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2022 EMC FUNDAMENTALS GUIDE

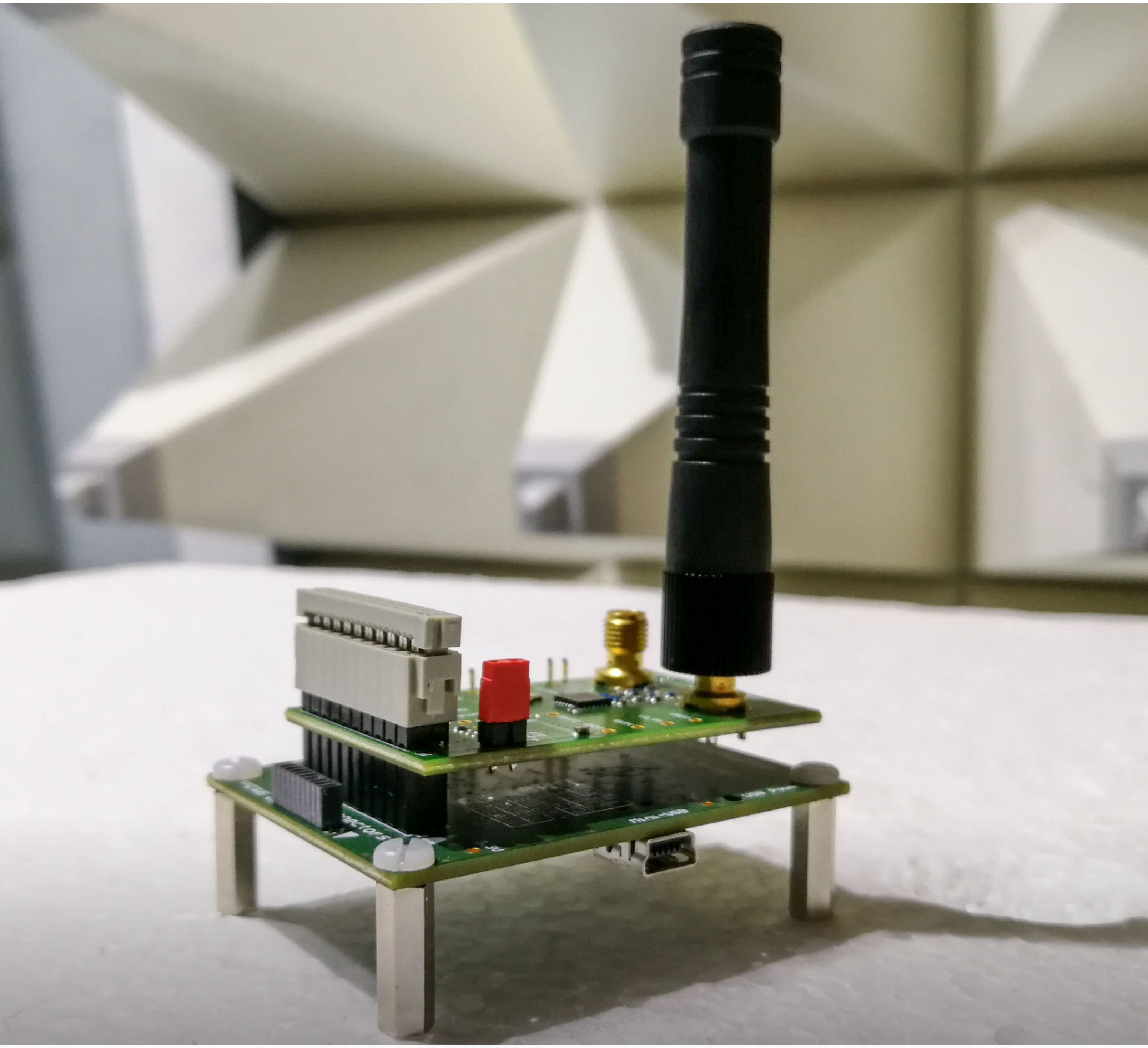

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TABLE OF CONTENTS

2022 EMC Supplier Guide 5

EMI FILTERING 101: UNDERSTANDING THE BASICS 10
DAVID ARMITAGE
Schaffner EMC, Inc.

EMC FOCUS—POWER SUPPLIES 18
RECOM Power GmbH

EMC 101 22
AR

5 STEPS TO SELECTING THE RIGHT RF POWER AMPLIFIER 26
JASON KOVATCH
AR

REFERENCE SECTION 34

Common Commercial EMC Standards 34

EMC Standards Organizations 39

Equations, Tools, & Calculators 40

LinkedIn Groups 43

Common Symbols & Acronyms 44

Recommended EMC Books, Magazines and Journals 47

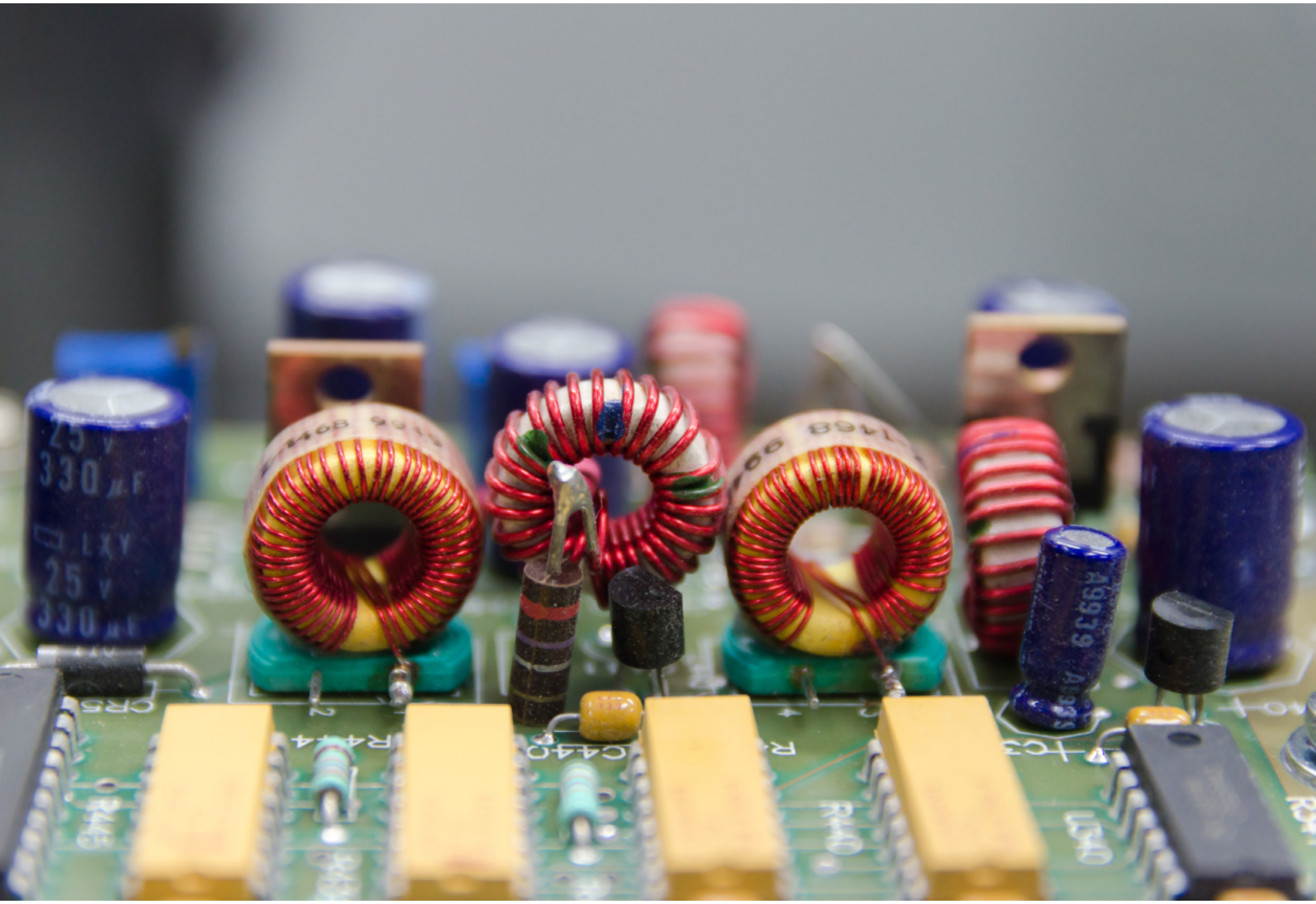
Index of Advertisers 49


REDEXPERT

2022 EMC SUPPLIER GUIDE

Introduction

In this section, we provide a quick guide to some of the top suppliers in each EMC category–test equipment, components, materials, services, and more. To find a product that meets your needs for applications, frequencies, standards requirements, etc., please search these individual supplier websites for the latest information and availability. If you have trouble finding a particular product or solution, email info@interferencetechnology.com for further supplier contacts.



	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
A	Aaronia AG	www.aaronia.com	X	X						X							X						
	Advanced Test Equipment Corp. (ATEC)	www.atecorp.com	X	X		X				X		X			X	X	X	X	X	X	X		
	AH Systems, Inc.	www.ahsystems.com	X	X	X													X	X	X			
	Altair- US	www.altair.com					X		X														
	American Certification Body Inc.	https://acbcert.com/				X	X		X												X	X	X
	Ametek- CTS Compliance Test Solutions	www.ametek-cts.com	X	X														X		X			X
	Anritsu Company	www.anritsu.com		X													X	X		X	X		
	APITech	www.apitech.com			X			X			X	X									X	X	
	AR RF/Microwave Instrumentation	www.arworld.us	X	X	X				X									X	X				
B	Beehive Electronics	www.beehive-electronics.com																			X		
	Bulgin	www.bulgin.com				X																	
C	Captor Corporation (EMC Div.)	www.captorcorp.com									X												
	Coilcraft	www.coilcraft.com						X			X												
	Compliance Direction, LLC	www.compliancedirection.com																					
	CPI- Communications & Power Industries (USA)	www.cpii.com/emc	X																				
D	Dassault System Simulia Corp	www.3ds.com/							X														
	Delta Electronics (Americas) Ltd.	www.delta-americas.com									X												
	DLS Electronic Systems, Inc.	www.dlsemc.com					X															X	
E	Electro Rent	www.electrorent.com	X							X				X			X		X				
	Elite Electronic Engineering Co.	www.elitetest.com																				X	
	EMC Live	www.emc.live																					X
	EMC Partner	www.emc-partner.com																X					
	Empower RF Systems, Inc.	www.empowerrf.com	X																X				
	EM TEST USA	www.emtest.com																X					
	Exemplar Global (iNarte)	www.exemplarglobal.org																					X
	EXODUS Advanced Communications	www.exoduscomm.com	X	X	X													X					
F	F2 Labs	www.f2labs.com				X	X														X	X	X
	Fair-Rite Products Corp.	www.fair-rite.com						X							X								
	Fischer Custom Communications	www.fischercc.com																		X			
	Frankonia Solutions	www.frankonia-solutions.com													X	X		X				X	
G	Gauss Instruments	www.gauss-instruments.com								X							X						
	Gowanda Electronics	www.gowanda.com						X															

	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
H	Haefely	www.haefely.com							X									X			X		
	Heilind Electronics, Inc	www.heilind.com									X												
	HV TECHNOLOGIES, Inc.	www.hvtechnologies.com	X	X						X		X				X	X	X		X			
I	Instrument Rental Labs	www.testequip.com	X							X							X		X				
	Interference Technology	www.interferencetechnology.com																					X
	Intertek	www.intertek.com																				X	
	ITG Electronics	www.itg-electronics.com									X												
K	Keysight Technologies	www.keysight.com								X							X		X	X			
	Kikusui America, Inc.	www.kikusuiamerica.com/solution/	X															X					
	Krieger Specialty Products	www.kriegerproducts.com														X							
	Kyocera AVX	www.kyocera-avx.com		X	X			X			X												
L	Laird a DuPont Business	www.laird.com									X			X	X								
	Langer EMV-Technik	www.langer-emv.de/en/index																		X			
M	Magnetic Shield Corp.	www.magnetic-shield.com													X								
	Master Bond Inc.	www.masterbond.com												X									
	MBP Srl	www.mbp.it/en/							X											X			
	Microlease	www.microlease.com	X							X							X		X				
	MILMEGA	www.ametek-cts.com	X																				
	Montrose Compliance Services	www.montrosecompliance.com					X																
	MVG Microwave Vision Group	www.mvg-world.com		X		X					X				X	X							
N	Narda Safety Test Solutions	www.narda-sts.com	X	X						X							X			X			
	Noise Laboratory Co., Ltd.	www.noiseken.com																				X	
	NTS	www.nts.com																			X		
O	Ohmite	www.ohmite.com								X													
	Ophir RF	www.ophirrf.com	X																				
P	Parker Chomerics	www.chomerics.com													X								
	Pearson Electronics	www.pearsonelectronics.com						X															
	Polymer Science, Inc.	www.polymerscience.com												X	X								
	PPG Cuming Lehman Chambers	www.cuminglehman.com													X	X					X		
	PPG Engineering Materials	www.dexmet.com													X								
	Prana	www.prana-rd.com	X																				
	Pulse Power & Measurement	https://ppmtest.com/																		X			
Q	Quell Corporation	www.eeseal.com			X						X	X									X		

	COMPANY	WEBSITE	AMPLIFIERS	ANTENNAS	CABLES & CONNECTORS	CERTIFICATION	CONSULTANTS	COMPONENTS	DESIGN / SOFTWARE	EMI RECEIVERS	FILTERS / FERRITE'S	LIGHTNING & SURGE	MEDIA	SEALANTS & ADHESIVES	SHIELDING	SHIELDED ROOMS	SPECTRUM ANALYZERS	TEST EQUIPMENT	TEST EQUIPMENT RENTALS	TEST EQUIPMENT OTHER	TESTING	TESTING LABORATORIES	TRAINING SEMINARS & WORKSHOPS
R	Radiometrics	www.radiomet.com																				X	
	R&B Laboratory, Inc.	www.rblaboratory.com																				X	
	Retlif Testing Laboratories	www.retlif.com																			X	X	X
	RECOM Power GmbH	www.recom-power.com									X										X		
	RIGOL Technologies	www.rigolna.com	X							X							X	X		X			
	R&K Company Limited	www.rk-microwave.com	X							X													
	Rohde & Schwarz GmbH & Co. KG	www.rohde-schwarz.com/de	X	X						X					X	X	X	X					
	Rohde & Schwarz USA, Inc.	www.rohde-schwarz.com	X	X						X					X	X	X	X					
S	Schaffner EMC, Inc.	www.schaffner.com						X			X										X	X	
	Schurter, Inc.	www.schurter.com			X		X	X			X												
	Schwarzbeck Mess-Elektronik	www.schwarzbeck.com		X																			
	Select Fabricators	www.select-fabricators.com													X	X							
	Siglent Technologies	www.siglentna.com																X					
	Signal Hound	www.signalhound.com						X		X							X				X		
	Solar Electronics	www.solar-emc.com		X																			
	Spira Manufacturing Corp.	www.spira-emi.com													X								
	Standex Electronics	www.standexelectronics.com						X															
T	TDK	www.tdk.com						X			X					X				X			
	Tektronix	www.tek.com																X					
	Teledyne LeCroy	www.teledynelecroy.com																X					
	TESEQ Inc.	www.teseq.com																X					
	Test Equity	www.testequity.com/leasing/	X							X							X		X				
	Thurlby Thandar (AIM-TTi)	www.aimtti.com								X							X						
	Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X						X							X						
	TPI	www.rf-consultant.com					X																
	Transient Specialists	www.transientspecialists.com																	X				
	TRSRenTelCo	www.trsrentelco.com/categories/spectrum-analyzers/emc-test-equipment	X	X						X							X	X	X		X		
V	Vectawave Technology	www.vectawave.com	X																				
	V Technical Textiles / Shieldex US	www.vtechtextiles.com													X								
W	Washington Laboratories	www.wll.com				X	X		X			X									X	X	X
	Windfreak Technologies	www.windfreaktech.com																X			X		
	Würth Elektronik eiSos GmbH & Co. Kg	www.we-online.com		X	X			X	X		X	X			X								X
	Wyatt Technical Services	www.wyatt-tech.net					X																X
X	XGR Technologies	www.xgrtec.com													X								

Fair-Rite Products Corp.

History of Ferrite

During the 1930's research on 'soft' ferrites were conducted, primarily in Japan and the Netherlands. However, it was not until 1945 that J. L. Snoek of the Phillips Research Laboratories in the Netherlands succeeded in producing a 'soft' ferrite for commercial applications. Originally manufactured in a few select shapes and sizes, primarily for inductor and antenna applications, 'soft' ferrite has proliferated into countless sizes and shapes for a multitude of uses. Ferrites are used predominately in three areas of electronics: low level applications, power applications, and Electro-Magnetic Interference (EMI) suppression.

History of Fair-Rite Products Corp.

Fair-Rite Products Corp. is a family owned business that was formed as a partnership in 1952. With his partners, Edmund Stanwyck and Jack Webb, Richard Parker created Fair-Rite Products Corp. in Wallkill, New York. Fair-Rite quickly expanded into the rapidly growing EMI suppression market, manufacturing ferrite shield beads.

With locations in New York, Illinois and China, Fair-Rite continues to be on the cutting edge of ferrite technology, expanding its product lines across a broad spectrum of exciting new markets.

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EMI FILTERING 101: UNDERSTANDING THE BASICS

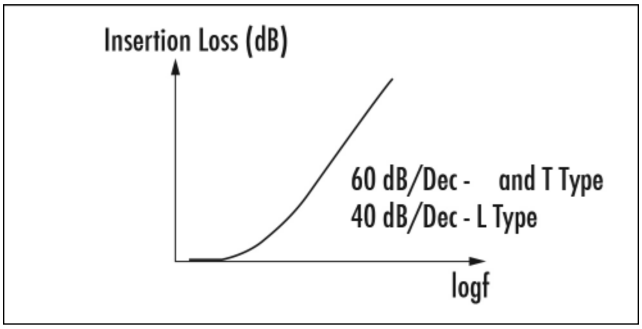
David Armitage
Manager of Engineering, Schaffner EMC, Inc.

INTRODUCTION

To start at the very beginning, what is an *electrical filter*? An electrical filter can be passive, active, analog, or digital. It is a device usually composed of discrete components which can be placed between circuits, networks, or equipment/systems to either emphasize, de-emphasize or control the frequency components of a desired or undesired signal. The term "signal" can be a communication or power type signal. Filters accept an electrical signal at its input and deliver a different or modified signal at its output depending upon the filters internal configuration. The general term filter, of course, can also be used for a device on control and signal type lines. However for this article, we will focus on the AC/Mains EMI (**E**lectro**M**agnetic **I**nterference) power type filter.

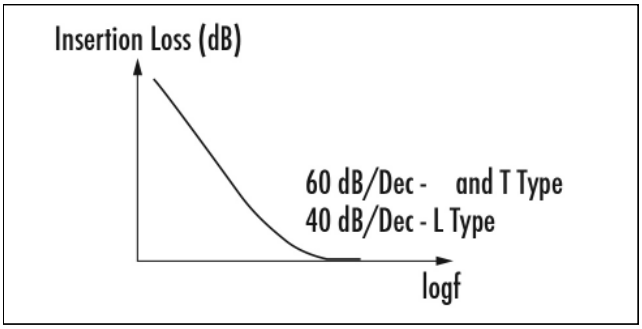
FILTER CLASSIFICATIONS

There are four basic types or classification of general filters. They are:

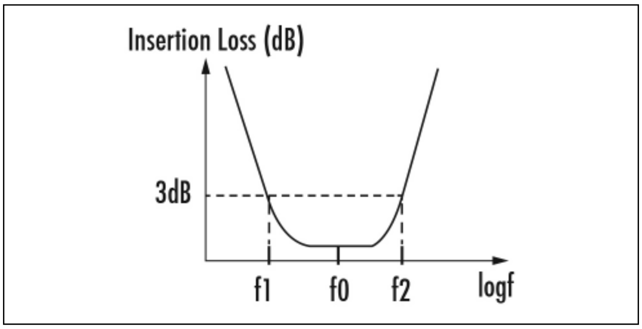


1. Low Pass
Rejects undesired RF energy above a desired cut-off frequency, passing frequencies below this point with little or no insertion loss.

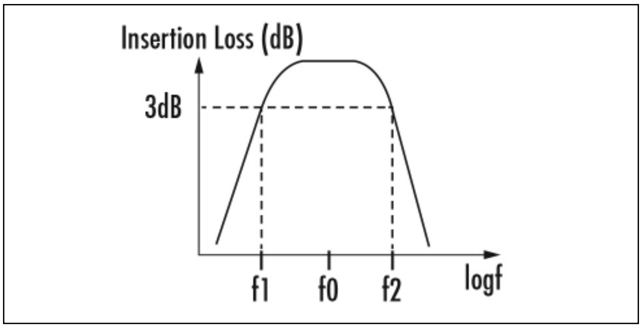
AC line filters are typically of the low pass variety.



2. High Pass
Rejects undesired RF energy below a desired cut-off frequency, passing frequencies above this point with little or no insertion loss.



3. Band Pass
Passes a range of desired frequencies with little or no insertion loss, rejecting frequencies outside this specific range.



4. Band Reject
Rejects a range of frequencies within a particular frequency band of operation while passing all other frequencies outside this band.

WHY DO WE NEED EMI FILTERS?

One reason is that regulatory agency requirements dictate that conducted and radiated emissions be constrained below specified limits, but the unit must also pass immunity/transient requirements. Designers often forget that an EMI filter can assist in meeting immunity and fast transients requirements and radiated emissions as well. Even for military/aerospace equipment, they must be protected from failure due to EMI noise and security requirements may call for filters to protect classified data. Contractual requirements imply or specify filters.

Essentially, an AC power or mains EMI filter is a low pass filter that blocks the flow of "noise" while passing the desired input which can be DC or 50/60/400 Hertz power frequency. An ideal EMI filter will reduce the amplitude of all frequency signals greater than the filter cut-off frequency. The cut-off frequency is the frequency between the signal's passband and the reject bands at 3 dB attenuation below the acceptance line. The measure of a filter's ability to reduce a given signal level is insertion loss or attenuation. A power line or mains EMI filter is placed at the power entry point of the equipment that it is being installed into to prevent noise from exiting **or** entering the equipment.

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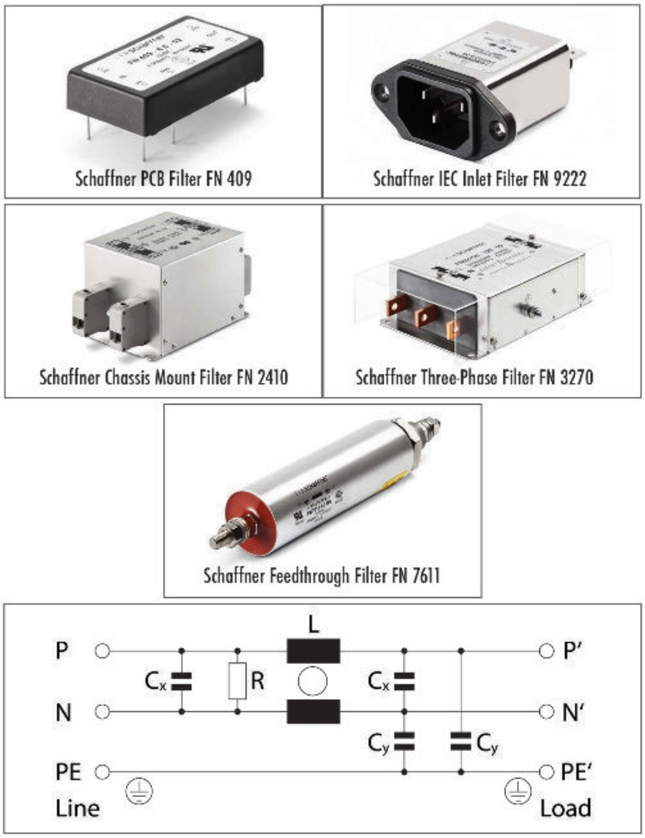


Figure 1. Examples of Various Filter Packages and a Typical Filter Configuration (Courtesy of Schaffner Company)

FILTER CONFIGURATIONS

Essentially, an EMI filter is made up of two basic types of components–capacitors and inductors. The simplest type is called a first-order filter consisting of just a single reactive component. Capacitors shunt noise current away from a load while inductors block or reduce the noise. Generally, these single component filters are not very useful as their attenuation only increases at a rate of 6 dB/octave or 20 dB/decade.

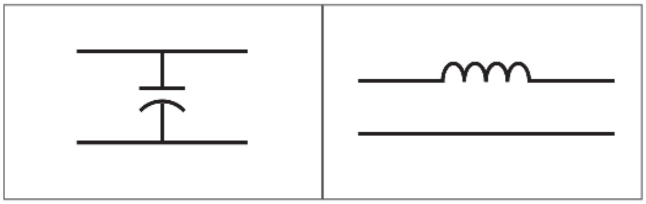


Figure 2. First Order Filters

To achieve greater attenuation, a second or higher-order filter as shown in *Figure 3* consisting of two reactive components or more is required. The value of the inductive or capacitive components is determined by the impedance of the source, load and the highest frequency to be passed (i.e. cutoff frequency). This two-element filter is sometimes referred to as an "L" filter. Filter resonances and ringing must be considered, and involves a design characteristic called damping factor which describes gain and the time response of the filter.

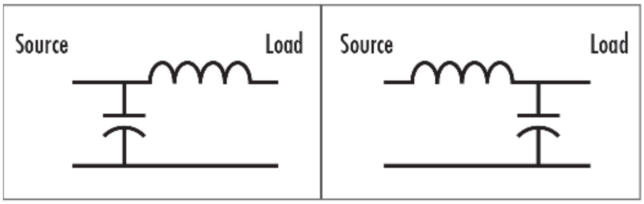


Figure 3. Second Order Filters

A third-order filter, of course, consists of three or more reactive elements as shown in *Figure 4*. These types of filters are sometimes referred to as "pi (π)" or "T" filters. The disadvantage of a larger filter is that physical size increases. The third-order filter is among the most popular topologies of filters used.

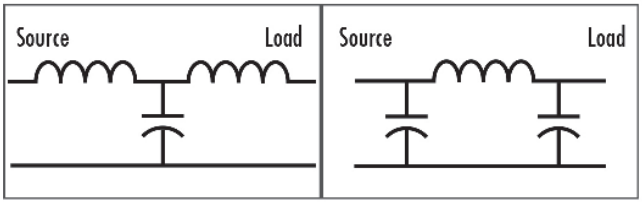


Figure 4. Third Order Filters

HOW TO DETERMINE WHICH CONFIGURATION TO USE

IMPEDANCE MISMATCH

Two different circuit configurations exist for the higher order filters in *Figures 3* and *4*. One aspect of filter design is impedance mismatch. So, which one should the designer use. If the designer has access to computer simulation software, then it can be used to determine the best configuration. However, if a simulation program is not available, then there is a simple "rule of thumb" that can be used to assist the designer. The first filter element nearest the source, or load end, should be selected to provide the highest possible mismatch at EMI frequencies. Typically, this means that if the source or load impedance is low (<100 Ohms), then the first filter element should be an inductive component. Conversely, if the source or load impedance is high (>100 Ohms), the first filter element should be capacitive. This provides the designer an extremely efficient design with the least number of stages or components. Refer to *Figure 5* as a quick, handy guide.

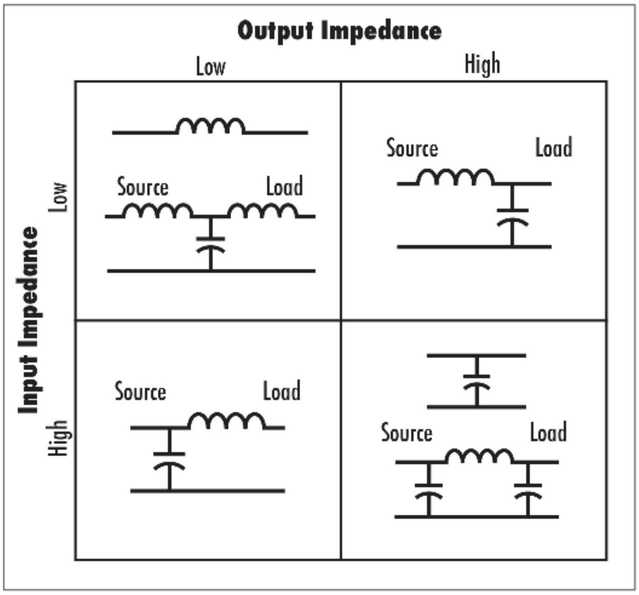


Figure 5. Handy Reference Chart for Impedance Mismatch (Reference 3)

COMMON-MODE CURRENTS VERSUS DIFFERENTIAL-MODE CURRENTS

Filters are not only for conducted emissions, but also help in meeting radiated emissions levels by controlling what propagate from the mains power cable and also helps in immunity issues like induced RF (Radio Frequency) signals and transients like electrical fast transients (EFT). In all circuits both common-mode (CM) and differential-mode (DM) currents are present. There is a significant difference between the two. Given a pair of transmission lines and a return path, one or the other mode will exist, usually both. Differential-mode signals carry data or a signal of interest (information). Common-mode is an undesired side effect from differential-mode transmission and is most troublesome for EMC.

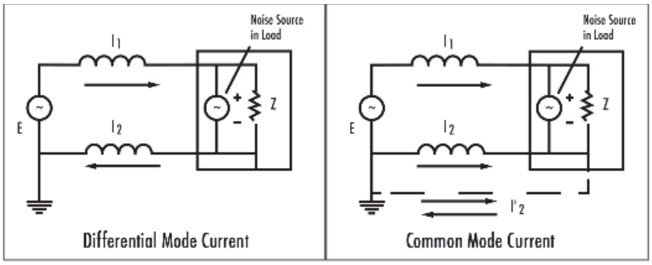


Figure 6. Common Mode and Differential Mode Current Flow (Reference 3)

When using simulation software to predict emissions, differential-mode analysis is usually the form of analysis used. It is impossible to predict radiated emissions based solely on differential-mode (transmission-line) currents. Common-mode currents are the primary source of EMI. If only calculating differential-mode currents, one can severely under-predict anticipated radiated emissions since numerous factors and parasitic parameters are involved in the creation of common-mode currents from differential- mode voltage sources. These parameters usually cannot be easily anticipated and are present in the formation of power surges in the power and return planes during edge switching times.

Differential-mode current is the component of RF energy present on both the signal and return paths that is equal and opposite of each other. If a 180° phase shift is established precisely, RF differential-mode currents will be canceled. Common-mode effects may however, be developed because of ground bounce and power plane fluctuation caused by components drawing current from a power distribution network.

Using differential-mode signaling, a device sends out current that is received by a load. An equal value of return current must be present. These two currents, traveling in opposite directions, represent standard differential-mode operation. Differential-mode filtering involves placing capacitors between lines and/or an inductor in series with either the high or low side of the line. Reference *Figure 7.*

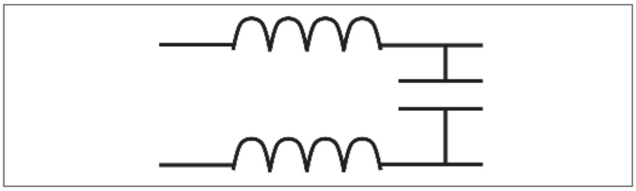


Figure 7. Differential Mode Filtering

Common-mode current is the component of RF energy that is present on both signal and return paths, often in common phase to each other. The measured RF field due to common- mode currents will be the sum of the currents that exist in both the signal and return trace. This summation could be substantial. Common-mode currents are generated by any imbalance in the circuit. Radiated emissions are the result of such imbalance.

Common-mode filtering involves capacitors to ground and/ or a common mode inductor in series with both side of the line or lines. A common-mode inductor does not affect differential- mode currents except for whatever imperfect coupling exists (i.e., leakage inductance). It is best to split the inductor evenly on both sides of the transmission line to maintain balance in the circuit. This is important for both common-mode and common-mode rejection ratio of the circuit. Mutual inductance will maximize the impedance to common-mode noise. Reference *Figure 8*.

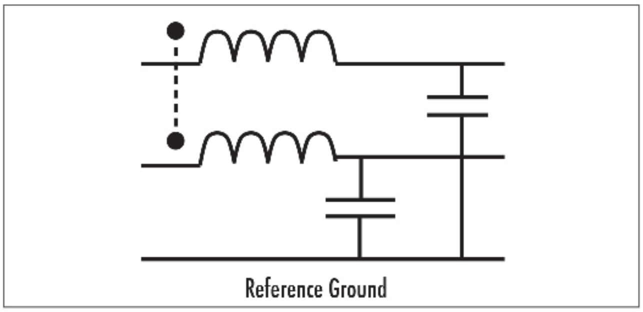


Figure 8. Common Mode Filtering

Because these are two different noise current modes of propagation, it is important to determine which type of noise current exists so that proper filtering can be implemented for maximum efficiency and cost. This is important for both common-mode and common-mode rejection ratio of the circuit. One can see that most typical filter configurations contains both common mode and differential mode filtering as shown in *Figure 6*.

LAYOUT HINTS

We will discuss the advantages and disadvantages of open printed circuit board (PCB) constructed filters versus filters in a metal can shield. There are two types of noise coupling (radiated and conducted). Radiated and conducted noise has a tendency for mutual transformation through a wire or trace by a process termed crosstalk. Crosstalk is observed where there are many wires or traces located in close proximity. Therefore, even if conducted noise is only a problem at one location, you cannot completely ignore the possibility of radiated coupling to another location. So, if a filter circuit is incorporated on a printed circuit board, then proper design and layout techniques must be done such as avoiding routing of traces parallel to each other, providing sufficient separation between traces to minimize inductive coupling or routing adjacent layers (microstrip or stripline) orthogonally to each other to prevent noise coupling between traces. See *Figure 9*. However, with the use of a metal shield, crosstalk/ radiated noise coupling crosstalk is controlled.

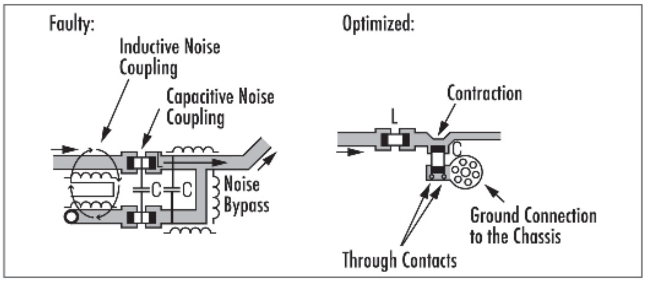


Figure 9. Proper Layout avoids parasitic couplings, which reduce filter performance (Figure, courtesy Würth Electronik)

Other things to consider are the high frequency parasitic and resonance effects. Real inductors and capacitors fall short in performance when compared to theoretical models. Some of this is due to the actual inductor and capacitor elements themselves (e.g. lead inductance, winding capacitance, resistance effects, etc.) while others are caused by the circuit board layout, packaging or wiring. Changing to a different EMI filter can affect the radiated emission characteristic because of these parasitic and resonance effects. So, when you change from a filter that passes testing, one must re-test not only for conducted emissions, but also re-test for radiated emission as the high frequency effects may not be the same between the two filters especially since most commercial filters are never tested beyond 30 MHz.

The filter should be placed directly at the exit point of the wire from the product. Good effective separation is essential. The separation prevents coupling of noise back into the input wires circumventing and nullifying the effects of the filter. This would be an excellent choice for an AC inlet mounted EMI filter or "power entry module (filter)".

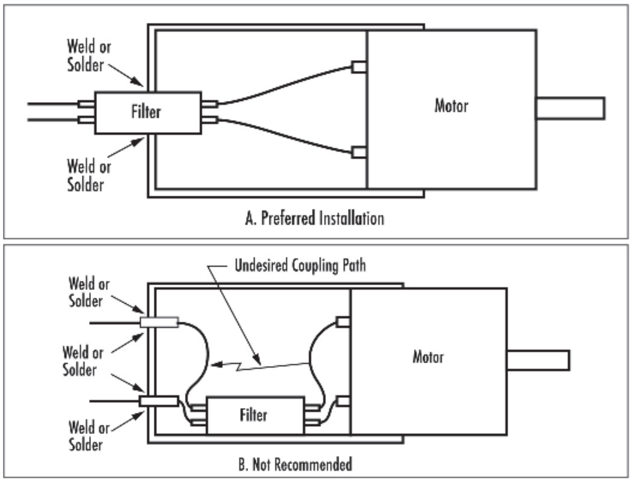
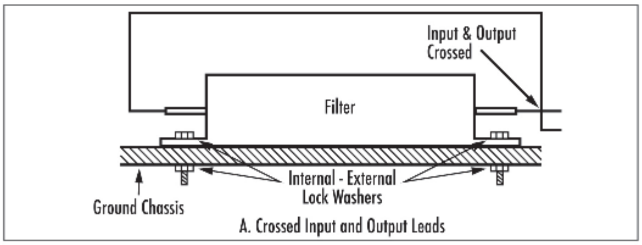
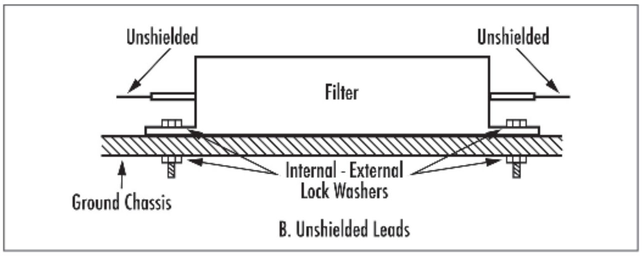


Figure 10. Lead Isolation (Reference 4)

To go along with the above item, avoid improper lead routing. Do not bundle or physically cross filter input and output wires. Again, with the leads physically crossing each other, it nullifies the effectiveness of the filter due crosstalk between wires as was discussed earlier.



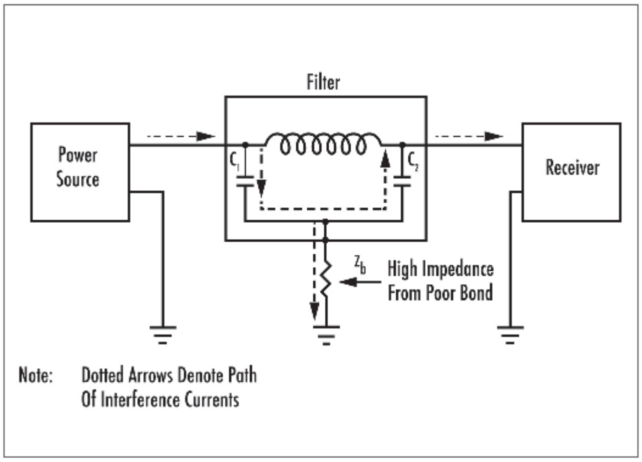
A. Crossed Input and Output Leads



B. Unshielded Leads

Figure 11. Separation of Input and Output Leads (Reference 4)

Provide a low impedance ground for the filter. It is imperative that the EMI filter mounting surface be clean and unpainted (e.g. conductive surface). Good filter grounding is an important factor for common mode filtering performance of the filter. A poor filter bond limits the filtering to chassis by adding series impedance, thus changing resonance effects and filtering capability of the common mode capacitors. See *Figure 12*.



Note: Dotted Arrows Denote Path Of Interference Currents

Figure 12. Effect of Poor Filter Bonding (Reference 4)

FINAL THOUGHT

Commercial filters are available for various applications with different insertion loss. There are other features to consider like Earth leakage, ambient temperature and over load characteristics. Before going to the test lab, procure different filter configurations from a commercial filter company to have on hand during testing. If the original one doesn't pass, then change over to an alternate one. Having them on hand will shorten the development time and save on test lab cost due to multiple revisits.

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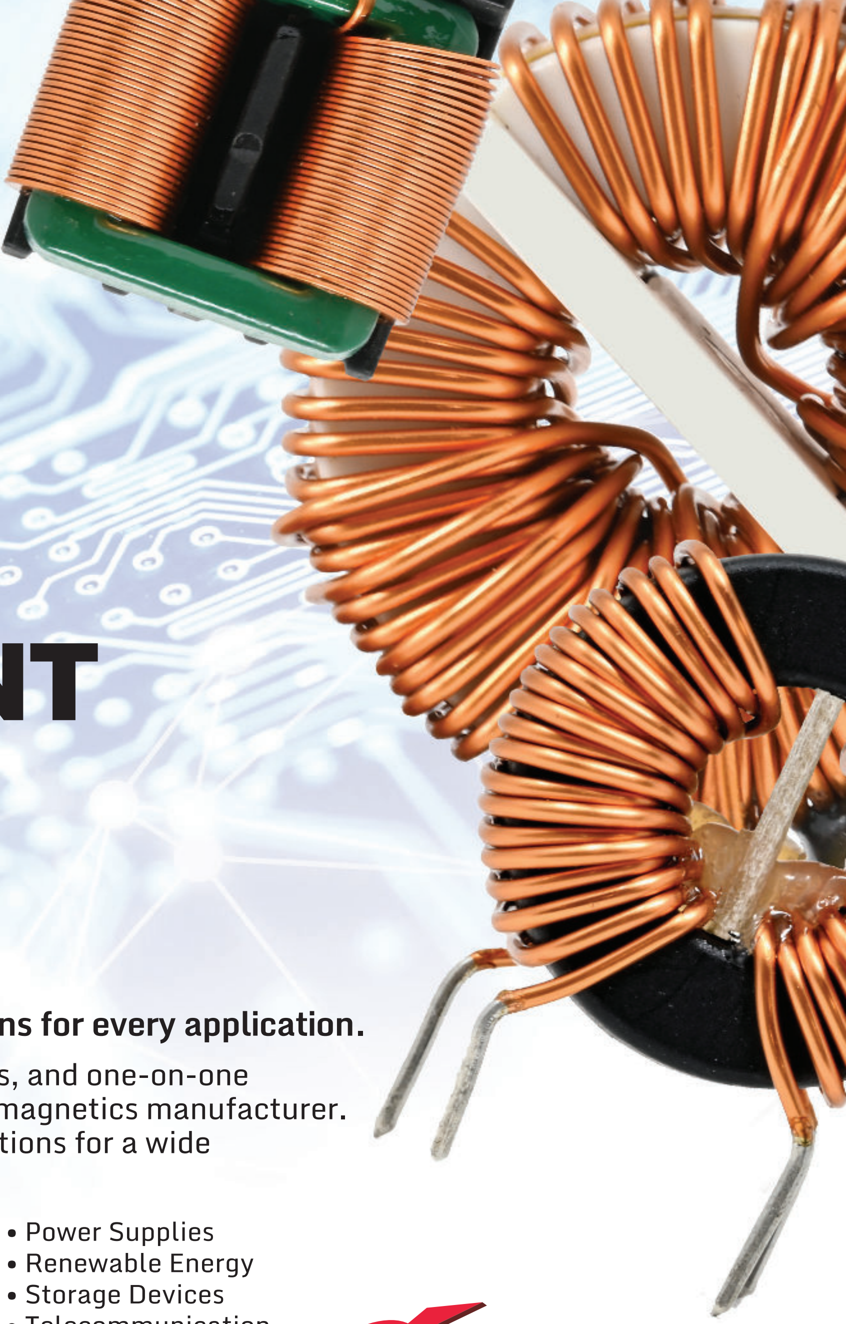

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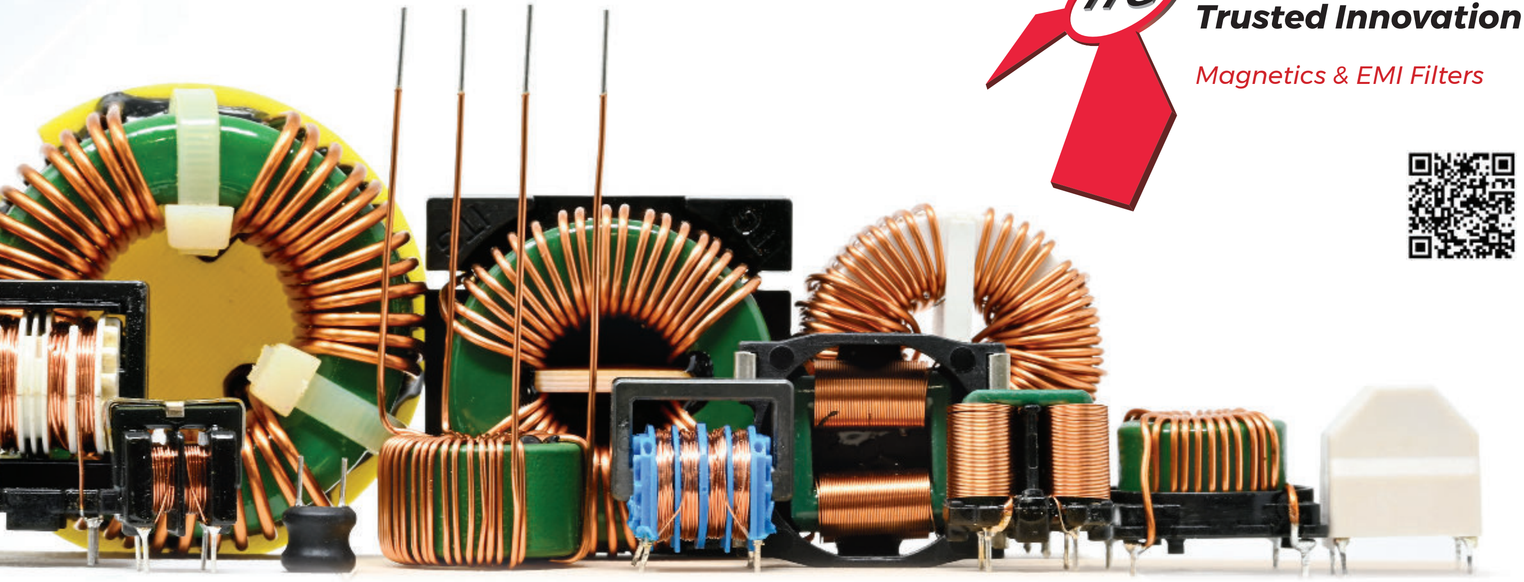

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EMC FOCUS—POWER SUPPLIES

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Electromagnetic Interference (EMI) is always a potential problem with switched-mode power supplies, both AC-DC and DC-DC converters. Modern designs can perform well for emissions and immunity but external connections must still be correct for best performance. Sometimes, extra filtering is necessary to meet specific application requirements. However, incorrect filter designs can actually make EMI worse. This article gives some guidelines for achieving the best conducted EMI performance from AC-DC and DC-DC converters including when using external filters.

Electromagnetic Compatibility (EMC) of equipment is a term covering conducted and radiated emissions, susceptibility to conducted voltage disturbances and radiated fields, and immunity to Electrostatic Discharge (ESD). Distortion of AC line current by AC-DC converters is also included. In Europe, the EMC directive 2014/30/EU mandates that end-equipment meets harmonised standards. In this article we look at conducted emissions from switched-mode AC-DC and DC-DC converters and how performance can be affected by filter components.

HIGH EFFICIENCY CAN RESULT IN HIGH NOISE

Engineers are familiar with the benefits of switched-mode converters - high efficiency with small size and weight, but many will also have struggled with the electrical noise they produce. Modern converter designs have however improved with better components and topologies that have inherently low noise, such as resonant types. Techniques such as 'frequency dithering' also help by reducing the energy of emissions in a given measurement bandwidth. The origin of the noise is the fast switching of semiconductors, with waveform rise and fall times measured in nanoseconds, necessary for high efficiency. The high dV/dt and di/dt levels though cannot be completely contained within the converter and can appear as voltage or current noise 'spikes', conducted along input or output lines. From Fourier analysis, the envelope of emissions from a generic switching waveform is shown in *Figure 1*, illustrating that as rise/fall time Tr, Tf decreases, the bandwidth of emissions increases with an overall amplitude affected by the duty cycle of the waveform Ton/Tp [1].

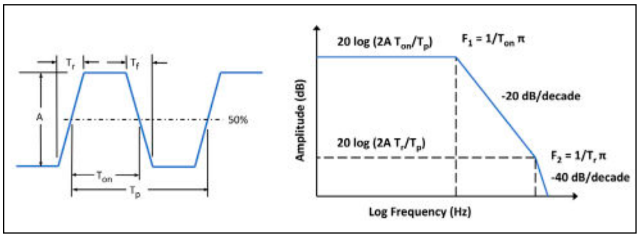


Figure1: Envelope of emissions from a switching waveform

NOISE COMPONENTS

Conducted noise is of two types, Differential Mode (DM) and Common Mode (CM), which are usually present together at some level. DM noise is measured as a voltage between a power line and its return. CM noise is measured between both power lines and system ground and is normally recorded as a voltage across a defined impedance. This is because power converters tend to operate as a current source for CM noise at high frequencies. *Figure 2* shows the two types diagrammatically.

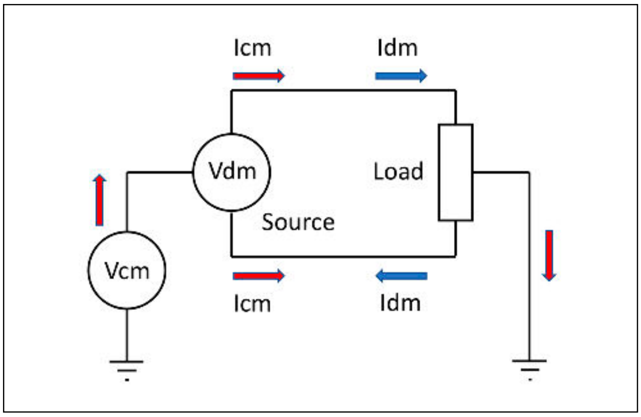


Figure 2: Types of noise that can be present

DM noise is easily measured with an oscilloscope or analyser but CM requires use of a standard termination network, a Line Impedance Stabilisation Network (LISN).

This includes the defined termination impedance and filtering necessary to isolate any effect from the upstream power source. The LISN is defined by CISPR standards, typically CISPR 22 for IT equipment, and is intended for AC-DC converter noise measurements but is often also used with DC-DCs. The LISN outputs a weighted combination of DM and CM noise so that even with no CM noise present, half of the amplitude of the DM noise is seen. This means that attenuation of both DM and CM noise types is necessary to meet the limit lines of CISPR 22 standard and its derivative EN 55022.

DC-DC CONVERTER INPUT FILTERS

There is no common standard for noise emissions from DC-DC converters as they are normally embedded in systems which overall must meet EMC regulations. Board-mount DC-DC manufacturers incorporate at least a parallel input capacitor in the product package and the resulting noise levels are often perfectly acceptable. Occasionally lower levels are needed in the application and the manufacturer will typically recommend an L-C filter added externally to reduce DM noise, L and C1 in *Figure 3*.

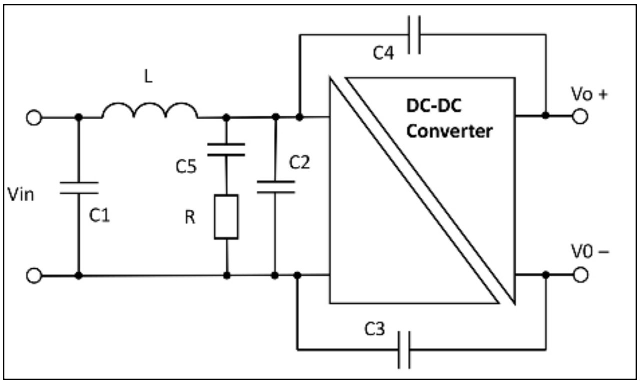
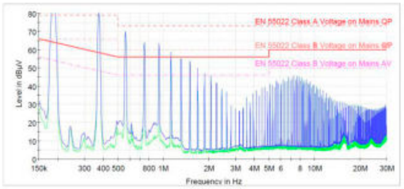
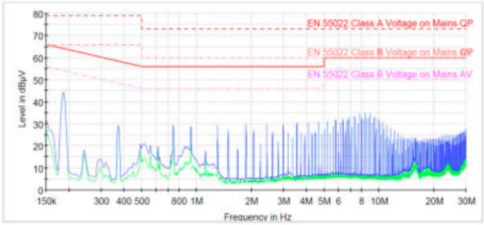


Figure 3: Filter components around a DC-DC converter

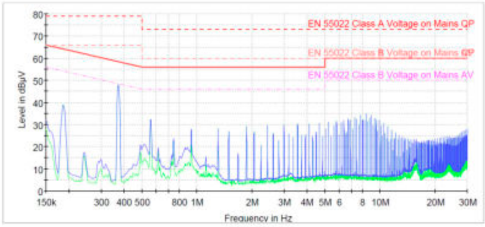
It might be tempting to add large value components thinking that this will give lowest noise but this can be counterproductive: large inductance values can have high resistance, producing voltage drop and power dissipation. Magnetic saturation with high inductance can be a problem and self-resonance may be low resulting in ringing and potential overvoltage at the DC-DC input. The effect can even make the measured noise spectrum worse. *Figure 4* shows the noise of a sample converter with no filter, just L and C1 fitted and then with C2 added, giving higher spectrum peaks.



Without Filter



C1 and L implemented



C1, L and C2 implemented

Figure 4: Extra filter components can actually make EMI worse

Another problem that can occur is instability of the converter control loop. This occurs when the output impedance of the filter, at its resonant frequency, is close to the input impedance of the DC-DC (which is incrementally negative - input current goes down as input voltage goes up). Middlebrook [2] investigated the effect and concluded that the output impedance of the input filter must be much less than the input impedance of the converter. This can be achieved with an extra damping circuit R and C5 in *Figure 3*. C5 is >>5 x C2, which may be internal to the DC-DC and R is = SQRT(L/C2). Alternatively, a lossy electrolytic capacitor has a similar effect but its capacitance and loss resistance are not as well controlled.

CM noise is often not an issue with DC-DC converters as both input and output may be grounded. If the input is floating, capacitors C3 and C4 can be added to reduce CM noise levels. However, there may be a limit to the capacitance allowable if the converter is forming part of a safety barrier to high voltage AC. C3 and C4 values will then set the maximum AC leakage current that can flow and must be 'Y' safety types with the right transient voltage rating. In the extreme, two capacitors may be needed in series for the most sensitive applications such as patient-connect medical in case one capacitor fails short.

In some applications, voltage transient suppression may be needed at the DC-DC converter input. Some standards for transient levels are established, for example in the automotive and rail industries, but in other application areas the levels are not well defined. A recent euronorn, EN IEC 61204-3:2018 'Low voltage switch mode power supplies -Part 3: Electromagnetic Compatibility', is not widely accepted yet but does define some overvoltages for different application categories of DC-DC converters.

AC-DC CONVERTER INPUT FILTERS

Actually, the situation with AC-DC converters is simpler. For high power products, there is usually a direct connection to AC mains. The converter therefore must meet the EMC directive so will have a filter fitted internally, suitable for the intended application; industrial, IT, medical, test equipment etc. However, there is a large market for board-mounted AC-DC converters that connect to AC mains through internal tracks and wiring. The converter will often have internal filtering for the highest EMC emissions standards, (Class B) such as the RECOM RAC20-K series but sometimes products are offered meeting the lower, class A limit line. This is a cost saving and may be sufficient, especially if the converter is supplied from AC which is already filtered elsewhere in the system. Manufacturers will suggest external filter components which will enable these parts to meet the class B limit, typically an 'X' rated capacitor across the AC line and 'Y' capacitors from both AC lines to ground. The RECOM RAC03-GA series is an example.

For these components to be effective, they should be placed very close to the converter with a direct, low impedance connection to ground. Remember that there are limits to values allowed: the 'X' capacitor for example must discharge to a safe voltage typically within one second after disconnection of the AC mains and may need a parallel discharge resistor, suitably rated. As mentioned for DC-DC converters, the 'Y' capacitors must not allow a dangerous leakage current to flow if the system ground becomes disconnected. The maximum current allowed can be as low as 10µA for the most sensitive medical applications, limiting capacitor values to around 100pF. Other applications allow much higher leakage currents, 3.5mA for example in IT areas, allowing higher 'Y' capacitor values.

System EMC performance cannot be easily predicted from the performance of individual components so compliant board-mount AC-DC converters, for example, cannot guarantee a system 'pass'. However, manufacturers such as RECOM [3] with their wide range of system and board-mount power supply products offer the use of their in-house EMC test facilities to help their customers with pre-compliance equipment testing.

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EMC 101

AR, Souderton, Pennsylvania, USA

The purpose of this document is to give background information to the reader about the basics of EMC (Electromagnetic Compatibility), EMI (Electromagnetic Interference), and how it relates to installations in the real world.

As manufacturers across the world continue to develop, innovate, and expand new technologies and products, one important facet of the design and implementation of these new technologies and products is the compliance to EMC regulations and standards for different economies and countries. Each of the standards define the compliance testing and requirements for product families within specific industries, and typically describe how to test those products.

DEFINITIONS:

EMC – Electromagnetic Compatibility – The ability of a product to operate (compatibility) within different electromagnetic environments.

EMI – Electromagnetic Interference – The amount of electromagnetic emissions (interference), either radiated or conducted, coming from a product.

EUT – Equipment Under Test

CE – Conducted Emissions – A measurement of the interference emitted from a product, typically measured on power input lines or telecommunications ports, with measurements and limits typically expressed in terms of voltage (dBμV) or current (dBμA).

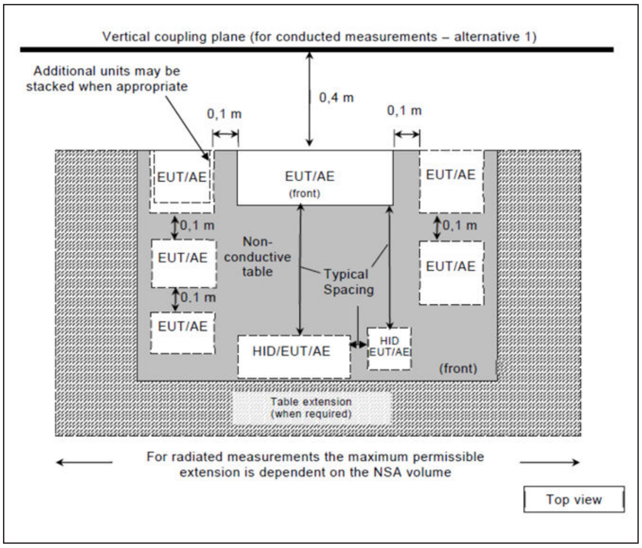

Figure 1: CISPR 32 Conducted Emissions Test Setup

RE – Radiated Emissions – A measurement of the over-the-air interference emitted from a product, from both the enclosure (often called the enclosure-port) or the cabling. Limits typically expressed in terms of Volts per meter (dBμV/m) for electric field, or Amperes per meter (dBμA/m).

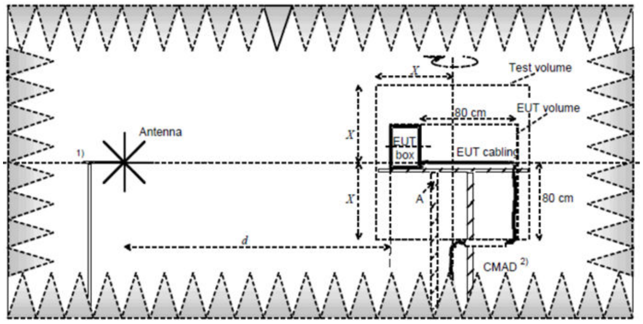

Figure 2: CISPR Radiated Emissions Test Setup

CS or CI – Conducted Susceptibility or Conducted Immunity – The application of a test signal, often imparted onto interfacing cables to EUTs via BCI, CND, EM Clamp, or other means, to observe that the EUT operates acceptably throughout the application of the test.

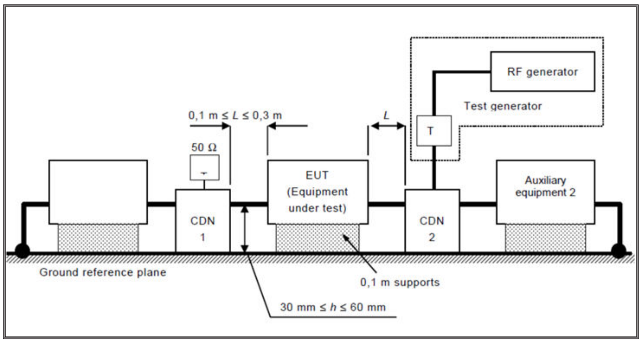

Figure 3: Conducted Immunity or Susceptibility Test Setup

RS or RI – Radiated Susceptibility or Radiated Immunity – The application of a test signal, applied with a test antenna over-the-air, to observe that the EUT operates acceptably throughout the application of the test.

Test Method – The specific test performed. Each test method typically has its own title, such as CS114, RE102, or IEC 61000-4-6, but will fall within the categories of CE, RE, CI, or RI.

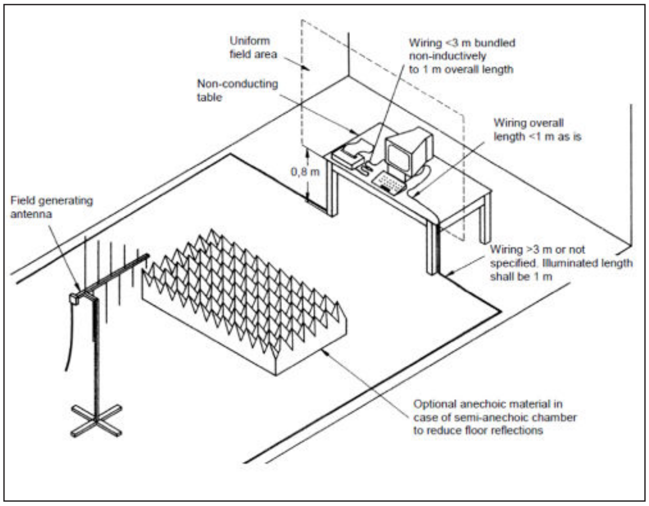

Figure 4: Radiated Immunity or Susceptibility Test Setup

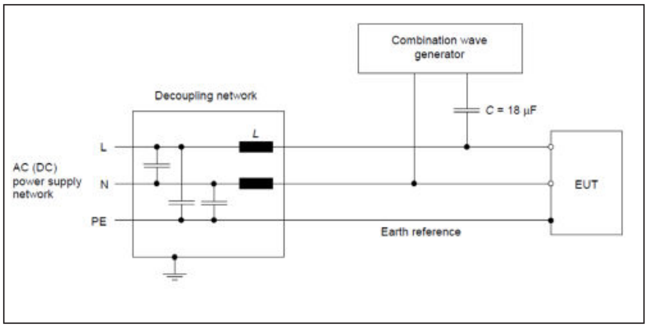

Figure 5: Transient Testing per IEC 61000-4-5, Surge Immunity, Test Setup

Test Standard – A document which defines the requirements, compliance criteria, and limits for a particular product family or industry. For a closer look at test standards, refer to Amplifier Research Application Note #67, EMC Standards Overview. The above definitions of CE, RE, CI, and RI describe the four (4) types of compliance tests performed for pieces of equipment. Within each category, there are two basic phenomena: Continuous and Transient Phenomena.

WHAT'S THE DIFFERENCE BETWEEN CONTINUOUS AND TRANSIENT IN THE WORLD OF EMC TESTING?

Continuous test methods typically involve testing within a defined frequency range (for example, 150 kHz to 80 MHz for Conducted Immunity and 80 MHz to 6 GHz for Radiated Immunity). The purpose of testing for continuous phenomena is to ensure that a device or product will operate as intended when a signal is ever-present within its installed environment, or, conversely, not emit a continuous signal that will interfere with other devices environment. For example, a product should always continue to operate when placed within a wireless transmitter's vicinity, be it Bluetooth, Wi-Fi, or an RFID reader.

Transient test methods involve testing which simulates phenomena in the real world that are not always present, such as electrostatic discharge (simulating an electrostatically charged human body touching the EUT), surge (simulating a lightning strike of the installed building or location), and electrical-fast transients (simulating load switching of relays). The waveforms defined by the transient test methods are specific to rise time, duration, repetition rate, and source impedance.

During transient testing, an EUT upset or malfunction may be permitted, provided it can return to the previous state or operating mode without user intervention. The compliance criteria for this is dependent on the test standard being tested.

WHAT'S THE PURPOSE OF EMC TESTING AND COMPLIANCE?

First, there are the legal issues. If regulatory requirements aren't met, then a manufacturer cannot legally sell the product in the country of intention. If a product is sold that doesn't meet the requirements, the product will likely be removed from the marketplace, fines may be imposed on the manufacturer, and prison time for owners and employees of the manufacturer is a possibility.

Second, EMC testing can and will reveal potential design flaws within a product, where the manufacturer can make a product better, and not just do the bare minimum to meet the requirements. This can alleviate the need for costly recalls and design changes.

WHAT'S THE MOST IMPORTANT ASPECT OF EMC TESTING AND COMPLIANCE?

EMC is a vast and complex worldwide industry which involves regulatory requirements, different economies, documentation, laboratories, equipment manufacturers, test standards, and test methods. There's one word that nearly every aspect comes back to, which is the most important word in the EMC dictionary:

IMPEDANCE

Impedance, or resistance, is where the applied limit, test level, waveform, and EUT response is derived. Impedance of a cable will define the amount of RF current that is imparted into an EUT, and the impedance of the shield of the cable will define how much of that RF current is shunted to ground. The impedance of an antenna will define its effectivity as a radiator, and the impedance of a ground connection, whether it be a shield, a ground strap, or a ground wire, will help define its effectiveness in either shielding for emissions or shunting RF current to ground.

OKAY, SO NOW I THINK HAVE THE BASIC UNDERSTANDING OF WHAT EMC IS, BUT NOW WHAT DO I DO?

Let's say that your company has a product that utilizes digital electronics. Depending on where you intend to sell that product, you'll need to meet regulatory requirements to ensure that the product isn't going to interfere with other products, or that other products aren't going to interfere with it. In the United States, the FCC is the government authority that enforces regulations, and the only thing that the US regulates is emissions. For most products, the regulatory requirements are found in Title 47 of the Federal Register under Part 15. If you need to sell into Europe, then you'll need to investigate testing under the EMC Directive (2014/30/EU) for compliance.

I HAVE A PRODUCT THAT I WANT TO SELL IN BOTH THE US AND IN EUROPE. WHAT'S MY NEXT STEP?

You'll have to have your product tested, of course. A testing laboratory should be able to help you define what your requirements are, depending on your product type and where you plan on selling it. Once you have the requirements defined, it's time to get to the test laboratory.

A test laboratory's services can be used in a few different ways. If you need to see how close you are to compliance, book some evaluation time to run through a few different tests to see where your product stands. Typically, evaluation of the radiated and conducted emissions as well as radiated immunity test methods is where many manufacturers start.

Many companies/manufacturers develop their own in-house testing laboratories to streamline the test phase of product development. This option enables a manufacturer to mitigate problems as they arise, and not be at the mercy of a test lab schedule.

Depending on which test laboratory you choose, or if you're using an internal or captive laboratory, some regulatory or approving bodies require the test laboratory to be accredited to ISO 17025 before compliance can be declared.

If you've done some pre-compliance testing, which can be done on an engineering bench with a small amount of equipment, and are ready for the full-bore test program, contact the test lab for a quotation to test the product for compliance. Once you have a test date, you're all set.

CONCLUSION

The above gives a very basic description of EMC, what it is, and why it's important. The end goal is to ensure that products in the marketplace do not interfere with each other and are immune to interference from other products (within reason). If you have additional questions or need guidance for your requirements, do not hesitate to contact AR's applications engineers at 800-933-8181.

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5 STEPS TO SELECTING THE RIGHT RF POWER AMPLIFIER

Jason Kovatch
Sr. Developmeant Engineer
AR, Souderton, Pennsylvania, USA

You need an RF power amplifier. You have measured the power of your signal and it is not enough. You may even have decided on a power level in Watts that you think will meet your needs. Are you ready to shop for an amplifier of that wattage? With so many variations in price, size, and efficiency for amplifiers that are all rated at the same number of Watts many RF amplifier purchasers are unhappy with their selection. Some of the unfortunate results of amplifier selection by Watts include: unacceptable distortion or interference, insufficient gain, premature amplifier failure, and wasted money. Following these 5 steps will help you avoid these mistakes.

Step 1 - Know Your Signal
Step 2 - Do the Math
Step 3 - Window Shopping
Step 4 - Compare Apples to Apples
Step 5 - Shopping for Bells and Whistles

STEP 1 – KNOW YOUR SIGNAL

You need to know 2 things about your signal: what type of modulation is on the signal and the actual Peak power of your signal to be amplified. Knowing the modulation is the most important as it defines broad variations in amplifiers that will provide acceptable performance. Knowing the Peak power of your signal will allow you calculate your gain and/or power requirements, as shown in later steps.

SIGNAL MODULATION AND POWER- CW, SSB, FM, AND PM ARE EASY

To avoid distortion, amplifiers need to be able to faithfully process your signal's peak power. No matter what the modulation type is, you need to know the Peak power.

Fortunately, for many modulation types Average power is the same as Peak power: CW, SSB (single tone and voice), FM, and Phase Modulation all have Average equal to Peak power. The power in these RF carriers is relatively easy to measure with an Average power meter, a Spectrum Analyzer, or an RF Wattmeter. Many RF amplifiers are rated for CW power, so that spec will apply for SSB (single tone and voice), FM, and Phase Modulated signals as well. For SSB, since the carrier is suppressed, the significant power is all in the sideband carrier.

WATCH OUT FOR AM MODULATION

AM Peak power depends on the percentage of modulation, but you may need to allow for 100% modulation, which creates signal peaks of 4x the un-modulated carrier, or +6dB. That means that you would need a 400W amp to faithfully AM modulate a 100W CW signal. If you have less power available, or "headroom", your amplifier will be operating in compression, which will distort the signal by "clipping" or cutting off the peaks of the waveform. Although some distortion may by tolerable for speech communication, since AM communications are subject to a variety of other impairments, you should specify your RF amplifier to produce the minimum AM distortion possible. AM voice communications usually use modulation depth in the range of 60-80%. Specifying performance at 90% modulation will provide a safe margin for most AM communications.

AM Peak Power (dBm) = CW Power (dBm) + 6db (100% modulation)
AM Peak Power (Watts) = CW Power (Watts) x 4 (100% modulation)

A 100W amplifier will begin to clip a 100W carrier as soon as any AM modulation is applied. Clipping is a form of distortion that causes more problems than just reducing signal "readability". Clipping also causes increased harmonic products in the form of carriers of substantial power, which can cause interference far off-frequency.

AM average power is not the same as CW average power, as it varies with the modulation depth. The average power increases with modulation depth. For sine wave modulation, the relationship is as follows:

Modulation Index (M) = Modulation Depth / 100
AM Average Power Increase = $(1 + M^2 / 2)$
AM Average Power Increase in dB = $10 \log_{10} (1 + M^2 / 2)$

Example: For a 100 WCW with 70% Modulation:
AM Average Power Increase = $(1 + 0.70^2 / 2)$
AM Average Power Increase = (1 + .245)
AM Average Power Increase (ratio) = 1.245

AM Average Power Increase in dB = 10 log10 (1 + M2 / 2)
(Continued from the example above)
AM Average Power Increase dB = $10 \log_{10} (1.245)$
AM Average Power Increase dB = 0.95

To calculate the Peak power required when you know your AM Modulation Depth or Index:

AM Peak Power (Watts) = $(M + 1)^2$ x CW Power

Example: For a 3WCW signal with 80% Modulation Depth:
Peak Power (W) = $(0.8 + 1)^2$ x 3 WCW
Peak Power (W) = $(1.8)^2$ x 3 WCW
Peak Power = 9.72 Watts

Example: For a 100 WCW signal with 90% Modulation Depth:
Peak Power (W) = $(0.9 + 1)^2$ x 100 WCW
Peak Power (W) = $(1.9)^2$ x 100 WCW
Peak Power = 361 Watts

MULTI-TONE OR MULTI-CARRIER SIGNALS CAN BE A BIG SURPRISE

If your signal has multiple discrete carriers it will require more power to faithfully amplify than you probably think. You cannot simply add the individual powers. The Peak power required for 100% fidelity is equal to the individual carrier Peak power times the square of the number of carriers. That is because the Peak Power is equal to E^2/R. In this formula R is the load, so the voltages across the load must be squared. That means if you have two carriers with a Peak Power of 1W each, it will require a 4W amplifier to avoid signal compression. If you have 10 carriers with 1W Peak Power each it will take a 100W class A amplifier to avoid compression! That may be overkill for your application, as your modulation may not require such very low distortion.

For a multicarrier signal with equal amplitude carriers:
Peak Power (Watts) = (number of carriers)2 x Peak Power (W) of a single signal

If your signal contains carriers with varying power levels or modulation types, you can't go wrong by taking the square of the number or carriers and multiplying it by the highest single Peak Power signal expected.

Once you calculate the Peak Power you need, the surprisingly high wattage may force you to consider economizing. Before you begin dropping the Peak Power wattage number and shop for lower power amplifiers, bump the amplifier class down to from A to AB. That will provide your required Peak Power number with typically a modest amount of distortion and higher efficiency at lower cost per Watt.

COMPLEX MODULATION PEAK POWER IS A LITTLE MORE COMPLEX

If your signal is modulated by complex (simultaneous phase and amplitude) modulation you will need to resort to specialized means of measurement. If you have a peak power meter, and you are sure no other significant contributions to the signal power are present, it should provide a valid peak measurement. Checking with a spectrum analyzer is always prudent to be sure of what a broadband power sensor is "seeing". Lacking a peak power meter, a spectrum analyzer that has a peak detector may be used. Lastly, try a peak search marker on a sample detector trace set to the Max Hold function.

You can estimate Peak Power from an Average power measurement based on your signal format Peak-to-Average ratio (PAR) or Crest Factor. For example, 64QAM has a PAR value of about 3.7dB. PAR actually uses the RMS value, not average, so add 1.5dB to the average power to get RMS power. For a 64QAM signal with 0 dBm average power:

0dBm average + 1.5dB ≅ 1.5dBm RMS
1.5dBm RMS + 3.7dB PAR ≅ 5.2dBm Peak

Modulation Format	Approx. PAR (dB) Without CFR	Approx. PAR (dB) With CFR
64QAM	3.7	N/A
8VSB	6.5-8.1	4-6
W-CDMA (DL)	10.6	2.2-6.5
WIMAX/OFDM/WLAN	12-13	6-7

These higher PAR levels translate to higher power being needed in an amplifier. That can be seen as inefficiency, as the heavy lifting is being done at lower power levels, or as a reasonable cost of increasing the density of the data. Crest Factor Reduction (CFR) schemes that pre-clip the signal can reduce the PAR for some types of modulation, but even so, complex modulated signals will still degrade slowly over a wide power range as the signal peaks are increasingly clipped in the amplifier (see **fig. 1**). This causes progressively increasing digital errors and also pushes energy into adjacent channels, creating "noise". It is important to remember that PAR for complex-waveform signals can vary with the data payload sent, so try to test your system with a worst-case data set. Pseudo-noise (PN) data produced by a signal generator may not represent your worst- case signal.

SO WHAT IF THE AMPLIFIER RUNS OUT OF HEADROOM?

Running an amplifier out of the linear range doesn't just mean you get less power out. It can create big problems:

1. **You can damage the amplifier.** Power amps typically specify a P_1 level to represent a safe power output level (see **Step 4** for a brief discussion about P_1). It is good practice to make sure your Peak signal levels stay under the P_1 level to avoid over-driving the amplifier. Some of the excess power that can not be translated into the output waveform can appear on the output transistors as heat. Typical destructive levels for these expensive devices are about P_6 or P_7, only 5-6 dB above P_1. Add attenuation to the amplifier input as necessary to keep under P_1 levels. Many AR Modular RF amplifier designs offer over-drive protection in the form of an Automatic Limiter Circuit (ALC) to prevent accidental over-drive levels. Amplifiers employing newer Gallium-Nitride (GaN) devices are more damage-resistant than the LDMOS devices that preceded them.

2. **You can ruin your signal.** As your signal peaks cannot be reproduced with the same gain as the lower level signals, they are distorted. This can mean the amplifier is useless at your desired power level, and must be used with lower gain or drive levels and less power out. In general, you must adjust the input level to reduce the output power, or get a bigger amp. Many AR Modular RF models offer wide-range gain controls that help with fixed power levels.

3. **You can make other problems.** The power that is missing from your distorted signal is appearing somewhere else- as interference out of your frequency channel or as harmonics way off-frequency. Complex-modulated signals can create interference in adjacent channels. Harmonics are especially a problem with broadband amplifiers that amplify the 2nd or 3rd harmonic of the lower frequencies covered. Since no input filters can be employed, a conservative design with lots of headroom is needed. Output filters can fix harmonics but can dissipate a lot of heat at high power, and need to be well designed mechanically to be able to transfer the heat to a sink.

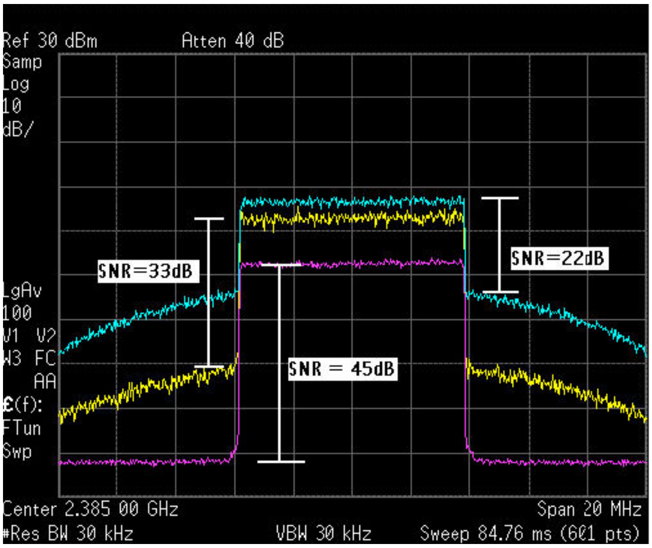


Fig.1

Figure 1 shows an OFDM signal degrading in an amplifier as the Peak power approaches and crosses over the P_1 compression point. The lowest trace is an uncompressed signal with better than a 45dB signal-to-noise ratio (SNR). The middle Trace 2 shows the input signal 10dB higher than for Trace 1, with signal peaks just touching the P_1 point. While the gain across the data channel has increased by 10dB, Intermodulation distortion has created “shoulders” of noise, reducing the SNR to 33dB. Increasing the drive by only 5dB in Trace 3 shows that the power in the adjacent channels has increased by 16dB, and SNR has been reduced to about 22dB. Your specific application will determine what level of SNR is required or can be tolerated.

COMPLEX MODULATION NEEDS MORE HEADROOM BUT HOW MUCH?

As shown, complex-modulation formats exhibit high Peak powers compared to their Average power. With Crest Factor reduction (CFR) schemes, digital and amplifier linearization techniques, and the variables of the signal payload, the effective PAR and range of acceptable non-linearity is wide. Most digital formats can suffer modest to moderate distortion and remain usable. For example, absent other distortion, WLAN modulation can still provide acceptable performance when Peak power is limited to an amplifier’s P_1 power point (see **Step 4** for an explanation of P_1).

OFDM modulation with a PAR of 12 may allow a Peak power de-rating of as much as 6 dB from Peak. De-rating the input power to allow the amp to meet the Peak power requirements is commonly referred to as “back off” and is expressed in dB. Even de- rating by 6dB leaves the Peak power still 6dB over average, and that must allowed for by either backing off the CW P_1 point by 6dB or by adding 6dB of headroom to the output power rating of the amp. Your specific application must determine the effective PAR value you apply to the average power of your signal when calculating the Peak power, but Peak power will always be significantly more than average power. Using an effective PAR, or “back off” of 6-7dB should provide a useful working number.

PULSE MODULATION

Measuring pulse Peak power can be done easily with a Peak power meter regardless of pulse width. You can also calculate Peak power by dividing Average Power by the duty cycle of the pulse modulation.

Duty Cycle (dB) = 10 log(duty cycle ratio)

Example: For a pulsed RF train with an Average power of 0dBm and a duty cycle of 15%:

0dBm + 10 log(0.15) = 8.24dBm Peak

Try to use representative pulse trains or a worst-case scenario to obtain Peak values that will allow enough headroom for your pulse peaks.

STEP 2 – DO THE MATH – DO YOU NEED GAIN OR POWER NUMBERS?

Your application determines either the signal level you want your amplifier to produce (in Watts or dBm) or the amount of gain you require. If you require a specific signal level, the difference between that power level and the peak power of your signal is the minimum degree of amplification, or gain, you require. If you have a specific gain requirement then your signal peak power added to the gain will provide the minimum power out necessary for the amplifier to produce.

Power Out (dBm) – Peak Power In (dBm) = Gain (dB) Required

For example, you may know the Peak Envelope Power (PEP) required to provide a specific Effective Radiated

Power (ERP) at an antenna. In that case, for a signal with a Peak power of +10dBm and a desired PEP of 50 Watts:

dBm = 10 log(milliwatts)

10 log(50,000 mW) = +47 dBm

+47dBm PEP - 10dBm Peak = +37dB Gain @ 50W Peak Output (+10 dBm Input)

Many RF amplifiers with have different power input specifications, but 0 dBm is fairly common. In the example above, to avoid over-driving the amplifier, it may be necessary to add 10 dB attenuation to the RF amplifier input to reduce the input power to 0 dBm. In that case the example looks like this:

+47dBm PEP - 10dBm Peak + 10 dB Attenuation = +47dB Gain (0 dBm Input)

If you know the Gain required but not the Wattage necessary to provide it, add the Peak power to the gain, and convert the sum to Watts:

Peak power (dBm) + Gain (dB) = Peak power out (dBm)

Power (Watts) = antilog10(dBm/10)

For example, you have a Peak signal power of +3dBm and require a Gain of 40dB to obtain a final peak power level of +43dBm to drive a larger power amplifier. Remember to add 3dB to the Gain to compensate for the 3 dB attenuator to bring the input level to 0dBm:

0dBm Peak + 40dB Gain + 3dB Attenuation = +43dBm = 20 Watts Peak

If your signal level is below 0dBm, you can search for amplifiers with higher gain that will produce the desired power level in **Step 3**. To determine the maximum Input Power level for an amplifier, subtract Gain from the CW P_1 power out:

Peak power out dB – Gain dB = Peak Input level

For example, to find the Peak input level for a 20W amp with 48dB gain:

20W = +43dBm
+43dBm – 48dB = -5dBm

STEP 3 – WINDOW SHOPPING- SELECT BY TYPE, FREQUENCY, AND POWER

This step is where you can begin to pre-select amplifiers that might meet your requirements. Here is where CW and Pulse amps will diverge. The other big break point for selection is whether you are shopping for a “module”, or a system. A module is usually a smaller unit that comes with or without a heat sink, and usually without any controls or indicators, designed to be integrated into an assembly. A full system is self- contained, complete with chassis, cooling, AC-DC power supplies, front-panel and remote controls and indicators.

As amplifiers are usually designed over more frequency ranges than power levels, it can save time to first screen a vendor’s lists by Power Out, then by frequency, then by Gain.

REMEMBER, CHEAP SPECS WILL SHRINK IN THE WASH- SHOP FOR A SIZE LARGER

At this early stage of the process it is essential to make your initial selection based on a wider range of advertised powers and frequencies than you think you need. Print out the data sheets for any potential candidates for further scrutiny in **Step 4**. As you zoom into the specs you will find that the band edges may not perform as well as you might wish, or the power specs quoted are overly optimistic. You might need to get an amplifier with wider coverage to improve flatness across your frequency band, or pick a slightly more powerful amplifier than the rating specified to get a reasonable margin of gain or power. You may also find that another spec will invalidate otherwise attractive features, like poor Harmonic specs from an amplifier being pushed a little too hard.

STEP 4 – COMPARING APPLES TO APPLES

Here is where you need to look closely at the specs. Depending on the amplifiers you have selected so far, you need to make an educated choice which amps will actually provide the gain and power for your application. The important thing to accomplish at this step is to make sure you are comparing “apples to apples” or in this case Usable Watts to Usable Watts.

SIGNAL LINEARITY AND USABLE WATTS

All amplifiers will compress at some level. So this discussion will short-cut past the relative virtues of amplifier Classes of Operation so frequently seen in amplifier literature. Either an amplifier is Class A or it is not. If it is, the amplifier may be relied on to provide superior performance in terms of fidelity, low distortion, and immunity to VSWR over the entire linear power range.

AR Modular RF can provide Class A RF power amplifiers that exhibit the highest signal linearity for the most demanding applications, like the **KAW2180**, a 100W minimum dual-band Class A amplifier that operates from 0.01-1000 MHz. All other types of RF amplifier (usually Class AB) will provide some more distortion in exchange for efficiency, and may require some spec-diving to figure out how many linear watts you will really get.

RF power amplifier ratings can be expressed in many kinds of Watts: Average, P_1, CW, Peak, ALC Watts, even Peak-to-Peak (P-P). You job here is to “normalize” all the results to a common and meaningful value, like P_1 Watts, so a direct comparison can be made.

P_1 POWER VS. SATURATED POWER

All amplifiers exhibit gain compression at higher operating levels, meaning the gain (not the level) decreases as input power rises. The output level at which the power has deviated from true linearity by 1dB is typically specified as the P_1 point. Even Class A amplifiers have a P_1 point. The P_1 power level is the most useful reference to output power as it can be measured directly and accurately and indicates the practical power limit that may be safely and conservatively employed. Beyond the P_1 point, as input power increases, compression also increases until the departure from linear gain is -3dB, or one-half the power out that occurs at lower powers. This is known as the Saturation level or P_3. This not generally regarded as a usable or safe power level. The P_1 level is typically about 2dB below the P_3 saturated power level.

Saturated Power P3 – 2dB = Usable Power P1

For example, for an amp specified at 100W out P3 saturated power, the actual “usable” power, or P1 level, is found:

100W P_3 – 2dB = +50dBm P_3 – 2dB = +48dBm P_1 = antilog$_{10}$(4.8) = 63 Watts P_1

Modulation usually requires some of linearization to be effective when using power levels above P_1. Your job here is to look through all the specs of amplifiers that have “made the cut” so far, and make sure that for any amp specified in Watts, or anything other than P_1 watts, you find the P_1 level specification. If you don’t, you may discover that the rated power is the saturation level. AR Modular RF typically specifies a minimum power level below P_1 as the rated power out. See if any amp specifications provide you with a margin, and when you look at P_1 power levels, include that margin in your comparison.

GAIN- TOO MUCH OF A GOOD THING?

Make sure you are checking the gain of the amplifiers that can provide the power out you want, and referencing it to your signal level. The designed input power level may be too far from your signal level. You don’t want to have add a preamplifier or use excessive attenuation, but it is not unusual have to add a small amount of attenuation on the input. Pick an amplifier that provides enough margin that you can add a pad on the input in case you find it is necessary later to reduce the power out of the amplifier. Variable Gain is a useful feature for setting system levels.

CONVERTING CW TO AM MODULATION SPECS

As stated before, AM Peak power is 4x CW power or +6dB. Use the P1 level for CW watts to calculate AM power. Divide CW-rated power by 4 (or subtract 6dB) to estimate available AM Power. If the specs say something like “100W CW, AM, FM, PM, SSB”, it does not mean you may modulate a 100W carrier with 100% AM. You should be able to modulate 25W with 100% AM. With an under-powered amp, your only alternative available to produce low-distortion AM is to reduce the RF “drive” to the amp until the un-modulated carrier is 25% of the linear output (-6 dB), drastically reducing the output power. This is an especially poor outcome if the original power spec was for saturated power, as the result is decreased by another 37%.

CW P_1 Watts ÷ 4 = AM Peak Watts

For P_1 in dB:

CW P_1 dB – 6dB = AM Peak Watts

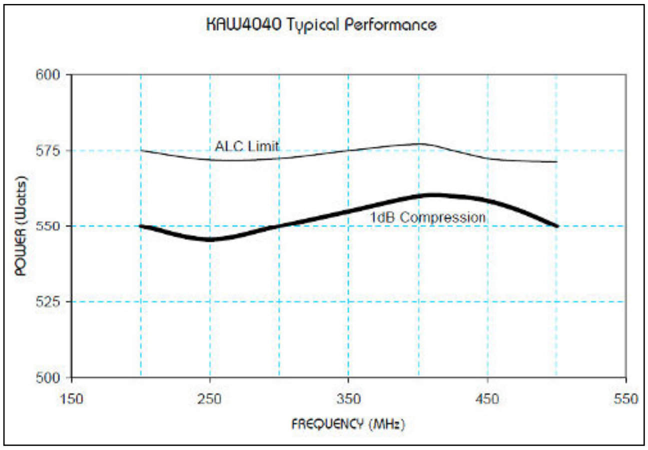
FLATNESS AND ALC POWER LEVELS

Most RF amplifiers specify Flatness. In general, the wider the frequency coverage, the looser the Flatness spec becomes. Flatness is a good indication of the relative quality of broadband design quality. Flatter amps are easier to use as the gain is more predictable.

Automatic Level Control (ALC) is a feature mainly used for CW modulation. RF power amplifiers with ALC will usually specify an ALC Power level in addition to P_1 Watts. The main function of ALC is to provide overdrive protection to the device at the output of the amplifier. For CW signals the ALC level defines the maximum RF level available from the amplifier, regardless of drive level. ALC can help protect the amplifier from over-drive, and can also provide improved Flatness, especially for CW signals. An adjustable ALC can allow you to vary the ALC level below the P_1 point. ALC is a “friendly” limiter, creating much lower distortion than P_1. The ALC function will need to be slowed or disabled for non-CW modulated signals, or serious distortion will result. Amplifiers with ALC Fast/Slow selection can enable some limited ALC functionality for non-CW signals, but it will be less responsive. For amplifiers with variable Gain, reducing the gain below the ALC Limit will also reduce Flatness as the gain lowers.

RF PULSE AMPLIFIERS – A DIFFERENT WORLD

Pulse amplifiers are a separate breed of RF amplifier. Pulse amplifiers are rated in Peak Watts and are commonly run at saturated power levels, where compression makes no difference to the modulation fidelity. Pulse-specific amp designs come in two types depending on the pulse



modulation method. The first, Pulse Gated amplifiers can have a CW signal applied to the input and an external gating signal is applied to the amp to produce the pulsed output. Alternatively, a pulse train is applied to the amp input and the gating is used to quiet the amp between pulses. The non-Gating type has design features specifically for preserving the shape of pulsed signals with fast rise-times. A CW rated amp can also pass pulses, but the highest pulse fidelity is obtained by design features not usually contained in a CW amp. If your main requirement is for pulse performance, select from pulse amps with the correct Peak power rating.

HARMONIC DISTORTION – TROUBLE IS JUST AN OCTAVE AWAY

Having worked your way down to a short list of amps that will meet your P_1 , gain and frequency requirements, you need to pick an amplifier with low Harmonic levels, as compared to other like designs. Harmonics are a relative indicator of amplifier design quality and stress. Harmonic distortion is measured in dBc, or the power level as compared to the output carrier power. Harmonic specs vary widely, from relatively high levels in the low teens, like -13 dBc, to much lower levels like -60 dBc or less. The higher power range of numbers is usually associated with broader-band amplifiers that can not employ a filter at a harmonic frequency as it is in the gain passband. Out of the gain passband, filters can knock harmonics way down, but a filter following a high power amplifier can get really hot, depending on the energy absorbed, and that heat can lead to a short filter life. For narrower amps with a bandwidth less than an octave wide, a better scheme is to reduce them with a conservative design and then a cooler-running filter, if needed. Make sure when comparing harmonics specs you understand any big differences as they can be the result of completely different types of amplifiers. If you require the absolute minimum of harmonic distortion, use a Class A amplifier.

WIDE-BAND OR BAND-SWITCHED – AUTOMATIC OR MANUAL TRANSMISSION?

Finally, make sure how your wide-band operating frequencies are provided, either by “band-switching” or by a true, single broad-band design. Some frequencies just can not be effectively amplified by the same design if they are too far apart. If you can switch from one band to another (by switching from one amplifier to another) you may be able to get improved Gain, Flatness and Harmonic distortion performance for less cost.

STEP 5 – SHOP FOR FEATURES – THE “BELLS AND WHISTLES”

When you have worked your way this far you should have a short list of the available amplifiers in the power and frequency range that have a good chance of meeting your needs. Within this selection you can shop for the accessory functions that will make your amplifier more usable, like blanking, remote controls, variable Gain control, VSWR tolerance, efficiency or power consumption, size, other kinds of protection, interfaces, and finally cost.

Some intangible factors can make a big difference to your long-term happiness with your final selection. Chief among these is robustness of design, which appears as a gain or power margin above the rated power, which will equate to longer life with fewer problems. Other factors include the vendor’s willingness to adapt a design for your specific needs, a long-term commitment to service by the vendor, and responsive customer support.

ABOUT IMPEDANCE MISMATCH TOLERANCE

You may feel some important factors have been left out of this selection process, like load impedance variability. The truth is no one knows what happens with random VSWR. Almost anything is possible, even gain. The main thing is you want to avoid damaging the amplifier. Remember, reflected power has done its work, and whether it is an antenna or another amplifier, the important thing is to present the signal accurately to the load at as close to the right level as you can, and survive whatever returns. AR Modular RF is known for RF power amplifiers that can withstand nearly infinite mismatch conditions, like the **KAW4040**, a 200-500 MHz amplifier rated for 500W CW (minimum), with P1 well above the 500W level, and full VSWR protection.

At this point, you may find no amplifier is a perfect fit for you. AR Modular RF would like to speak with you about your requirements. We routinely produce quality custom amplifier modules and systems and can modify our existing designs to meet your needs. AR Modular RF fabricates all our amplifiers in Bothell, Washington, where the company has attained the reputation for making and supporting the finest RF Power amplifiers for almost 4 decades.

COMMON COMMERCIAL 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 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 (Withdrawn and replaced by CISPR 35:2016)
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

OTHER RELEVANT STANDARDS

https://webstore.iec.ch

Document Number	Title
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

EMC STANDARDS ORGANIZATIONS

American National Standards Institute
www.ansi.org

ANSI Accredited C63
www.c63.org

Asia Pacific Laboratory Accreditation Cooperation (APLAC)
https://www.apac-accreditation.org/

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

Canadian Standards Association (CSA)
www.csa.ca

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

CNCA (China)
http://english.cnca.gov.cn

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

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

Federal Communications Commission (FCC)
www.fcc.gov

Federal Standards
https://quicksearch.dla.mil/qsSearch.aspx

Gosstandart (Russia)
https://gosstandart.gov.by/en/

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

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

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

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

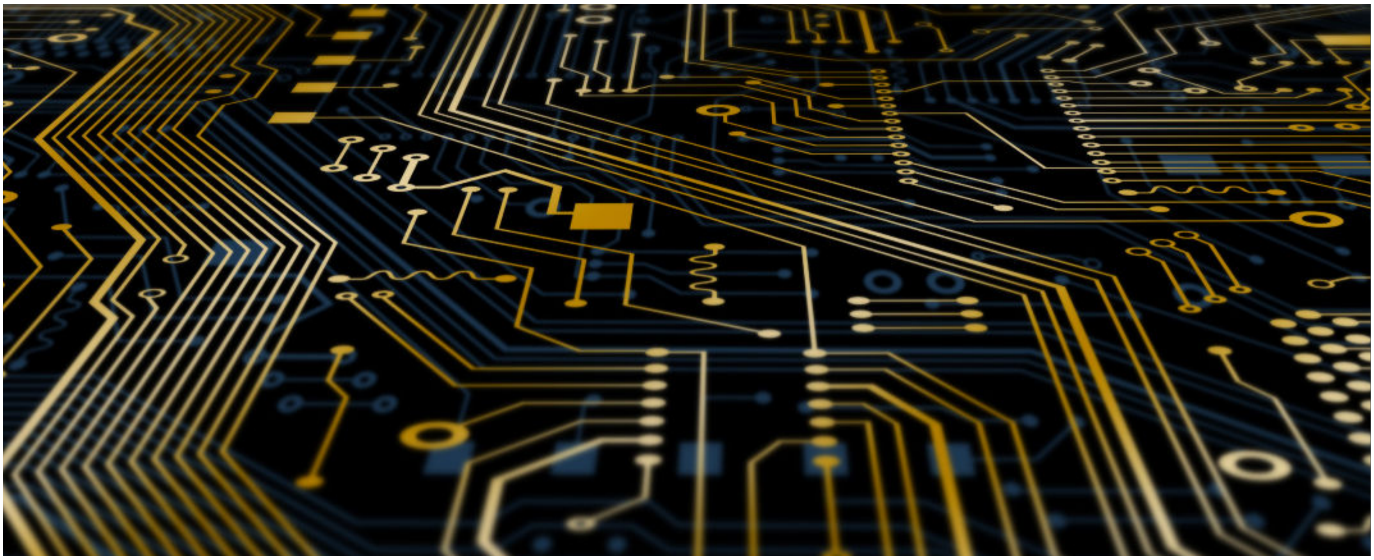
ISO (International Organization for Standards)
http://www.iso.org/iso/home.html

RTCA
https://www.rtca.org

SAE EMC Standards Committee
www.sae.org

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

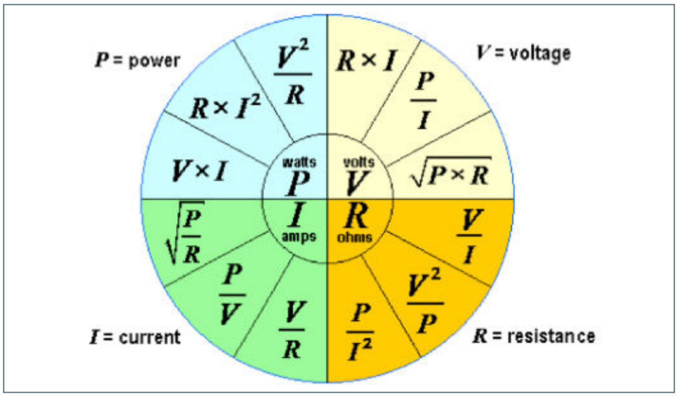
VCCI (Japan, Voluntary Control Council for Interference)
http://www.vcci.jp/vcci_e/



EQUATIONS, TOOLS, & CALCULATORS

COMMON EMC-RELATED EQUATIONS

OHMS LAW



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

BANDWIDTH VERSUS RISE TIME

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

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

BANDWIDTH VERSUS CLOCK FREQUENCY

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

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

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

PERIOD VERSUS FREQUENCY

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

PARTIAL SELF-INDUCTANCE OF A ROUND WIRE (1MM)

25 nH/inch or 1 nH/mm
Example, a 1.5 mm long via has a partial self-inductance of about 1.5 nH.

IMPEDANCE OF A WIRE

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

Example, a 1-inch wire (25 nH) has an impedance of 16 Ohms at 100 MHz.

SPEED OF SIGNALS

In air: 12 inches/nsec

In most PC board dielectrics: 6 inches/nsec

VSWR AND RETURN LOSS

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

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

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

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

RETURN LOSS, GIVEN FORWARD/REVERSE POWER

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

EQUATIONS, TOOLS, & CALCULATORS

RETURN LOSS, GIVEN VSWR

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

Return Loss, given reflection coefficient (ρ)

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

E-FIELD FROM DIFFERENTIAL-MODE CURRENT

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

ID = differential-mode current in loop (A)

f = frequency (Hz)

L = length of loop (m)

s = spacing of loop (m)

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

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

E-FIELD FROM COMMON-MODE CURRENT

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

IC = common-mode current in wire (A)

f = frequency (Hz)

L = length of wire (m)

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

TEMPERATURE CONVERSIONS

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

ANTENNA (FAR FIELD) RELATIONSHIPS

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

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

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

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

Field Strength given watts, numeric gain, distance in meters

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

Field Strength given watts, dBi gain, distance in meters

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

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

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

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

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

PC BOARD EQUATIONS

1 oz. copper = 1.4 mils = 0.036 mm

0.5 oz. copper = 0.7 mils = 0.018 mm

Convert mils to mm: multiply by 0.0254 mm/mil

Convert mm to mils: multiply by 39.4 mil/mm

Signal velocity in free space: approx. 12 in/ns

Signal velocity in FR-4: approx. 6 in/ns

EQUATIONS, TOOLS, & CALCULATORS

WORKING WITH DB

The decibel is always a ratio

Power Gain = Pout/Pin

Power Gain(dB) = 10log(Pout / Pin)

Voltage Gain(dB) = 20log(Vout/Vin)

Current Gain(dB) = 20log(Iout/Iin)

We commonly work with:

dBm (referenced to 1 mW)

dBµV (referenced to 1 µV)

dBµA (referenced to 1 µA)

Power Ratios

3 dB = double (or half) the power

10 dB = 10X (or /10) the power

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

DBM, DBµV, DBµA (CONVERSION)

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

Note: For current relationships, substitute A for V

FIELD STRENGTH EQUATIONS

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

DBM TO DBUV CHART

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

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

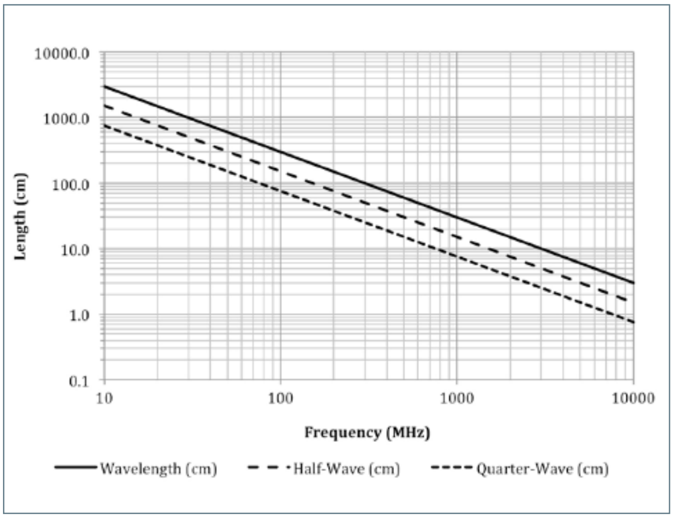
dBm to dBµV, use: dBµV = dBm + 107

EQUATIONS, TOOLS, & CALCULATORS

WAVELENGTH EQUATIONS (FREE SPACE)

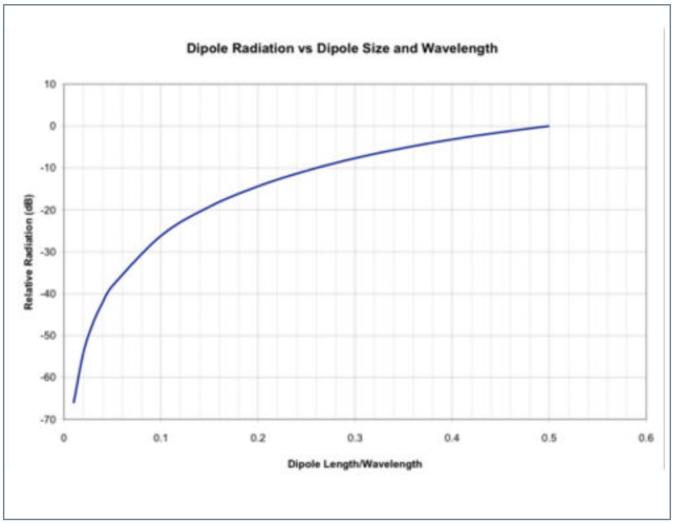
Wavelength(m) = 300/f(MHz)
Half wavelength(ft.) = 468/f(MHz)

RESONANCE OF STRUCTURES



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

DIPOLE RADIATION VERSUS LENGTH



Use this chart to for determining the relative radiation versus size in wavelength. Image Source: Bruce Archambeault.

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

LINKEDIN GROUPS

Electromagnetic Compatibility Forum

Electromagnetics and Spectrum Engineering Group

EMC - Electromagnetic Compatibility

EMC Experts

EMC Troubleshooters

ESD Experts

Signal & Power Integrity Community

EMI/EMC Testing

iNARTE

IEEE

COMMON SYMBOLS

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

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

ACRONYMS

AF	(Antenna Factor) - The ratio of the received field strength to the voltage at the terminals of a receiving antenna. Units are 1/m.
ALC	(Absorber-Lined Chamber) - A shielded room with RF-absorbing material on the walls and ceiling. In many cases, the floor is reflective.
AM	(Amplitude Modulation) - A technique for putting information on a sinusoidal carrier signal by varying the amplitude of the carrier.
BCI	(Bulk Current Injection) - An EMC test where common-mode currents are coupled onto the power and communications cables of an EUT.
CE	(Conducted Emissions) - The RF energy generated by electronic equipment, which is conducted on power cables.
CE Marking	The marking signifying a product meets the required European Directives.
CENELEC	French acronym for the “European Committee for Electrotechnical Standardization”.
CI	(Conducted Immunity) - A measure of the immunity to RF energy coupled onto cables and wires of an electronic product.
CISPR	French acronym for “International Special Committee on Radio Interference”.
Conducted	Energy transmitted via cables or PC board connections.
Coupling Path	A structure or medium that transmits energy from a noise source to a victim circuit or system.
CS	(Conducted Susceptibility) - RF energy or electrical noise coupled onto I/O cables and power wiring that can disrupt electronic equipment.
CW	(Continuous Wave) - A sinusoidal waveform with a constant amplitude and frequency.
EMC	(Electromagnetic Compatibility) - The ability of a product to coexist in its intended electromagnetic environment without causing or suffering disruption or damage.
EMI	(Electromagnetic Interference) - When electromagnetic energy is transmitted from an electronic device to a victim circuit or system via radiated or conducted paths (or both) and which causes circuit upset in the victim.
EMP	(Electromagnetic Pulse) - Strong electromagnetic transients such as those created by lightning or nuclear blasts.
ESD	(Electrostatic Discharge) - A sudden surge in current (positive or negative) due to an electric spark or secondary discharge causing circuit disruption or component damage. Typically characterized by rise times less than 1 ns and total pulse widths on the order of microseconds.
ESL	(Equivalent Series Inductance) - Generally refers to the parasitic series inductance of a capacitor or inductor. It could also include the extra series inductance of any connecting traces or vias on a PC board.
ESR	(Equivalent Series Resistance) - Generally refers to the parasitic series resistance of a capacitor or inductor.
EU	European Union.
EUT	(Equipment Under Test) - The device being evaluated.
Far Field	When you get far enough from a radiating source the radiated field can be considered planar (or plane waves).
FCC	U.S. Federal Communications Commission.
FM	(Frequency Modulation) - A technique for putting information on a sinusoidal “carrier” signal by varying the frequency of the carrier.
IEC	International Electrotechnical Commission
ISM	(Industrial, Scientific and Medical equipment) - A class of electronic equipment including industrial controllers, test & measurement equipment, medical products and other scientific equipment.
ITE	(Information Technology Equipment) - A class of electronic devices covering a broad range of equipment including computers, printers and external peripherals; also includes, telecommunications equipment, and multi-media devices.

ACRONYMS

LISN	(Line Impedance Stabilization Network) - Used to match the 50-Ohm impedance of measuring receivers to the power line.
MLCC	(Multi-Layer Ceramic Capacitor) - A surface mount capacitor type often used as decoupling or energy storage capacitors in a power distribution network.
Near Field	When you are close enough to a radiating source that its field is considered spherical rather than planar.
Noise Source	A source that generates an electromagnetic perturbation or disruption to other circuits or systems.
OATS	(Open Area Test Site) - An outdoor EMC test site free of reflecting objects except a ground plane.
PDN	(Power Distribution Network) - The wiring and circuit traces from the power source to the electronic circuitry. This includes the parasitic components (R, L, C) of the circuit board, traces, bypass capacitance and any series inductances.
PLT	(Power Line Transient) - A sudden positive or negative surge in the voltage on a power supply input (DC source or AC line).
PI	(Power Integrity) - Refers to the quality of the energy transfer along the power supply circuitry from the voltage regulator module (VRM) to the die of the ICs. High switching noise or oscillations mean a low PI.
Radiated	Energy transmitted through the air via antenna or loops.
RE	(Radiated Emissions) - The energy generated by a circuit or equipment, which is radiated directly from the circuits, chassis and/or cables of equipment.
RFI	Radio Frequency Interference) - The disruption of an electronic device or system due to electromagnetic emissions at radio frequencies (usually a few kHz to a few GHz). Also EMI.
RI	Radiated Immunity) - The ability of circuits or systems to be immune from radiated energy coupled to the chassis, circuit boards and/or cables. Also Radiated Susceptibility (RS).
RF	(Radio Frequency) - A frequency at which electromagnetic radiation of energy is useful for communications.
RS	(Radiated Susceptibility) - The ability of equipment or circuits to withstand or reject nearby radiated RF sources. Also Radiated Immunity (RI).
SSCG	Spread Spectrum Clock Generation) - This technique takes the energy from a CW clock signal and spreads it out wider, which results in a lower effective amplitude for the fundamental and high-order harmonics. Used to achieve improved radiated or conducted emission margin to the limits.
SI	(Signal Integrity) - A set of measures of the quality of an electrical signal.
SSN	(Simultaneous Switching Noise) - Fast pulses that occur on the power bus due to switching transient currents drawn by the digital circuitry.
TEM	(Transverse Electromagnetic) - An electromagnetic plane wave where the electric and magnetic fields are perpendicular to each other everywhere and both fields are perpendicular to the direction of propagation. TEM cells are often used to generate TEM waves for radiated emissions (RE) or radiated immunity (RI) testing.
Victim	An electronic device, component or system that receives an electromagnetic disturbance, which causes circuit upset.
VRM	(Voltage Regulator Module) - A linear or switch-mode voltage regulator. Generally, there will be several of these mounted to a PC board in order to supply different levels of required voltages.
VSWR	(Voltage Standing Wave Ratio) - A measure of how well the load is impedance matched to its transmission line. This is calculated by dividing the voltage at the peak of a standing wave by the voltage at the null in the standing wave. A good match is less than 1.2:1.
XTALK	(Crosstalk) - A measure of the electromagnetic coupling from one circuit to another. This is a common problem between one circuit trace and another.

RECOMMENDED EMC BOOKS, MAGAZINES AND JOURNALS

ITEM 2022
(Interference Technology Engineer's Master)
ITEM is an exhaustive guide full of invaluable EMC directories, standards, formulas, calculators, lists, and "how-to" articles, compiled in easy-to-find formats.
https://learn.interferencetechnology.com/item-2022/

2021 EMC Fundamentals Guide
The Fundamentals Guide keeps your project running smoothly by better understanding how to address EMI and EMC in the early design phases.
https://learn.interferencetechnology.com/2021-emc-fundamentals-guide/

2020 Europe EMC Guide
This guide features technical articles, reference materials, a company directory, and a products and services list for more than 10 countries.
https://learn.interferencetechnology.com/2020-europe-emc-guide/

2019 Components & Materials Guide
This guide is updated with the most critical changes in standards, upcoming events, new product distributors, and more as they relate to EMI shielding and filtering.
https://learn.interferencetechnology.com/2019-components-and-materials-guide/

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

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

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

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

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

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

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

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

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.

Kunkel,
Shielding of Electromagnetic Waves, Theory and Practice
Springer. 2019. Provides efficient ways for design engineers to apply electromagnetic theory in shielding of electrical and electronic equipment.

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.

RECOMMENDED EMC BOOKS, MAGAZINES AND JOURNALS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Wyatt and Gruber,
Radio Frequency (RFI) Pocket Guide
SciTech Publishing, 2015. A handy pocket-sized reference guide to radio frequency interference.

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Break the same old pattern.