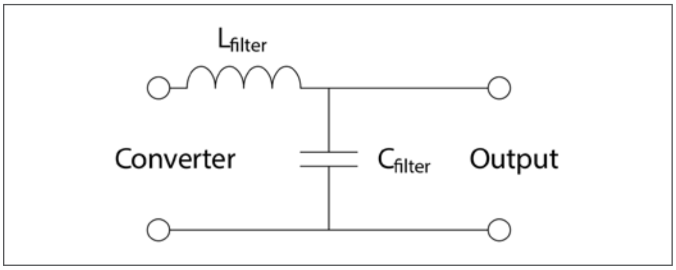


Figure 8 – Output filter

MEASURING THE NOISE VOLTAGE

The noise voltage is measured according to the basic standard IEC CISPR 16-2-1, which describes the types of the interference variables to be measured, the equipment to be used for the various interfaces, and the measurement set-up for table-top and floor-standing devices. The interferences are evaluated in the frequency range from 9 kHz to 30 MHz. The measuring devices include besides the EMI receiver a variety of line impedance stabilizing networks (LISNs), voltage probes, current clamps and capacitive couplers. In a measurement set-up for table-top devices, as shown in *Figure 9,* the test object (DUT, "device under test") is positioned on a non-conductive table standing on a ground reference plane. The table should be 40 cm in height. In the case that a vertical ground reference plane is also present, the table should be at least 80 cm in height. The LISN must be connected to the ground plane ensuring good conductivity. The DUT itself and any attached cables are to be arranged so that they are 40 cm distant from the ground plane.

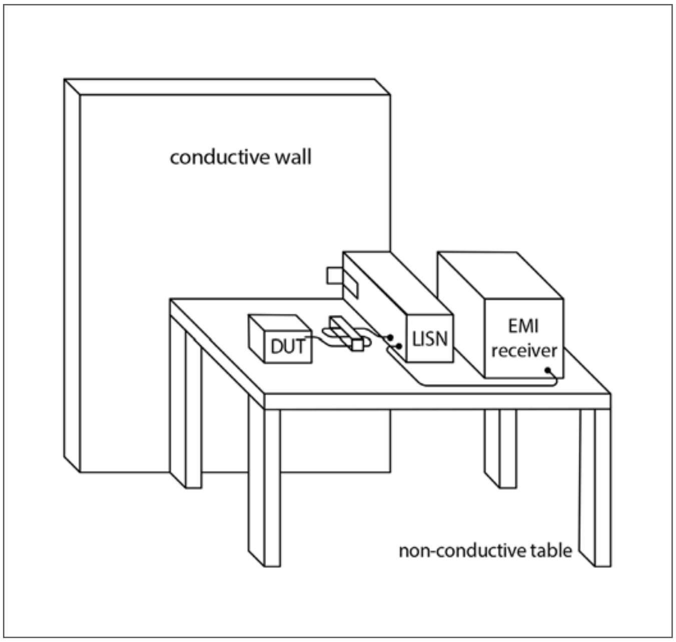


Figure 9 – Test set-up for measuring conducted interferences on power-supply lines

The length of the cable between the DUT and the LISN should not exceed 80 cm. The EMI receiver evaluates the asymmetric noise voltage that is decoupled at the LISN for the separate leads of the cable.

MEASURING THE RADIATED NOISE

The method for measuring the radiated noise above 30 MHz is described in the IEC CISPR16-2-3 basic standard. The measurement environment is generally in the form of an anechoic room with a conductive floor or, at a smaller scale, an anechoic chamber. Here, too, the DUT is positioned on a non-conductive table (for portable or table-top devices, see *Figure 10,* or on the floor. To enable the DUT to revolve on its own axis in its default state during the measurement, it is placed on a turntable. In larger anechoic rooms, the receiving antenna is placed at a distance of 10 m from the DUT and adjusted in its height during the measurement to find the maxi-mum electric field strength at each measurement frequency (peak spectrum). In addition, the orientation of the antenna is altered (horizontal and vertical polarization). In smaller anechoic chambers, the distance between antenna and DUT should be 3 m; since the antenna height needs to be fixed, the height scan is omitted and he floor between the antenna and the DUT must be covered with absorbing material.

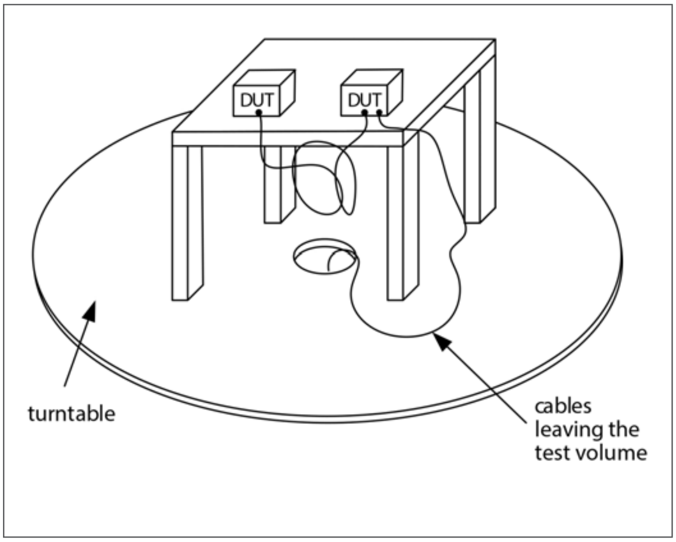


Figure 10 – Test set-up for measuring the radiated noise in anechoic rooms or chambers

CASE STUDY – MEASURED NOISE VOLTAGE

The following section describes the measurement of the noise volt-age using a Würth Elektronik MagI³C power module evaluation board fitted with a Variable Step Down Regulator Module (171 020 601) as an example.

Already during the preliminary phase it is possible to measure the AC component at the power module's input using an oscilloscope. By running an analysis within the time domain, the anticipated interference spectrum can be estimated at the start of the work on the design of the filter.

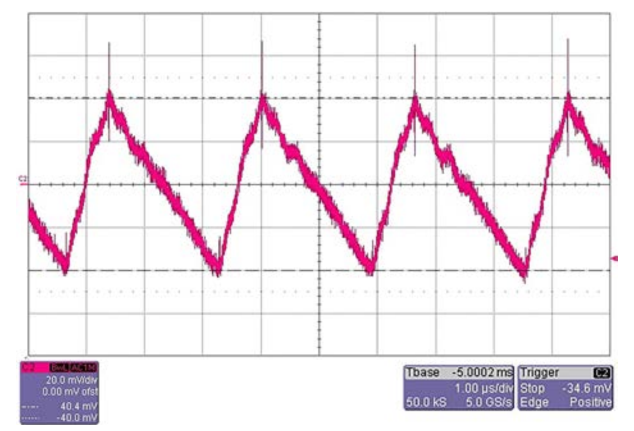


Figure 11 – Time-domain signal with a broadband spectral content

Figure 11 shows an AC component of 80 mV, measured at an in-put voltage of the power module of 7.5 V, an average input current of 1.2 A, and an average load current of 2 A. Switching controllers have the property to show up as a negative differential resistance from the viewpoint of the power supply. The input current rises with decreasing input voltage. For this reason, the noise voltage is measured under "worst case" conditions – minimum input voltage, maximum current.

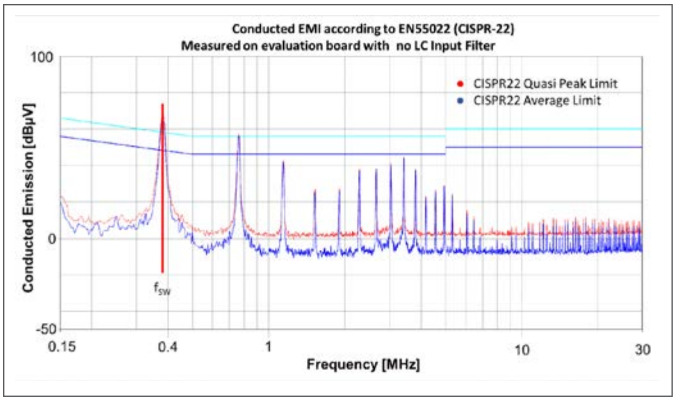


Figure 12 – Noise voltage without an input filter

The decisive factor in the analysis of this type of noise emission, however, remains the measurement of noise voltage as can be per-formed in an EMC laboratory. *Figure 12* shows the result of a noise voltage measurement without an input filter.

This power module operates at a clock frequency of 370 kHz. In the interference spectrum, the highest amplitude (red peak: 68 dBµV) can be measured at this frequency. The amplitude density of the noise voltage drops at a rate of approx. 40 dB/decade, meaning that no significant interference level can be seen above the 15th harmonic. Nevertheless, it is only above the 9th harmonic that the interference level is more than 10 dB below the limit for the average detector (dark blue line).

Equation (3) can now be used to calculate a suitable LC input filter. Due to the relatively low switching frequency, an inductor with a low SRF and an inductance of 4.7 µH is selected and the filter capacitance is calculated.

$$C_f = \frac{1}{(2\pi \cdot 0.1 \cdot f_{sw})^2 \cdot L_f} \tag{9}$$

The selected filter capacitor is the one with a little higher capacitance of 10 µF. The maximum input current is calculated using *Equation (8)*.

This calculation requires the efficiency of the evaluation board, which is determined by measurement and in this case has a value of 91%.

$$I_{in} = \frac{5\,V \cdot 2\,A}{6\,V \cdot 0.91} = 1.83\,A \tag{10}$$

On the basis of the calculations of the filter inductance and input current, it is now possible to select an appropriate inductor. Picked for the purpose is an unshielded inductor from the Würth Elektronik PD2 series, size 5820. *Figure 13* shows the result of the noise voltage measurement with the matched filter.

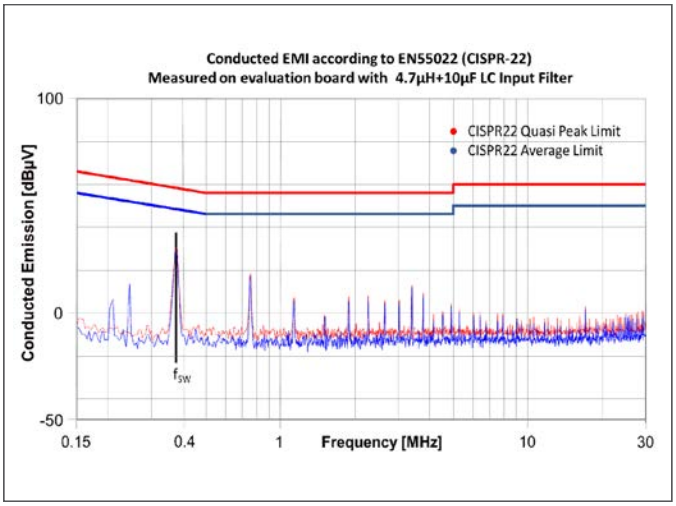


Figure 13 – Noise voltage with an input filter

The interference level measured at the 370 kHz switching frequency has a value of 30 dBµV. The levels of all harmonics are lower than 20 dBµV and are thus sufficiently attenuated. The average level at 370 kHz corresponds to the peak level and is 18 dB lower than the average limit of 47 dBµV. In measuring such conducted interferences in the practical context, a signal-to-noise ratio of this dimension is entirely sufficient in order to confirm the conformity of this measurement.

The purpose of the measurement of the noise voltage is to demonstrate the usefulness of an analysis of the interference potential in the time domain; though an analysis in the frequency domain is still indispensable.

Finally, the equations can be used to calculate an attenuating resistance.

$$R_d = \sqrt{\frac{4.7\,\mu H}{10\,\mu F}} = 0.686\,\Omega \tag{11}$$

The higher the value of the attenuation resistance, the higher the attenuation of the filter resonance. In this case, the next higher resistance of the E12 series of 1 Ω can be selected.

A value of 47 µF is selected for the attenuation capacitor. This may be, for example, a Würth Elektronik eiCap ceramic capacitor of the WCAP-CSGP series.

MEASURING ACCORDING TO IEC CISPR 22

The above measurements were performed according to the IEC CISPR16-2-1 standard, as described in Section 8. The use of a LISN enabled the asymmetric voltage to be decoupled and equated to the asymmetric (common-mode) voltage, which was then compared to the limit, taken from the IEC CISPR 22 standard for devices for private and commercial use (Class B). For power-supply components – and this includes all types of switching controllers – there is no directly applicable EMC standard. The entire application in which the switching controller is used must be assigned to a specific category of devices and then tested according to the corresponding standard applicable for the product or product family. In this case, the product-family standard IEC CISPR 22 for IT installations was taken only with reference to the limits, which are also given in the IEC 61000-6-3 generic standard. The generic standards can be used in cases for which there is no specific standard for the device in question.

SUMMARY

Irrespective of the size of the AC component involved, an input filter is today as ever a requisite factor for a successful EMC validation of a switching controller. Simple-to-apply equations can be used to calculate such an input filter on an individual basis. Taking the impedances of the filter and the switching controller into account in the equations, this enables oscillations to be avoided and also ensures the control stability of the switching controller itself. A targeted selection of the filter components lays the foundations for an optimal design of the filter. Equipped with an appropriate degree of technical skill in EMC testing methods, the hardware developer can design his switch purposefully and, wherever necessary, make any adjustments to the filter himself.

NARROWBAND VERSUS BROADBAND HARMONIC SIGNALS

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Introduction

Laboratory demonstrations show why modern EMC testing uses the spectrum analyzer noise floor measurement as opposed to the older method of sampling radio channels and listening for noise. The attendee will witness a demonstration of the effects of narrow and broadband noise on both the ability of a victim radio to properly receive a signal, and also the ability of a test engineer to properly discern if there is interference.

NARROWBAND VERSUS BROADBAND HARMONIC SIGNALS

Radiated and conducted emissions measurements are often comprised of both narrowband and broadband sources. So what differentiates "narrowband" and "broadband" signals?

NARROWBAND VERSUS BROADBAND SIGNALS

The definition of whether a signal is narrowband or broadband as measured using a spectrum analyzer, depends entirely on the receiver bandwidth (resolution bandwidth, or RBW). For commercial EMI signals, the test standards define what the RBW should be.

For example, when measuring from 150 kHz to 30 MHz, the RBW is specified as 9 kHz. For frequencies between 30 and 1000 MHz, the RBW is 120 kHz. This was originally defined as the typical broadcast radio (AM and FM) receiver bandwidth.

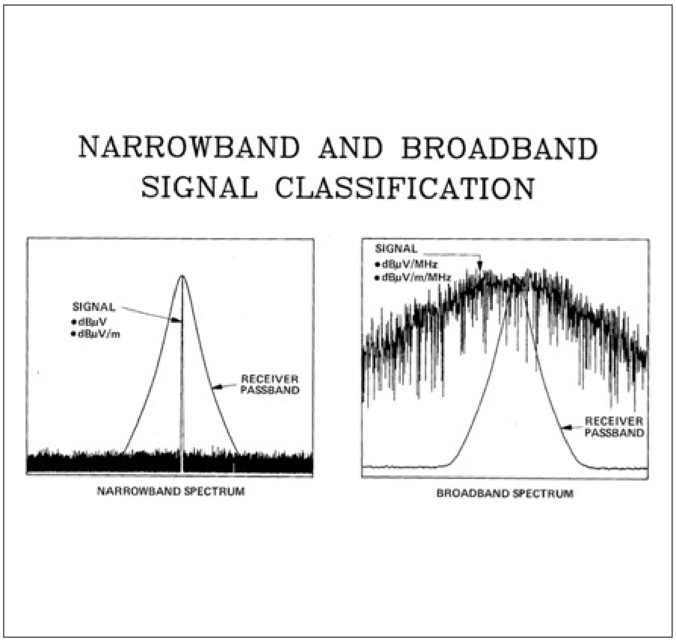
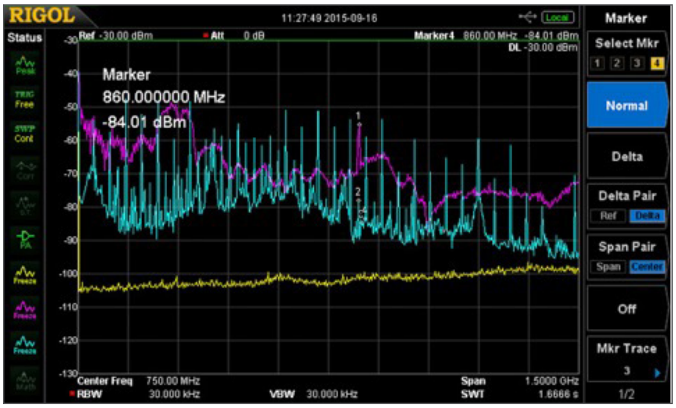


Figure 1 – Idealized example of a narrowband signal, which fits within the RBW (receiver passband in figure), and broadband, whose energy does not fit within the RBW. Diagram, courtesy Hewlett Packard

Figure 2 shows the difference between the two measured sets of harmonic signals as we're looking from 9 kHz to 1.5 GHz. The RBW has been adjusted to 30 kHz for this example. Typically, DC-DC converters or data/address bus data will appear as a very broad signal with several resonant peaks (violet trace in *Figure 2*), while crystal oscillators or high speed clocks (anything with fast switching edge speeds) will appear as a series of narrow spikes (aqua trace in *Figure 2*). Unless the product is designed for EMC compliance, both these types of signals can radiate or conduct high frequency energy well into the mobile phone bands.



Ref -30.00 dBm Att 0 dB
Marker4 860.00 MHz -84.01 dBm
DL -30.00 dBm
Marker
860.000000 MHz
-84.01 dBm
Center Freq 750.00 MHz
RBW 30.000 kHz
VBW 30.000 kHz
Span 1.5000 GHz
SWT 1.6666 s

Figure 2 - There are two common types of high frequency harmonics; narrowband (in the aqua trace) and broadband (violet trace). The yellow trace is the ambient noise level of the measurement system and is always a good idea to document a measurement system baseline

Note that by reducing the RBW way down to 1 kHz, or so, you'll be able to start resolving the harmonics from DC-DC converters or other switching power supplies. You'll see that the signals are actually narrowband! This illustrates that a series of harmonic signals can be both narrowband and broadband. It all depends on the RBW.

Rohde & Schwarz has three useful references that describe this concept in much more detail.

REFERENCES:

1. Rohde & Schwarz, Measuring with Modern Spectrum Analyzers: https://www.rohde-schwarz.com/us/applications/measuring-with-modern-spectrum-analyzers-educational-note_230850-36424.html
2. Rohde & Schwarz, Making Spectrum Measurements with Rode & Schwarz Network Analyzers: https://cdn.rohde-schwarz.com/pws/dl_downloads/dl_application/application_notes/1ez62/1EZ62_0e.pdf
3. Narrowband/Broadband - Not Just An Arcane Discrimination, but the Key to System-Level EMC (Demonstration): https://emc.live/2017/narrowband-broadband-not-just-arcane-discrimination-key-system-level-emc-demonstration/

COMMON COMMERCIAL, AUTOMOTIVE, MEDICAL, WIRELESS & MILITARY EMC STANDARDS

►COMMERCIAL STANDARDS

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

FCC

(https://www.ecfr.gov)

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

ANSI

(http://webstore.ansi.org)

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

IEC

(https://webstore.iec.ch)

Document Number	Title
IEC 60601-1-2	Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests
IEC 60601-2-2	Medical electrical equipment - Part 2-2: Particular requirements for the basic safety and essential performance of high frequency surgical equipment and high frequency surgical accessories
IEC 60601-4-2	Medical electrical equipment - Part 4-2: Guidance and interpretation - Electromagnetic immunity: performance of medical electrical equipment and medical electrical systems
IEC 61000-3-2	Electromagnetic compatibility (EMC) - Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
IEC 61000-3-3	Electromagnetic compatibility (EMC) – Part 3-3: Limits – Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current ≤ 16 A per phase and not subject to conditional connection
IEC 61000-4-2	Electromagnetic compatibility (EMC)- Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
IEC 61000-4-3	Electromagnetic compatibility (EMC) - Part 4-3 : Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
IEC 61000-4-4	Electromagnetic compatibility (EMC) - Part 4-4 : Testing and measurement techniques – Electrical fast transient/burst immunity test

IEC 61000-4-5	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
IEC 61000-4-6	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
IEC 61000-4-7	Electromagnetic compatibility (EMC) - Part 4-7: Testing and measurement techniques - General guide on harmonics and interharmonics measurements and instrumentation, for power supply systems and equipment connected thereto
IEC 61000-4-8	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
IEC 61000-4-9	Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test
IEC 61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
IEC 61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
IEC 61000-4-12	Electromagnetic compatibility (EMC) - Part 4-12: Testing and measurement techniques - Ring wave immunity test
IEC 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
IEC 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
IEC 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
IEC 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
IEC 61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environments
IEC 61000-6-7	Electromagnetic compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations
IEC 61326-1	Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements
IEC 61326-2-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-1: Particular requirements - Test configurations, operational conditions and performance criteria for sensitive test and measurement equipment for EMC unprotected applications
IEC 61326-2-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-2: Particular requirements - Test configurations, operational conditions and performance criteria for portable test, measuring and monitoring equipment used in low-voltage distribution systems
IEC 61326-2-3	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-3: Particular requirements - Test configuration, operational conditions and performance criteria for transducers with integrated or remote signal conditioning
IEC 61326-2-4	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-4: Particular requirements - Test configurations, operational conditions and performance criteria for insulation monitoring devices according to IEC 61557-8 and for equipment for insulation fault location according to IEC 61557-9
IEC 61326-2-5	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-5: Particular requirements - Test configurations, operational conditions and performance criteria for field devices with field bus interfaces according to IEC 61784-1

IEC 61326-2-6	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 2-6: Particular requirements - In vitro diagnostic (IVD) medical equipment
IEC 61326-3-1	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-1: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - General industrial applications
IEC 61326-3-2	Electrical equipment for measurement, control and laboratory use - EMC requirements - Part 3-2: Immunity requirements for safety-related systems and for equipment intended to perform safety-related functions (functional safety) - Industrial applications with specified electromagnetic environment
IEC 61340-3-1	Electrostatics - Part 3-1: Methods for simulation of electrostatic effects - Human body model (HBM) electrostatic discharge test waveforms

CISPR

(https://webstore.iec.ch)

Document Number	Title
CISPR 11	Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
CISPR 13	Sound and television broadcast receivers and associated equipment - Radio disturbance characteristics - Limits and methods of measurement
CISPR 14-1	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission
CISPR 14-2	Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 2: Immunity – Product family standard
CISPR 15	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
CISPR 16-1-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-1: Radio disturbance and immunity measuring apparatus - Measuring apparatus
CISPR 16-1-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-2: Radio disturbance and immunity measuring apparatus - Coupling devices for conducted disturbance measurements
CISPR 16-1-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-3: Radio disturbance and immunity measuring apparatus - Ancillary equipment - Disturbance power
CISPR 16-1-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-4: Radio disturbance and immunity measuring apparatus - Antennas and test sites for radiated disturbance measurements
CISPR 16-1-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-5: Radio disturbance and immunity measuring apparatus - Antenna calibration sites and reference test sites for 5 MHz to 18 GHz
CISPR 16-1-6	Specification for radio disturbance and immunity measuring apparatus and methods - Part 1-6: Radio disturbance and immunity measuring apparatus - EMC antenna calibration
CISPR 16-2-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-1: Methods of measurement of disturbances and immunity - Conducted disturbance measurements

CISPR 16-2-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-2: Methods of measurement of disturbances and immunity - Measurement of disturbance power
CISPR 16-2-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements
CISPR 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement
CISPR 22	Information technology equipment - Radio disturbance characteristics - Limits and methods of measurement (Withdrawn and replaced by CISPR 32:2015)
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements

►AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY STANDARDS

The following abbreviated list of automotive EMC standards was developed by Dr. Todd Hubing, Professor Emeritus of Clemson University Vehicular Electronics Lab (http://www.cvel.c lemson.edu/auto/auto_emc_standards.html). A few of these standards have been made public and are linked below, but many others are considered company confidential and are only available to approved automotive vendors or test equipment manufacturers. While several standards are linked on this list, an internet search may help locate additional documents that have been made public. For a more complete list, refer to the link above. Permission to republish has been granted.

CISPR (AUTOMOTIVE EMISSIONS REQUIREMENTS)

(https://webstore.iec.ch)

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

ISO (AUTOMOTIVE IMMUNITY REQUIREMENTS)

(https://www.iso.org)

Document Number	Title
ISO 7637-1	Road vehicles -- Electrical disturbances from conduction and coupling -- Part 1: Definitions and general considerations
ISO 7637-2	Road vehicles -- Electrical disturbances from conduction and coupling -- Part 2: Electrical transient conduction along supply lines only
ISO 7637-3	Road vehicles -- Electrical disturbance by conduction and coupling -- Part 3: Vehicles with nominal 12 V or 24 V supply voltage -- Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
ISO/TR 10305-1	Road vehicles -- Calibration of electromagnetic field strength measuring devices -- Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz
ISO/TR 10305-2	Road vehicles -- Calibration of electromagnetic field strength measuring devices -- Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz
ISO 10605	Road vehicles -- Test methods for electrical disturbances from electrostatic discharge
ISO/TS 21609	Road vehicles -- (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment
ISO 11451-1	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 1: General principles and terminology
ISO 11451-2	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 2: Off-vehicle radiation sources
ISO 11451-3	Road vehicles -- Electrical disturbances by narrowband radiated electromagnetic energy -- Vehicle test methods -- Part 3: On-board transmitter simulation
ISO 11451-4	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)

ISO 11452-4	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)
ISO 11452-7	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 7: Direct radio frequency (RF) power injection
ISO 11452-8	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 8: Immunity to magnetic fields
ISO 11452-10	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 10: Immunity to conducted disturbances in the extended audio frequency range

SAE (AUTOMOTIVE EMISSIONS AND IMMUNITY)

(http://standards.sae.org)

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

J551/16	Electromagnetic Immunity - Off-Vehicle Source (Reverberation Chamber Method) - Part 16 - Immunity to Radiated Electromagnetic Fields
J551/17	Vehicle Electromagnetic Immunity -- Power Line Magnetic Fields
J1812	Function Performance Status Classification for EMC Immunity Testing
J2628	Characterization--Conducted Immunity
J2556	Radiated Emissions (RE) Narrowband Data Analysis--Power Spectral Density (PSD)

GM

(https://global.ihs.com)

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

FORD

(https://www.fordemc.com)

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

DaimlerChrysler

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

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

►MEDICAL STANDARDS

COLLATERAL STANDARDS

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

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

OTHER RELEVANT STANDARDS

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

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

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

►COMMON WIRELESS STANDARDS

ETSI STANDARDS

(https://www.etsi.org)

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

►COMMON MILITARY RELATED DOCUMENTS AND STANDARDS

The following references are not intended to be all inclusive, but rather a representation of available sources of additional information and point of contacts. Downloadable from: http://everyspec.com.

Document Number	Title
MIL-HDBK-235-1	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010
MIL-HDBK-1857	Grounding, Bonding and Shielding Design Practices, 27 Mar 1998
MIL-STD-220C	Test Method Standard Method of Insertion Loss Measurement, 14 May 2009
MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973
MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 Dec 2007
MIL-STD-461G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015
MIL-STD-464C	Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010

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

►AEROSPACE STANDARDS

AIAA STANDARDS

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

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

RTCA STANDARDS

www.rtca.org/

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

SAE STANDARDS

www.sae.org/

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

REFERENCES

(ARTICLE LINKS, STANDARDS, 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/

►EMC STANDARDS ORGANIZATIONS

American National Standards Institute
http://www.ansi.org

ANSI Accredited C63
http://www.c63.org

Asia Pacific Laboratory Accreditation Cooperation (APLAC)
http://www.aplac.org

BSMI (Taiwan)
https://www.bsmi.gov.tw/wSite/xslgip/chinese/index.html

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

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

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

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

Federal Communications Commission (FCC)
http://www.fcc.gov

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

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

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

IEEE EMC Society Standards Development Committee (SDCOM)
https://standards.ieee.org/project/2665.html

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

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

RTCA
https://www.rtca.org

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

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

►RECOMMENDED BOOKS

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

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

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

HALL, HALL, AND MCCALL
High-Speed Digital System Design - A Handbook of Interconnect Theory and Design Practices
Wiley, 2000.

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

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

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

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

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

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

MONTROSE
EMC Made Simple - Printed Circuit Board and System Design
Montrose Compliance Services, 2014. Includes basic theory and product design information

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

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

MORRISON
Fast Circuit Boards - Energy Management
Wiley, 2018. A brand new book explaining how electromagnetic energy moves through circuit boards. Destined to be a classic.

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

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

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

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

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

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

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

►RECOMMENDED MINI-GUIDES FROM INTERFERENCE TECHNOLOGY

(FREE DOWNLOADS)

2019 Directory & Design Guide
https://learn.interferencetechnology.com/2019-directory-and-design-guide/

2019 Military & Aerospace EMC Guide
https://learn.interferencetechnology.com/2019-military-and-aerospace-emc-guide/

2019 Components & Materials Guide
https://learn.interferencetechnology.com/2019-components-and-materials-guide/

2019 Europe EMC Guide
https://learn.interferencetechnology.com/2019-europe-emc-guides/

2018 EMC Fundamentals Guide
http://learn.interferencetechnology.com/2018-emc-fundamentals-guide/

2018 EMC Digest
https://learn.interferencetechnology.com/2018-emc-digest/

2018 EMC Automotive Guide
https://learn.interferencetechnology.com/2018-automotive-emc-guide/

2018 EMC Testing Guide
https://learn.interferencetechnology.com/2018-emc-testing-guide/

2018 Military & Aerospace EMC Guide
http://learn.interferencetechnology.com/2018-military-and-aerospace-emc-guide/

2018 Directory & Design Guide
https://learn.interferencetechnology.com/2018-directory-design-guide/

2018 Components & Materials Guide
https://learn.interferencetechnology.com/2018-components-and-materials-guide/

2018 Europe EMC Guide
https://learn.interferencetechnology.com/2018-europe-emc-guide-int-tech/

►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

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

2019 EMC CONFERENCES

JUN 3 – 7

2019 JOINT INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY AND ASIA-PACIFIC INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY

Sapporo, Japan | https://www.aconf.org/conf_169775.html

EMC Sapporo & APEMC 2019 is the 8th International Symposium on Electromagnetic Compatibility organized by IEICE-CS, and the first joint symposium under technical co-sponsorship by Asia-Pacific EMC (APEMC). We would like to invite all engaged in research and development in the various fields of electromagnetic compatibility to participate in this Symposium.

JUN 18 – 21

23RD IEEE WORKSHOP ON SIGNAL AND POWER INTEGRITY (SPI)

Chambery, France | https://spi2019.sciencesconf.org/

Over the past two decades, the IEEE Workshop on Signal and Power Integrity (SPI) has evolved into a forum of exchange on the latest research and developments on design, characterization, modeling, simulation and testing for Signal and Power Integrity at chip, package, board and system level. The workshop brings together developers and researchers from industry and academia in order to encourage cooperation.

JUN 25 – 26

AUTOMOBIL ELEKTRONIK KONGRESS

Ludwigsburg, Germany | https://www.automobil-elektronik-kongress.de/en/

The European Electric & Hybrid Vehicle Congress is a global platform to foster exchange of views between the R&D, the industry, the authorities, and end users to develop synergies in the field of e-mobility.

JUL 22 – 26

THE 2019 SYMPOSIUM ON EMC+SIPI

New Orleans, Louisiana | http://www.emc2019.emcss.org

The Symposium on EMC+SIPI is the leading event to provide education of EMC and Signal and Power Integrity techniques to specialty engineers. The Symposium features five full days of innovative sessions, interactive workshops, tutorials, experiments, demonstrations, and social networking events.

SEPT 2 – 6

EMC EUROPE 2019

Barcelona, Spain | https://emceurope2019.eu/

EMC Europe 2019 focuses on the high quality of scientific and technical contributions providing a forum for the exchange of ideas and latest research results from academia, research laboratories and industry from all over the world. The symposium gives the unique opportunity to present the progress and results of your work in any EMC topic, including emerging trends. Special sessions, workshops, tutorials and an exhibition will be organized along with regular sessions.

2019 EMC CONFERENCES CONTINUED

SEPT 10 – 12

ELECTRIC & HYBRID VEHICLE TECHNOLOGY SHOW

Novi, Michigan | http://www.evtechexpo.com

The Electric & Hybrid Vehicle Technology Expo connects you with more than 8,000 automotive engineers and executives, and more than 600 leading suppliers, from across the H/EV manufacturing industry. A powerful end-to-end showcase, this mega event delivers up-to-the-minute insights on electric, hybrid, and plugin hybrid vehicle technology, along with the latest manufacturing solutions along the supply chain including electrical powertrains and components, battery management systems, materials and equipment.

SEPT 10 – 13

INTERNATIONAL CONFERENCE ON LIGHTNING & STATIC ELECTRICITY 2019 (ICOLSE 2019)

Wichita, Kansas | http://www.ICOLSE.com

ICOLSE, held every two years, focuses on lightning phenomenology, effects on and protection of aircraft and other air vehicles, and a wide variety of ground-based systems and facilities such as alternative energy (wind, solar), space launch, telecom, and recreational theme parks. Conference sessions will also address static electricity generation, effects, and protection for aerospace vehicles and industrial facilities that experience the effects of static electricity.

OCT 6 – 11

ATMA 2019

San Diego, CA | http://www.amta.org

The Antenna Measurement Techniques Association (AMTA) is a non-profit, international organization dedicated to the development and dissemination of theory, best practices and applications of antenna, radar signature and other electromoagnetic measurement technologies. Visit www.amta.org for more information.

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