interferencetechnology.com

2024

ITEM

INTERFERENCE TECHNOLOGY ENGINEER'S MASTER

REFERENCE GUIDES | FUNDAMENTALS | EMC TESTING
WIRELESS, 5G, & IOT | MILITARY & AEROSPACE | SI, PI, & EMI

INTERFERENCE TECHNOLOGY®

EXODUS ADVANCED COMMUNICATIONS

Powerful Solutions, Racked & Stacked
Maximizing Performance

Model Number	Frequency Range	Rated Power Watts	Gain dB
10KHz-250MHz, Low Frequency Amplifiers			
AMP2080B	10kHz-250MHz	100	50
AMP2080C-1	10kHz-250MHz	150	52
AMP2080C	10kHz-250MHz	300	55
AMP2080D	10kHz-250MHz	600	58
80-1000MHz, VHF, UHF Range Amplifiers			
AMP2032	80-1000MHz	300	55
AMP2071-2	80-1000MHz	500	57
AMP2071A-LC	80-1000MHz	750	60
AMP2115-LC	80-1000MHz	1300	61
AMP2121-LC	80-1000MHz	2000	63
700MHz-6.0GHz, Broadband Amplifiers			
AMP2070C	0.7-6.0GHz	100	50
AMP2070A	1.0-6.0GHz	150	52
AMP2030-LC	1.0-6.0GHz	300	55
AMP2030-600-LC	1.0-6.0GHz	600	58
AMP2030D-LC	1.0-6.0GHz	750	59
AMP2030LC-1KW	1.0-6.0GHz	1000	60
2.0-8.0GHz, SC Band Amplifiers			
AMP2085-1	2.0-8.0GHz	120	51
AMP2085C	2.0-8.0GHz	200	53
AMP2085E-1LC	2.0-8.0GHz	250	54
AMP2085E	2.0-8.0GHz	400	56
6.0-18.0GHz, High Frequency Amplifiers			
AMP2118	6.0-18.0GHz	40	46
AMP2111	6.0-18.0GHz	50	47
AMP2033-LC	6.0-18.0GHz	100	50
AMP2065A-LC	6.0-18.0GHz	200	53
AMP2065B-LC	6.0-18.0GHz	300	55
AMP2065E-LC	6.0-18.0GHz	500	57
18-26.5GHz, K-Band, Millimeter Amplifiers			
AMP4032	18.0-26.5GHz	10	40
AMP4065LC-1	18.0-26.5GHz	20	43
AMP4065-LC	18.0-26.5GHz	40	46
AMP4065A-LC	18.0-26.5GHz	100	50
AMP4065B-LC	18.0-26.5GHz	200	53
26.5-40.0GHz, Ka-Band, Millimeter Amplifiers			
AMP4072	26.5-40.0GHz	10	40
AMP4066LC-1	26.5-40.0GHz	20	43
AMP4066-LC	26.5-40.0GHz	40	46
AMP4066A-LC	26.5-40.0GHz	100	50
AMP4066B-LC	26.5-40.0GHz	200	53
18.0-40.0GHz, Millimeter Amplifiers			
AMP2145A-LC	18.0-40.0GHz	10	40
AMP2145B-LC	18.0-40.0GHz	25	44
AMP2145C-LC	18.0-40.0GHz	50	47
40.0-50.0GHz, Q-Band, Millimeter Amplifiers			
AMP4076-1	40.0-50.0GHz	5	37
AMP4076A	40.0-50.0GHz	20	43
AMP4076B	40.0-50.0GHz	40	46
AMP4076C	40.0-50.0GHz	80	49

RF & Microwave Amplifiers

10KHz-75GHz

Amplifiers
CW & Pulse
Watts to KW

Versatile Across All Modulation Standards
Achieve Immediate Wide Bandwidth Access
Reliable and Durable
Powerful Precision with Class A/AB Linear Design

10KHz-250MHz
3000 Watts

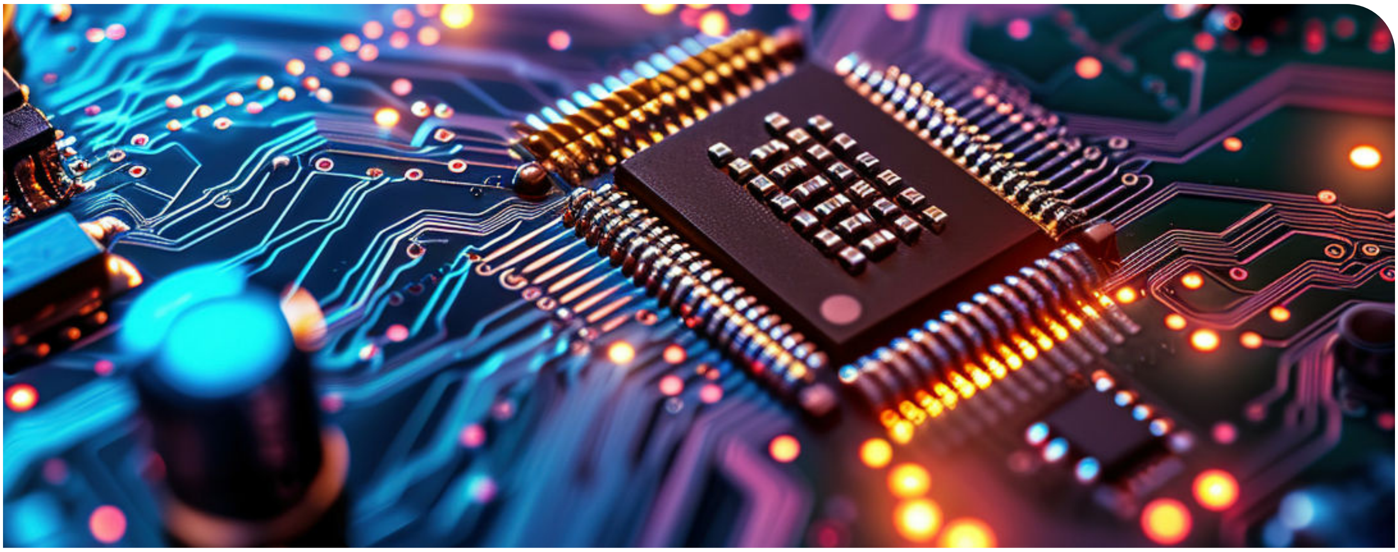
800MHz-6.0GHz
1000 Watts

2.0-8.0GHz
500 Watts

3674 E. Sunset Road, Suite 100, Las Vegas, Nevada 89120 USA
Tel : 1-702-534-6564 Email : sales@exoduscomm.com

www.exoduscomm.com


All you
need in one
small package
Antennas | Probes | Accessories | Preamplifiers | Low-Loss Cables | Recalibration Services
Travel Made Easy
with Next-Day,
On-Time
Delivery
Don't Leave home without it. A.H. Systems provides many models of Portable Antenna Kits, each containing all the necessary Antennas, Current Probes, and Cables to satisfy numerous customer requirements. Excellent performance, portability (compact size and lightweight), along with ease of setup make all of the Antenna Kits your choice for indoor or field testing. Loss and breakage are virtually eliminated as each component has a specific storage compartment within the case. All Antenna Kits are accompanied with a Tripod and Azimuth & Elevation Head, both contained in a Tripod Carrying Case**...and don't forget your keys!**
ANTENNAS...
and KITS TOO...
Innovation
Quality
Performance
Phone: (818)998-0223 ♦ Fax (818)998-6892
www.AHSystems.com?IT
A.H. Systems



FREE SUBSCRIPTIONS

ITEM, Interference Technology — is distributed annually at no charge to engineers and managers engaged in the application, selection, design, test, specification or procurement of electronic components, systems, materials, equipment, facilities or related fabrication services. Subscriptions are available through www.interferencetechnology.com.

2024 *Interference Technology* Engineer's Master (ITEM)

INTERFERENCE TECHNOLOGY

Chief Executive Officer
GRAHAM KILSHAW

Business Development Director
ASHLEE ZAPATA-MCCANTS

Sr. Director, Content
MIKE CHAMBERS

Creative Director
KATE TETI

Graphic Designer
MARCOS CRUZ

Delivery Manager
MACKENZIE MANN

LECTRIX

USA
716 Dekalb Pike #351
Blue Bell, PA 19422
Phone: +1 484-688-0300
info@interferencetechnology.com
interferencetechnology.com

China, Taiwan, Hong Kong
ACT International
Mainland China - Linda Li, +86-21-62511200
Email: lindaL@actintl.com.hk
Hong Kong - Mark Mak, +85-22-8386298
Email: markm@actintl.com.hk

JAPAN
e-OHTAMA, LTD.
Masaki Mori, +81-3-6721-9890
Email: masaki.mori@ex-press.jp

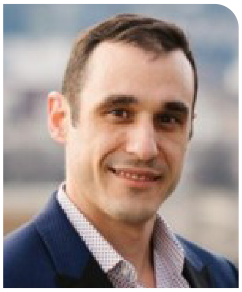
2024 TECHNICAL EDITORIAL BOARD

DAVID A. WESTON

iNARTE EMC Engineer

David A. Weston is an electromagnetic compatibility (EMC) consultant and certified National Association of Radio and Telecommunications Engineers (iNARTE) EMC engineer at EMC Consulting Inc. Merrickville, Ontario, Canada. A life member of the Institute of Electrical and Electronics Engineers, Weston has worked in electronic design for 55 years, specializing in the control, prediction, measurements, problem solving, analysis, and design aspects of EMC for the last 44 years.

He is the author of the third edition of the 1,157-page book Electromagnetic Compatibility, Methods, Analysis, Circuits, and Measurement published by CRC press in 2017, as well as numerous papers of a practical nature.



ZACHARIAH PETERSON

PCB Design Expert & Electronics Design Consultant

Zachariah Peterson received multiple degrees in physics from Southern Oregon University and Portland State University, and he received his MBA from Adams State University. In 2011, he began teaching at Portland State University while working towards his Ph.D. in Applied Physics. His research work originally focused on topics in random lasers, electromagnetics in random materials, metal oxide semiconductors, sensors, and select topics in laser physics; he has also published over a dozen peer reviewed papers and proceedings. Following his time in academia, he began working in the PCB industry as a designer and technical content creator. As a designer, his experience focuses on high-speed digital systems and RF systems for commercial and mil-aero applications. His company also produces technical content for major CAD vendors and consults on technology strategies for these clients. In total, he has produced over 2,000 technical articles on PCB design, manufacturing, simulation, modeling, and analysis. Most recently, he began working as CTO of Thintronics, an innovative PCB materials startup focusing on high-speed, high-density systems.

He is a member of IEEE Photonics Society, IEEE Electronics Packaging Society, American Physical Society, and the Printed Circuit Engineering Association (PCEA). He previously served as a voting member on the INCITS Quantum Computing Technical Advisory Committee working on technical standards for quantum computing and quantum electronics. He now sits on the IEEE P3186 Working Group focused on Port Interface Representing Photonic Signals Using SPICE-class Circuit Simulators.

MIKE VIOLETTE

iNARTE Certified EMC Engineer

Mike is CEO of Washington Laboratories and Director of American Certification Body. He has over 35 years of experience in the field of EMC evaluation and product approvals and has overseen the development of engineering services companies in the US, Europe and Asia. Mike is currently on the Board of Directors of the IEEE EMC Society.

He is a Professional Engineer, registered in the State of Virginia. He has given numerous presentations on compliance topics and is a regular contributor to technical and trade magazines.

2024 TECHNICAL EDITORIAL BOARD

TOM BRAXTON

iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer

Tom Braxton has worked in the EMC industry since 1981, with experience at Lucent Technologies / AT&T Bell Laboratories, Shure Incorporated, and as an independent consultant.

Tom is an IEEE Life Senior Member, a past EMC Society Director at Large, and is the author of EMC-awareness articles for online and print publications. He chairs Technical Committee TC1 on EMC Management and was General Chair of the 2005 IEEE International EMC Symposium and Vice-Chair in 1994, both in Chicago. He is also the Vice-Chair and Program Chair of the EMC Society Chicago Chapter.

An iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer, Tom holds a BSEET from Purdue University, an MSEE from the Illinois Institute of Technology, and Amateur Radio license WB9VRW.

EMC AT THE FOREFRONT

Tom Braxton
iNARTE-Certified EMC Engineer and an iNARTE-Certified ESD Engineer

Electromagnetic compatibility has come a long way. It can trace its origins to the birth of wireless at the dawn of the 20th century when Guglielmo Marconi was told by his early customer, the British Navy, that only one pair of his wireless telegraphs could operate at a time because of mutual interference. His staff hadn't heard of EMC, but they did some re-tuning and stopped the interference.

In 1933, an ad hoc conference was held in Paris to discuss radio interference. That meeting led to the formation of International Special Committee on Radio Interference (French: CISPR), the far-reaching international standards body.

It could be argued that EMC as a science came into being in 1954, when the US military sponsored a conference on radio interference reduction. That conference led to research and more conferences, and ultimately led to the formation of the IEEE EMC Society.

Wherever its starting point, the forward-moving EMC industry keeps marching right alongside the forward-moving technology. With new uses for wireless devices and new materials to build them, the EMC industry has been keeping pace: new standards, new procedures, new equipment, and new strategies to bring them together.

This issue of ITEM brings all of that and more in one volume for 2024. The need for EMC tools and expertise continues to grow as circuit speeds increase and mitigation techniques expand as far as outer space. EMC practice begins at the circuit design level, moves forward to pre-compliance and final compliance testing, and further to mitigation techniques when found to be necessary.

The basics haven't changed. EMC's mathematical foundations are here in clear, readable form, and the standards built on those foundations are outlined for ready reference. The laboratories and suppliers that keep the industry compliant and safe are indexed here as well, supplemented by articles and insights the practicing EMC engineer needs.

Today the EMC testing laboratories are larger and better equipped, and the standards they follow are better focused and more precise. The proliferation of vehicles with collision avoidance and self-driving capability make good EMC practice a vital concern. The EMC industry is more valuable than it has ever been.

This issue of the ITEM catalogs the EMC industry as it grows to fit the current need. No one knows what the future will offer. But no matter where technology takes us, there will be a need for good EMC practice and for professionals with the tools to keep it that way.

2024 EMC SUPPLIER GUIDE

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 updates@lectrixgroup.com for further supplier contacts.

2024 EMC SUPPLIER MATRIX SPOTLIGHT

ADVERTISERS	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
	AH Systems, Inc. t: 818-998-0223 e: sales@ahsystems.com w: www.ahsystems.com	X	X	X													X	X	X			
	Coilcraft t: 800-322-2645 e: sales@coilcraft.com w: www.coilcraft.com						X			X												
	Exodus Advanced Communications t: 702-534-6564 e: sales@exoduscomm.com w: www.exoduscomm.com	X	X	X															X			
	Fair-rite Products Corp. t: 1-888-FAIRRITE e: ferrites@fair-rite.com w: www.fair-rite.com						X							X								
	R&K Company Limited t: +81-545-31-2600 e: info@rkco.jp w: www.rk-microwave.com	X							X													
	Spectrum Control t: 814-474-1571 e: info@am.spectrumcontrol.com w: www.spectrumcontrol.com	X		X			X			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
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		
	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												
	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															
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			

	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
I	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				
	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		
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		
	RF Consultant	www.rf-consultant.com					X																
	RIGOL Technologies	www.rigolna.com	X							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	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		
	Spectrum Control	www.spectrumcontrol.com	X		X			X			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	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						
	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								

2024 EMC TEST LAB DIRECTORY

WHEREVER YOU ARE IN THE UNITED STATES you now have access to local testing facilities. We have created an easy-to-use directory of national labs and their services grouped alphabetically by state and city, so that our readers can identify labs closest to them. We have strived to make this directory as accurate as possible; our goal is to have the most concise, informative, and up-to-date information. E-mail any additions, revisions, and suggestions to updates@lectrixgroup.com.

USA

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
ALABAMA																						
Huntsville	EMC Compliance www.emccompliance.com	(256) 650-5261			•									•						•		
Huntsville	National Technical Systems www.nts.com	(256) 837-4411		•	•		•	•	•	•	•			•	•	•	•		•	•	•	
ARIZONA																						
Chandler	DNB Engineering, Inc. www.dnbenginc.com	(480) 405-6160			•	•	•				•		•	•	•			•		•	•	
Mesa	Compliance Testing, LLC, aka Flom Test Lab www.compliancetesting.com	(480) 926-3100		•	•		•	•	•		•				•	•		•			•	
Mesa	Robinson's Engineering Consultants www.robinsonsenterprises.com	(480) 361-2539	Contact lab for testing capabilities.																			
Scottsdale	General Dynamics Missions Systems gdmissionsystems.com/	(480) 441-3033												•	•						•	•
Tempe	National Technical Systems www.nts.com	(480) 966-5517	•	•	•	•	•	•	•	•	•	•	•	•				•		•	•	
CALIFORNIA																						
Anaheim	EMC TEMPEST Engineering http://emctempest.com	(714) 778-1726			•		•					•		•				•		•	•	
Brea	CKC Laboratories, Inc. www.ckc.com	(714) 993-6112		•	•		•	•	•		•				•	•					•	
Brea	Compatible Electronics, Inc. www.celectronics.com	(714) 579-0500	•	•	•		•	•	•	•	•			•	•					•		
Carlsbad	NEMKO www.nemko.com	(760) 444-3500	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	
Costa Mesa	Independent Testing Laboratories, Inc. www.itltesting.net	(714) 662-1011			•			•			•			•						•		
Dana Point	NTS nts.com/ntsblog/venues/nts-dana-point/	(949) 429-8602		•	•	•	•	•	•		•	•		•				•		•		
El Dorado Hills	Sanesi Associates	(916) 496-1760		•	•		•	•	•		•										•	
Fremont	CKC Laboratories, Inc. www.ckc.com	(510) 249-1170		•	•	•	•	•	•		•	•		•	•	•		•		•	•	
Fremont	Underwriters Laboratories, Inc. www.ul.com	(510) 319-4000	•	•	•		•	•	•	•	•				•	•						

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Fremont	Elma Electronics, Inc. www.elma.com	(510) 656-3400			•				•												•	
Fremont	HCT America http://hctamerica.com	(510) 933-8848		•	•		•		•		•			•		•				•		
Fullerton	DNB Engineering, Inc. www.dnbenginc.com	(714) 870-7781			•	•	•					•	•	•	•			•		•	•	
Fullerton	National Technical Systems (NTS) www.nts.com	(714) 879-6110		•	•	•	•	•	•		•	•	•	•	•			•		•	•	
Irvine	7Layers, Inc. www.7layers.com	(949) 716-6512		•	•		•	•	•		•											
Irvine	Element EMC www.nwemc.com	(949) 861-8918		•	•		•		•		•				•							
Lake Forest	Compatible Electronics, Inc. www.celectronics.com	(949) 587-0400		•	•		•	•	•		•			•	•	•				•		
Lake Forest	Intertek (Lake Forest) www.intertek.com	(800) 967 5352		•	•	•	•	•	•		•				•	•						
Los Angeles	Field Management Services www.fms-corp.com	(323) 937-1562																			•	
Mariposa	CKC Laboratories, Inc. www.ckc.com	(209) 966-5240		•	•		•	•	•		•			•	•	•					•	
Menlo Park	Intertek (Menlo Park) www.intertek.com	(800) 967-5352	•	•	•	•	•	•	•		•			•	•	•						
Milpitas	CETECOM Inc. www.cetecom.com	(408) 586-6200		•	•		•	•	•		•				•	•						
Moffett Field	RMV Technology Group LLC - NASA Ames Research Center: www.esdrmv.com	(650) 964-4792					•									•					•	
Mountain View	Electro Magnetic Test, Inc. www.emtlabs.com	(650) 965-4000		•	•		•	•	•	•	•	•			•	•						
Newark	NTS https://www.nts.com/locations/silicon_valley	(877) 245-7800		•	•			•	•		•					•						
North Highlands	Northrop Grumman ESL www.northropgrumman.com	(916) 570-4340			•		•		•		•			•						•	•	•
Orange	G & M Compliance, Inc. www.gmcompliance.com	(714) 628-1020	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•	•	•
Pleasanton	Intertek (Pleasanton) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Pleasanton	MiCOM Labs www.micomlabs.com	(925) 462-0304			•		•	•	•		•				•							
Pleasanton	TÜV Rheinland of North America, Inc. www.tuv.com	(925) 249-9123		•	•		•	•	•		•				•	•	•					
Rancho St. Margarita	Aegis Labs, Inc. http://aegislabsinc.com	(949) 751-8089	•		•			•	•		•				•	•						
Redondo Beach	Northrop Grumman Space Tech. Sector www.northropgrumman.com	(310) 812-3162			•	•	•				•		•	•			•	•		•	•	•
Riverside	DNB Engineering, Inc. www.dnbenginc.com	(951) 637-2630	•		•		•	•	•	•	•					•						
Sacramento	Northrop-Grumman EM Systems Lab www.northropgrumman.com	(916) 570-4340			•		•		•		•			•						•	•	•

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
San Diego	Intertek (San Diego) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
San Diego	TDK-Lambda Electronics www.us.lambda.tdk.com	(619) 575-4400			•				•		•											
San Diego	TÜV SÜD America, Inc. www.tuvamerica.com	(858) 678-1400		•	•		•	•	•		•	•	•		•	•				•		
Santa Clara	Montrose Compliance Services, Inc. www.montrosecompliance.com	(408) 247-5715			•			•	•		•					•						
Santa Clara	MET Laboratories, Inc. www.metlabs.com	(408) 748-3585	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	
Santa Clara	TÜV Rheinland EMC Test Center www.tuv.com	(408) 492-9395		•	•		•	•	•		•				•	•	•					
San Jose	Arc Technical Resources, Inc. www.arctechnical.com	(408) 263-6486					•	•	•	•	•	•	•	•				•		•	•	
San Jose	ATLAS Compliance & Engineering Inc. www.atlasce.com	(866) 573-9742			•		•	•	•		•	•			•	•					•	
San Jose	EMCE Engineering, Inc. www.universalcompliance.com	(510) 490-4307	•	•	•		•	•	•	•	•			•		•		•				
San Jose	Safety Engineering Laboratory www.seldirect.com	(408) 544-1890						•								•						
San Jose	Underwriters Laboratories, Inc. www.ul.com	(408) 754-6500	•		•		•	•	•	•	•				•	•					•	
San Marcos	RF Exposure Lab, LLC www.rfexposurelab.com	(760) 471-2100													•		•					
Sunnyvale	Bay Area Compliance Labs. www.baclcorp.com	(408) 732-9162	•	•	•	•	•	•	•	•	•				•	•						
Sunol	ITC Engineering Services, Inc. www.itcemc.com	(925) 862-2944			•		•	•	•	•	•			•	•	•		•				
Trabuco Canyon	RFI International www.rfiinternational.com	(949) 888-1607			•				•	•	•					•						
Union City	MET Laboratories, Inc. www.metlabs.com	(510) 489-6300	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
COLORADO																						
Boulder	Ball Aerospace & Technology Corp. www.ballaerospace.com	(303) 939-4618			•		•				•		•	•				•		•	•	
Boulder	Intertek (Boulder) www.intertek.com	(800) 967-5352		•	•	•	•	•	•		•			•	•	•			•			
Denver	Element www.element.com	(720) 340-7810	Contact lab for testing capabilities.																			
Lakewood	Electro Magnetic Applications, Inc. www.ema3d.com/location/	(303) 980-0070			•	•	•					•							•			
Longmont	NTS www.nts.com/location/longmont-co-vista-view/	(303) 776-7249		•	•		•	•	•		•			•	•					•	•	
CONNECTICUT																						
Newtown	TÜV Rheinland of North America, Inc. www.tuv.com	(203) 426-0888		•	•		•	•	•		•				•	•	•					

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
FLORIDA																						
Lake Mary	Test Equipment Connection www.testequipmentconnection.com	(800) 615-8378																	•			
Newberry	Timco Engineering, Inc. www.timcoengr.com	(352) 472-5500		•	•		•	•	•	•	•				•	•						
Orlando	NTS www.nts.com/location/orlando-fl-emi/	(407) 313-4230		•	•		•	•	•		•			•	•			•		•		
Tampa	TÜV SÜD America, Inc. www.tuv-sud-america.com/us-en	(813) 284-2715	•	•	•	•	•	•	•		•	•		•	•	•		•		•	•	
GEORGIA																						
Alpharetta	EMC Testing Laboratories, Inc. www.emctesting.com	(770) 475-8819			•		•		•	•	•		•			•					•	
Alpharetta	U.S. Technologies, Inc. www.ustechnologies.com	(770) 740-0717	•		•		•	•	•	•	•	•			•	•				•	•	
Duluth	Intertek (Duluth) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Peachtree	Panasonic Automotive: https://na.panasonic.com/us/automotive-solutions	(770) 487-3356			•		•				•				•							
Suwanee	SGS North America www.sgsgroup.us.com	(770) 570-1800			•		•	•	•		•				•	•				•		
ILLINOIS																						
Downers Grove	Elite Electronic Engineering, Inc. www.elitetest.com	(630) 495-9770	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	
Mundelein	Midwest EMI Associates, Inc. www.midemi.com	(847) 393-7316			•		•	•	•		•			•		•				•	•	
Northbrook	Underwriters Laboratories, LLC. www.ul.com	(847) 272-8800	•	•	•		•	•	•	•	•				•	•					•	
Mount Prospect	National Technical Systems NTS www.nts.com	(847) 934-5300	•	•	•	•	•	•	•		•	•		•	•	•				•	•	
Poplar Grove	LF Research EMC Design & Test Facility www.lfresearch.com	(815) 566-5655			•	•	•	•	•		•	•		•		•		•	•	•	•	
Rockford	National Technical Systems NTS www.nts.com	(815) 315-9250		•	•		•	•	•		•											
Romeoville	Radiometrics Midwest Corp. www.radiomet.com	(815) 293-0772	•		•	•	•	•	•		•	•		•	•			•		•	•	
Roselle	Electri-Flex Company www.electriflex.com	(800) 323-6174																			•	
Wheeling	D.L.S. Electronic Systems, Inc. www.dlsemc.com	(847) 537-6400	•	•	•	•	•	•	•		•	•		•	•	•		•		•	•	
INDIANA																						
Indianapolis	Raytheon Technical Services Co., EMI Lab www.raytheon.com	(317) 306-4872			•						•			•	•							•
Indianapolis	F2 Labs, Inc. http://f2labs.com	(877) 405-1580			•	•	•	•	•	•	•	•			•	•				•		

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
KANSAS																						
Louisburg	Rogers Labs, Inc. www.rogerslabs.com	(913) 837-3214			•		•		•		•			•	•					•		
KENTUCKY																						
Lexington	Lexmark International EMC Lab www.lexmark.com	(859) 232-2000							•													
Lexington	Intertek (Lexington) www.intertek.com	(800) 976-5352	•	•	•	•	•	•	•		•			•	•							
MAINE																						
Portland	Enerdoor www.enerdoor.com	(207) 210-6511			•		•	•			•											
MARYLAND																						
Baltimore	MET Laboratories, Inc. www.metlabs.com	(410) 354-3300	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	
Columbia	Advanced Programs Inc. www.advprograms.com	(410) 312-5800												•						•		•
Damascus	F2 Labs, Inc. http://f2labs.com	(301) 253-4500			•	•	•	•	•	•	•	•			•	•				•		
Elkridge	ATEC Industries, Ltd. www.atecindustries.com	(443) 459-5080				•	•					•	•	•	•						•	
Frederick	The American Association for Lab Accreditation; www.a2la.org	(301) 644-3248													•							
Frederick	Washington Labs www.wll.com	(301) 216-1500							•							•						
Gaithersburg	Washington Laboratories, Ltd. www.wll.com	(301) 216-1500			•	•		•	•		•	•	•	•	•	•	•	•		•	•	
Rockville	P.J. Mondin, P.E. Consultants	(301) 460-5864							•					•							•	•
MASSACHUSETTS																						
Billerica	Quest Engineering Solutions www.qes.com	(978) 667-7000																			•	
Boxborough	Intertek (Boxborough) www.intertek.com	(800) 967-5352		•	•	•	•	•	•	•	•			•	•	•		•		•	•	
Boxborough	National Technical Systems www.nts.com	(978) 266-1001	•	•	•	•	•	•	•	•	•	•	•	•	•			•		•	•	
Burlington	NELCO www.nelcoworldwide.com	(781) 933-1940																			•	
Littleton	TÜV Rheinland of North America, Inc. www.tuv.com	(978) 266-9500		•	•		•	•	•		•					•						
Littleton	Compliance Management Group www.cmgcorp.net	(978) 431-1985	•		•		•	•	•		•				•	•					•	
Milford	Test Site Services, Inc. www.testsiteservices.com	(508) 634-3444	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Newton	EMC Test Design, LLC www.emctd.com	(508) 292-1833															•					
Peabody	TÜV SUD America Inc. www.tuv-sud-america.com/us-en	(978) 573-2500	•	•	•	•	•	•	•		•	•		•	•	•		•		•	•	
Pittsfield	National Technical Systems www.nts.com	(413) 499-2135		•	•	•	•	•	•		•	•			•					•		
Woburn	Chomerics, Div. of Parker Hannifin Corp. www.chomerics.com	(781) 935-4850			•	•	•	•	•		•	•	•	•	•	•	•	•		•	•	
MICHIGAN																						
Brighton	Willow Run Test Labs, LLC www.wrtest.com	(734) 252-9785			•		•		•												•	
Burton	Trialon Corporation (Now Element) element.com/landing/CTM-trialon-is-now-element	(810) 742-8500			•		•				•				•							
Detroit	National Technical Systems www.nts.com	(313) 835-0044		•	•		•	•	•		•				•			•				
Detroit	TÜV Rheinland of North America, Inc. www.tuv.com/en/middleeast/home.jsp	(734) 207-9852		•	•		•	•	•		•					•						
Grand Rapids	Intertek (Grand Rapids) www.intertek.com	(800) 967-5352		•	•	•	•	•	•		•	•			•	•		•		•		
Holland	TÜV SÜD America, Inc. www.tuv-sud-america.com/us-en	(616) 546-3902		•	•		•	•	•		•								•			
Novi	Underwriters Laboratories, Inc. www.ul.com	(248) 427-5300			•		•	•			•			•	•	•				•	•	
Plymouth	Intertek (Plymouth) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Plymouth	TÜV SÜD America, Inc. www.tuvamerica.com	(734) 455-4841	•	•	•	•	•	•	•		•	•		•	•	•		•			•	
Sister Lakes	AHD EMC Lab www.ahde.com	(269) 313-2433			•		•	•	•		•			•	•						•	
MINNESOTA																						
Brooklyn Park	Element www.element.com	(612) 638-5136		•	•		•		•		•				•							
Glencoe	International Certification Services, Inc. www.icsi-us.com	(320) 864-4444	•		•		•	•	•		•			•	•	•				•	•	
Minneapolis	Element www.element.com	(952) 888-7795													•							
MISSOURI																						
St. Louis	Boeing-St. Louis EMC Lab www.boeing.com	(314) 232-0232												•	•			•			•	
NEBRASKA																						
Lincoln	NCEE Labs www.nceelabs.com	(402) 323-6233			•		•	•	•		•			•	•	•				•		
NEW HAMPSHIRE																						
Goffstown	Retlif Testing Laboratories www.retlif.com	(603) 497-4600		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Hudson	Core Compliance Testing Services www.corecompliancetesting.com	(603) 889-5545			•		•		•		•	•			•							
Sandown	Compliance Worldwide, Inc. www.cw-inc.com	(603) 887-3903			•		•		•	•	•	•			•							
NEW JERSEY																						
Annandale	NU Laboratories, Inc. www.nulabs.com	(908) 713-9300					•							•	•						•	
Bridgewater	Lichtig EMC Consulting www.lichtigemc.com	(908) 541-0213	•																			
Camden	L-3 Communication Systems-East www.l3harris.com/	(856) 338-3000	Contact lab for testing capabilities.																			
Clifton	NJ-MET www.njmetmtl.com	(973) 546-5393	•							•												•
Edison	Metex Corporation www.metexcorp.com	(732) 287-0800																			•	
Edison	TESEQ, Inc. www.teseq.com	(732) 417-0501				•				•												
Fairfield	Intertek (Fairfield) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Fairfield	SGS U.S. Testing Co., Inc. www.sgsgroup.us.com	(973) 575-5252	•		•			•							•	•						
Farmingdale	EMC Technologists A Div. of I2R Corp. www.emctech.com	(732) 919-1100	•		•		•	•	•	•	•			•								
Hillsborough	Advanced Compliance Laboratory, Inc. http://ac-lab.com	(908) 927-9288 ext. 106			•			•	•	•	•				•	•						
Rutherford	SGS International Certification Services, Inc.; www.sgsgroup.us.com	(201) 508-3000						•														
Thorofare	NDI Engineering Company www.ndieng.com	(856) 848-0033																			•	
Tinton Falls	National Technical Systems (NTS) www.nts.com	(732) 936-0800	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	•
NEW MEXICO																						
Albuquerque	Advanced Testing Services, Inc. www.advanced-testing.com	(505) 292-2032											•				•				•	
White Sands	USA WSMR, Survivability Directorate www.wsmr.army.mil	(575) 678-1621			•	•	•				•	•		•			•	•			•	
NEW YORK																						
College Point	Aero Nav Laboratories, Inc. www.aeronavlabs.com	(718) 939-4422	•			•			•		•	•		•	•			•		•	•	•
Deer Park	Universal Shielding Corp. www.universalshielding.com	(631) 392-4888																			•	
Endicott	BAE Systems Controls, Inc. www.baesystems.com	(607) 770-2000			•	•						•		•	•			•		•		
Medford	American Environments Co. www.aeco.com	(631) 736-5883	•		•	•	•	•	•		•	•		•		•				•	•	
Melville	Underwriters Laboratories, LLC. www.ul.com	(631) 271-6200	•	•	•		•	•	•	•	•				•	•					•	

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Poughkeepsie	IBM Corp. Poughkeepsie EMC Lab www.ibm.com	(845) 433-1234		•					•													
Webster	TÜV Rheinland Of North America www.tuv.com	(585) 645-0125		•	•		•	•	•		•				•	•	•					
Ronkonkoma	Retlif Testing Laboratories www.retlif.com	(631) 737-1500		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
NORTH CAROLINA																						
Cary	CertifiGroup www.certifigroup.com	(919) 466-9283		•				•							•	•						
Cary	MET Laboratories, Inc. www.metlabs.com	(919) 481-9319	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
Greensboro	Schneider Electric Industrial Repair Services www.schneiderelectricrepair.com	(800) 950-9550																	•			
Greenville	Lawrence Behr Associates (LBA) www.lbagroup.com	(252) 757-0279															•				•	
Res. Triangle Pk.	Educated Design & Dev., Inc. (ED&D) www.productsafet.com	(919) 469-9434		•											•	•			•			•
Res. Triangle Pk.	IBM RTP EMC Test Labs www.ibm.com	(800) 426-4968			•				•		•											
Res. Triangle Pk.	Underwriters Laboratories, LLC. www.ul.com	(919) 549-1400	•	•	•		•	•	•	•	•				•	•					•	
OHIO																						
Cleveland	CSA International www.csagroup.org	(216) 524-4990						•								•						
Cleveland	NASA GRC EMI Lab www1.grc.nasa.gov	(216) 433-4000												•							•	
Colombus	Intertek (Colombus) www.intertek.com	(800) 967 5352		•	•		•	•	•		•											
Mason	L-3 Cincinnati Electronics www.cinele.com	(513) 573-6100			•		•				•			•				•		•		
Middlefield	F2 Labs, Inc. http://f2labs.com	(440) 632-5541		•	•	•	•	•	•	•	•	•			•	•					•	
Springboro	Pioneer Automotive Technologies	(937) 746-6600			•		•		•		•			•	•							
OREGON																						
Beaverton	Tektronix www.tek.com	(503) 627-4133	•												•					•		
Fairview	Intertek (Fairview) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Hillsboro	Element www.element.com	(503) 648-1818	•												•					•		
Hillsboro	ElectroMagnetic Investigations, LLC https://emicomply.com/contact/	(503) 466-1160			•		•	•	•		•			•	•						•	
Hillsboro	Element www.element.com	(503) 844-4066		•	•		•		•		•				•					•	•	
Portland	TÜV SÜD America, Inc. www.tuv-sud-america.com/us-en	(503) 598-7580		•	•	•	•	•	•		•					•						

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
PENNSYLVANIA																						
Chambersburg	Cuming Lehman Chambers http://cuminglehman.com	(717) 263-4101			•						•			•						•		
Glenside	Electro-Tech Systems, Inc. www.electrotechsystems.com	(215) 887-2196	•				•														•	
Harleysville	Retlif Testing Laboratories www.retlif.com	(215) 256-4133		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
Hatfield	Laboratory Testing Inc. www.labtesting.com	(800) 219-9095													•				•			
New Castle	Keystone Compliance LLC www.keystonecompliance.com	(724) 657-9940	•		•	•	•	•	•		•	•	•	•	•	•	•	•		•	•	
Pottstown	BEC Inc. www.bec-ccl.com	(610) 970-6880			•		•		•		•				•						•	
State College	Videon Central, Inc. www.videon-central.com	(814) 235-1111			•		•	•	•											•		
West Conshohocken	R&B Laboratory www.rblaboratory.com	(610) 825-1960			•	•	•				•	•		•			•	•		•	•	
TENNESSEE																						
Knoxville	Global Testing Labs LLC www.globaltestinglabs.com	(865) 523-9972			•				•		•				•							
Knoxville	AMS Corporation www.ams-corp.com	(865) 691-1756			•		•				•			•								
TEXAS																						
Austin	BAE Systems IDS Test Services www.baesystems.com	(512) 926-2800											•					•				
Austin	MET Laboratories, Inc. www.metlabs.com	(512) 287-2500	•	•	•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	
Bartonville	Nemko USA www.nemko.com	(940) 294-7057		•	•		•	•	•	•	•			•	•	•	•	•		•	•	
Cedar Park	TDK RF Solutions, Inc. www.tdkrfsolutions.tdk.com	(512) 258-9478			•		•	•	•	•	•				•							
Elmendorf	Intertek (Elmendorf) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Plano	National Technical Systems www.nts.com	(972) 509-2566	•	•	•	•	•	•	•	•	•	•		•	•			•		•	•	
Plano	Element www.element.com	(469) 304-5255		•	•		•		•		•				•							
Plano	Intertek (Plano) www.intertek.com	(800) 967-5352		•	•	•	•	•	•		•				•	•						
Round Rock	Professional Testing (EMI), Inc. www.ptitest.com	(512) 244-3371			•		•		•		•	•		•	•	•			•	•	•	
San Antonio	Southwest Research Institute www.swri.org	(210) 684-5111	•		•	•	•	•	•	•	•	•	•	•	•	•		•		•	•	
UTAH																						
Coalville	DNB Engineering, Inc. www.dnbenginc.com	(435) 336-4433	•		•		•	•	•	•	•					•						

USA continued

CITY/STATE	COMPANY NAME / WEBSITE	PHONE #	BELLCORE/TELCORDIA	CB/CAB/TCB CB/CAB/TCB	EMISSIONS	EMP/LIGHTNING EFFECTS	ESD	EURO CERTIFICATIONS	FCC PART 15 & 18	FCC PART 68	IMMUNITY	LIGHTNING STRIKE	MIL-STD 188/125	MIL-STD 461	NVLAP/A2LA APPROVED	PRODUCT SAFETY	RADHAZ TESTING	RS103 > 200 V/METER	REPAIR/CALIBRATION	RTCA DO-160	SHIELDING EFFECTIVENESS	TEMPEST
Draper	VPI Technology www.vpitechnology.com	(801) 495-2310			•		•	•	•	•	•			•	•	•						
Ogden	Little Mountain Test Facility (LMTF)	(801) 315-2320			•	•	•				•		•	•				•		•	•	
Salt Lake City	L3 Communication Systems-West www.l3harris.com	(801) 594-2000			•			•	•					•						•		
VERMONT																						
Middlebury	Green Mountain Electromagnetics, Inc. www.gmelectro.com	(802) 388-3390						•	•	•			•	•								
VIRGINIA																						
Fredericksburg	E-LABS INC. www.e-labsinc.com	(540) 834-0372			•		•				•			•	•		•			•	•	
Fredericksburg	Vitatech Engineering, LLC http://vitatech.net	(540) 286-1984	•		•				•	•	•		•	•							•	
Herndon	Rhein Tech Laboratories, Inc. www.rheintech.com	(703) 689-0368			•		•	•	•		•			•	•	•				•	•	
Reston	TEMPEST, Inc. (VA) www.tempest-inc.com	(703) 836-7378			•		•	•	•	•	•		•	•							•	•
Richmond	Technology International, Inc. www.techintl.com	(804) 794-4144		•	•		•	•			•					•						•
WASHINGTON																						
Bothell	CKC Laboratories, Inc www.ckc.com	(425) 402-1717		•	•	•	•	•	•		•	•	•	•	•			•		•	•	
Bothell	Element www.element.com	(425) 984-6600			•		•		•		•				•	•						
WISCONSIN																						
Genoa City	D.L.S. Electronic Systems, Inc. www.dlsemc.com	(262) 279-0210		•	•				•						•							
Middleton	Intertek www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
Neenah	International Compliance Laboratories www.icl-us.com	(920) 720-5555			•		•		•		•				•							

EMC/EMI CONSULTANTS DIRECTORY

WYATT TECHNICAL SERVICES LLC

Consultancy Services: EMC Consultation, EMC Design Reviews, Pre-Compliance Testing, Training Services
Kenneth Wyatt, Principal Consultant
Phone: (719) 310-5418
www.emc-seminars.com

MIKE VIOLETTE, P.E., CEO

Consultancy Services: Radio Testing, Global Regulatory Standards
Mike Violette
Phone: (240) 401-1388
Email: mikev@wll.com
www.wll.com

DAVID A. WESTON/EMC ENGINEER

Consultancy Services: EMC Analysis, Circuit and Equipment Design for EMC, EMI Problem Solving, R&D
David A. Weston
Phone: (613) 269-4247
Email: emccons0@gmail.com
www.emcconsultinginc.com

GHERY S. PETTIT/PRESIDENT, PETTIT EMC CONSULTING LLC

Consultancy Services: EMC Standards, Product and Laboratory Design, and Troubleshooting Specializing in ITE Related EMC.
Ghery S. Pettit
Phone: (360) 790-9672
Email: Ghery@PettitEMCConsulting.com
www.PettitEMCConsulting.com

PATRICK G. ANDRÉ/CONSULTANT, ANDRÉ CONSULTING, INC.

Consultancy Services: Troubleshooting, Design, Training and Test Support
Patrick G. André
Phone: (206) 406-8371
Email: pat@andreconsulting.com
https://andreconsulting.com

2024 CONSOLIDATED STANDARDS

MANY IEC STANDARDS have been adopted by the European Union with and EN designation replacing the IEC while maintaining the same number. In several cases the standard may have been modified. When using an IEC standard, one should check for IEC – EN differences and in both cases check for the current edition.

The standards list adds a category column to help assign the identified standard to a particular type or discipline. Most are self-explanatory, but to avoid confusion the category assignments follow. Often a particular standard could fit in more than one category, so the assignment is simply a judgement call.

- Apparatus – this category is used to group standards for a product or device where it fails to fit in a specific group. For example, a medical device could be a product but it fits into the medical category more closely.
- Auto/Vehicle – standard primarily deals with automotive but includes ship or rail.
- General – primarily deals with definitive or general EM control information.
- Generic – deals with product standards not assigned to a particular group.
- Medical – medical equipment or methods
- MIL/Aero – MIL-STD, Space, Aeronautical equipment, or methods – includes associated design guides.
- Test – primarily deals with test methods
- Wireless – primarily deals with intentional RF emitters or receivers.

Useful websites associated with standards include but not limited to:

ANSI	http://webstore.ansi.org; www.ansi.org; www.c63.org
APLAC	Asia Pacific Laboratory Accreditation Cooperation (APLAC) https://www.apac-accreditation.org/
BSMI	https://www.bsmi.gov.tw/wSite/mp?mp=1
CSA	http://www.cnca.gov.cn/
EN	https://www.en-standard.eu/
FCC	Federal Communications Commission (FCC) www.fcc.gov; Electronic Code of Fderal Regulations https://www.ecfr.gov
FDA	FDA Center for Devices & Radiological Health (CDRH) https://www.fda.gov/MedicalDevices/default.htm
Ford	https://www.fordemc.com
GM	https://global.ihs.com
IC	Industry Canada (Certifications and Standards) http://www.ic.gc.ca/eic/site/smt-gst.nsf/eng/h_sf06165.html
IEC / CISPR	https://webstore.iec.ch
IEEE	IEEE Standards Association https://standards.ieee.org/
IEEE EMC	IEEE EMC Society Standards Development Committee (SDCOM) https://standards.ieee.org/develop/index.html
ISED	Innovation, Science and Economic Development Canada; https://www.ic.gc.ca/eic/site/icgc.nsf/eng/home
ISO	ISO (International Organization for Standards) http://www.iso.org/iso/home.html
MIL-STD	https://quicksearch.dla.mil/qsSearch.aspx
RTCA	https://www.rtca.org
Russia	Gosstandart (Russia) https://gosstandart.gov.by/en
SAE	SAE EMC Standards Committee www.sae.org
VCCI	VCCI (Japan, Voluntary Control Council for Interference) http://www.vcci.jp/vcci_e/

Category	Publisher	Number	Title
Apparatus	IEC	60118-13	Electroacoustics - Hearing aids - Part 13: Electromagnetic compatibility (EMC)
Apparatus	IEC	60255-26	Measuring relays and protection equipment - Part 26: Electromagnetic compatibility requirements
Apparatus	IEC	60364-4-44	Low-voltage electrical installations - Part 4-44: Protection for safety - Protection against voltage disturbances and electromagnetic disturbance
Apparatus	IEC	60728-12	Cabled distribution systems for television and sound signals - Part 12: Electromagnetic compatibility of systems IEC (continued)
Apparatus	IEC	60728-2	Cabled distribution systems for television and sound signals - Part 2: Electromagnetic compatibility for equipment
Apparatus	IEC	60870-2-1	Telecontrol equipment and systems - Part 2: Operating conditions - Section 1: Power supply and electromagnetic compatibility
Apparatus	IEC	60974-10	Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements
Apparatus	IEC	61000-3-11	Electromagnetic compatibility (EMC) - Part 3-11: Limits - Limitation of voltage changes, voltage fluctuations and flicker in public low voltage supply systems - Equipment with rated current <= 75 A and subject to conditional connection IEC (continued)
Apparatus	IEC	61000-3-12	Electromagnetic compatibility (EMC) - Part 3-12: Limits - Limits for harmonic currents produced by equipment connected to public low-voltage systems with input current >16 A and <=75 A per phase
Apparatus	IEC	61000-3-2	Electromagnetic compatibility (EMC)–Part 3-2: Limits - Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
Apparatus	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
Apparatus	IEC	61000-3-8	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 8: Signaling on low-voltage electrical installations - Emission levels, frequency bands and electromagnetic disturbance levels
Apparatus	IEC	61326-1	Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements
Apparatus	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
Apparatus	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
Apparatus	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
Apparatus	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
Apparatus	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

Category	Publisher	Number	Title
Apparatus	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
Apparatus	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
Apparatus	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
Apparatus	IEC	61543	Residual current-operated protective devices (RCDs) for household and similar use - Electromagnetic compatibility
Apparatus	IEC	61800-3	Adjustable speed electrical power drive systems - Part 3: EMC requirements and specific test methods
Apparatus	IEC	61967-1	Integrated circuits - Measurement of electromagnetic emissions, 150 kHz to 1 GHz - Part 1: General conditions and definitions
Apparatus	IEC	62040-2	Uninterruptible power systems (UPS) - Part 2: Electromagnetic compatibility EMC) requirements
Apparatus	IEC	62041	Power transformers, power supply units, reactors and similar products - EMC requirements
Apparatus	IEC	62209-1528	Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices - Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)
Apparatus	IEC	62310-2	Static transfer systems (STS) - Part 2: Electromagnetic compatibility (EMC) requirements
Apparatus	IEC	CISPR 11	Industrial, scientific and medical (ISM) radio-frequency equipment - Electromagnetic disturbance characteristics - Limits and methods of measurement
Apparatus	IEC	CISPR 14-1	Electromagnetic compatibility - Requirements for household appliances, electric tools and similar apparatus - Part 1: Emission
Apparatus	IEC	CISPR 14-2	Electromagnetic compatibility – Requirements for household appliances, electric tools and similar apparatus – Part 2: Immunity – Product family standard
Apparatus	IEC	CISPR 15	Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
Apparatus	IEC	CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
Apparatus	IEC	CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements
Apparatus	IEC	TR 61000-3-13	Electromagnetic compatibility (EMC) - Part 3-13: Limits - Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems
Apparatus	IEC	TR 61000-3-14	Electromagnetic compatibility (EMC) - Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems
Apparatus	IEC	TR 61000-3-15	Electromagnetic compatibility (EMC) - Part 3-15: Limits - Assessment of low frequency electromagnetic immunity and emission requirements for dispersed generation systems in LV network

Category	Publisher	Number	Title
Apparatus	IEC	TR 61000-3-6	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 6: Assessment of emission limits for distorting loads in MV and HV power systems - Basic EMC publication
Apparatus	IEC	TR 61000-3-7	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 7: Assessment of emission limits for fluctuating loads in MV and HV power systems - Basic EMC publication
Apparatus	IEC	TR 63170	Measurement procedure for the evaluation of power density related to human exposure to radio frequency fields from wireless communication devices operating between 6 GHz and 100 GHz
Apparatus	IEC	TS 61000-3-4	Electromagnetic compatibility (EMC) - Part 3-4: Limits - Limitation of emission of harmonic currents in low-voltage power supply systems for equipment with rated current greater than 16 A
Apparatus	IEC	TS 61000-3-5	Electromagnetic compatibility (EMC) - Part 3: Limits - Section 5: Limitation of voltage fluctuations and flicker in low-voltage power supply systems for equipment with rated current greater than 16 A
Apparatus	IEC/IEEE	63195-1	Assessment of power density of human exposure to radio frequency fields from wireless devices in close proximity to the head and body (frequency range of 6 GHz to 300 GHz) - Part 1: Measurement procedure
Auto/Vehicle	Audi	TL 82466	Electrostatic Discharge
Auto/Vehicle	BMW	600 13.0	Electric- / Electronic components in cars BMW GS 95002 Electromagnetic Compatibility (EMC) Requirements and Tests
Auto/Vehicle	BMW	GS 95003-2	GS 95003-2 Electric- / Electronic assemblies in motor vehicles
Auto/Vehicle	Chrysler	PF 9326	Electrical electronic modules and motors
Auto/Vehicle	Diamer Chrysler	DC-10614	EMC Performance Requirements – Components
Auto/Vehicle	Diamer Chrysler	DC-10615	Electrical System Performance Requirements for Electrical and Electronic Components
Auto/Vehicle	Diamer Chrysler	DC-11223	Performance Requirements -- Vehicle Automotive Electromagnetic Compatibility Standards
Auto/Vehicle	Diamer Chrysler	DC-11224	EMC Performance Requirements – Components
Auto/Vehicle	Diamer Chrysler	DC-11225	EMC Supplemental Information and Alternative Component Requirements
Auto/Vehicle	Fiat	9.90110	Electric and electronic devices for motor vehicles Freightliner 49-00085 EMC Requirements
Auto/Vehicle	FORD	EMC-CS-2009.1	Component EMC Specification. EMC-CS-2009.1
Auto/Vehicle	FORD	F-2	Electrical and Electronics System Engineering
Auto/Vehicle	FORD	WSF-M22P5-A1	Printed Circuit Boards, PTF, Double Sided, Flexible
Auto/Vehicle	GM	GMW3091	General Specification for Vehicles, Electromagnetic Compatibility (EMC)-Engl; Revision H; Supersedes GMI 12559 R and GMI 12559 V
Auto/Vehicle	GM	GMW3097	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility-Engl; Revision H; Supersedes GMW12559, GMW3100, GMW12002R AND GMW12002V
Auto/Vehicle	GM	GMW3103	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility Global EMC Component/Subsystem Validation Acceptance Process-Engl; Revision F; Contains Color; Replaces GMW12003, GMW12004 and GMW3106
Auto/Vehicle	Honda	3838Z-S5AA-L000	Noise Simulation Test

Category	Publisher	Number	Title
Auto/Vehicle	Honda	3982Z-SDA-0030	Battery Simulation Test
Auto/Vehicle	Hyundia Kia	ES 39111-00	EMC Requirements
Auto/Vehicle	Hyundia Kia	ES 95400-10	Battery Simulation Tests
Auto/Vehicle	Hyundia Kia	ES 96100-01	EMC Requirements
Auto/Vehicle	IEC	60533	Electrical and electronic installations in ships - Electromagnetic compatibility (EMC) - Ships with a metallic hull
Auto/Vehicle	IEC	61851-21-1	Electric vehicle conductive charging system - Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply
Auto/Vehicle	IEC	61851-21-2	Electric vehicle conductive charging system - Part 21-2: Electric vehicle requirements for conductive connection to an AC/DC supply - EMC requirements for off board electric vehicle charging systems
Auto/Vehicle	IEC	62236-1	Railway applications - Electromagnetic compatibility - Part 1: General
Auto/Vehicle	IEC	62236-2	Railway applications - Electromagnetic compatibility - Part 2: Emission of the whole railway system to the outside world
Auto/Vehicle	IEC	62236-3-1	Railway applications - Electromagnetic compatibility - Part 3-1: Rolling stock - Train and complete vehicle
Auto/Vehicle	IEC	62236-3-2	Railway applications - Electromagnetic compatibility - Part 3-2: Rolling stock – Apparatus
Auto/Vehicle	IEC	62236-4	Railway applications - Electromagnetic compatibility - Part 4: Emission and immunity of the signaling and telecommunications apparatus
Auto/Vehicle	IEC	62236-5	Railway applications - Electromagnetic compatibility - Part 5: Emission and immunity of fixed power supply installations and apparatus
Auto/Vehicle	IEC	CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
Auto/Vehicle	IEC	CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
Auto/Vehicle	IEC	TR 62482	Electrical installations in ships - Electromagnetic compatibility - Optimizing of cable installations on ships - Testing method of routing distance
Auto/Vehicle	ISL	11451-3	Road vehicles -- Electrical disturbances by narrowband radiated electromagnetic energy -- Vehicle test methods -- Part 3: On-board transmitter simulation
Auto/Vehicle	ISO	10605	Road vehicles -- Test methods for electrical disturbances from electrostatic discharge
Auto/Vehicle	ISO	11451-1	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 1: General principles and terminology
Auto/Vehicle	ISO	11451-2	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 2: Off-vehicle radiation sources
Auto/Vehicle	ISO	11451-4	Road vehicles -- Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)
Auto/Vehicle	ISO	11452-1	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology

Category	Publisher	Number	Title
Auto/Vehicle	ISO	11452-10	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 10: Immunity to conducted disturbances in the extended audio frequency range
Auto/Vehicle	ISO	11452-11	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 11: Reverberation chamber ISO 13766 Earth-moving machinery – Electromagnetic compatibility
Auto/Vehicle	ISO	11452-2	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Absorber-lined shielded enclosure
Auto/Vehicle	ISO	11452-3	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 3: Transverse electromagnetic mode (TEM) cell
Auto/Vehicle	ISO	11452-4	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 4: Bulk current injection (BCI)
Auto/Vehicle	ISO	11452-5	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 5: Stripline
Auto/Vehicle	ISO	11452-7	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 7: Direct radio frequency (RF) power injection
Auto/Vehicle	ISO	11452-8	Road vehicles -- Component test methods for electrical disturbances from narrowband radiated electromagnetic energy -- Part 8: Immunity to magnetic fields
Auto/Vehicle	ISO	7637-1	Road vehicles -- Electrical disturbances from conduction and coupling -- Part 1: Definitions and general considerations
Auto/Vehicle	ISO	7637-2	Road vehicles -- Electrical disturbances from conduction and coupling -- Part 2: Electrical transient conduction along supply lines only
Auto/Vehicle	ISO	7637-3	Road vehicles -- Electrical disturbance by conduction and coupling -- Part 3: Vehicles with nominal 12 V or 24 V supply voltage -- Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
Auto/Vehicle	ISO	TR 10305-1	Road vehicles -- Calibration of electromagnetic field strength measuring devices -- Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz
Auto/Vehicle	ISO	TR 10305-2	Road vehicles -- Calibration of electromagnetic field strength measuring devices -- Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz
Auto/Vehicle	ISO	TS 14907-1	Road transport and traffic telematics -- Electronic fee collection – Test procedures for user and fixed equipment – Part 1: Description of test procedures
Auto/Vehicle	ISO	TS 14907-2	Road transport and traffic telematics – Electronic fee collection -- Test procedures for user and fixed equipment -- Part 2: Conformance test for the onboard unit application interface
Auto/Vehicle	ISO	TS 21609	Road vehicles -- (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment
Auto/Vehicle	KVECO	16-2103	EMC Requirements
Auto/Vehicle	Lotus	17.39.01	Lotus Engineering Standard: Electromagnetic Compatibility
Auto/Vehicle	Mack	606GS15	EMC Requirements MAN 3285 EMC Requirements
Auto/Vehicle	Mazda	MES PW 67600	Automobile parts standard (electronic devices)
Auto/Vehicle	Mercedes	A 211 000 42 99	Instruction specification of test method for E/Ecomponents

Category	Publisher	Number	Title
Auto/Vehicle	Mercedes	AV EMV	Electric aggregate and electronics in cars
Auto/Vehicle	Mercedes	MBN 10284-2	EMC requirements and tests of E/E-systems (component test procedures)
Auto/Vehicle	Mercedes	MBN 2200-2	Electric / electronic elements, devices in trucks
Auto/Vehicle	Mitsubishi	ES-X82010	General specification of environment tests on automotive electronic equipment
Auto/Vehicle	Nissan	28400 NDS03	Low frequency surge resistance of electronic parts
Auto/Vehicle	Nissan	28400 NDS04	Burst and Impulse Waveforms
Auto/Vehicle	Nissan	28400 NDS07	Immunity against low frequency surge (induction surge) of electronic parts
Auto/Vehicle	Nissan	28401 NDS02	EMC requirements (instruction concerning vehicle and electrical ...)
Auto/Vehicle	Peugeot	B217110	Load Dump Pulses
Auto/Vehicle	Porsche	AV EMC EN	EMC Requirements
Auto/Vehicle	PSA	B21 7090	EMC Requirements (electric and electronics equipment)
Auto/Vehicle	PSA	B21 7110	EMC requirements (electric and electronics equipment)
Auto/Vehicle	Renault	36.00.400	Physical environment of electrical and electronic equipment
Auto/Vehicle	Renault	36.00.808	EMC requirements (cars and electrical / electronic components)
Auto/Vehicle	SAE	J1113/1	Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (Up to 15 M), and Machines (Except Aircraft) (50 Hz to 18 Ghz)
Auto/Vehicle	SAE	J1113/11	Immunity to Conducted Transients on Power Leads
Auto/Vehicle	SAE	J1113/12	Electrical Interference by Conduction and Coupling - Capacitive and Inductive Coupling via Lines Other than Supply Lines
Auto/Vehicle	SAE	J1113/13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Part 13: Immunity to Electrostatic Discharge
Auto/Vehicle	SAE	J1113/2	Electromagnetic Compatibility Measurement Procedures and Limits for Vehicle Components (Except Aircraft)--Conducted Immunity, 15 Hz to 250 kHz--All Leads
Auto/Vehicle	SAE	J1113/21	Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Part 21: Immunity to Electromagnetic Fields, 30 MHz to 18 GHz, Absorber-Lined Chamber
Auto/Vehicle	SAE	J1113/26	Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Immunity to AC Power Line Electric Fields
Auto/Vehicle	SAE	J1113/27	Electromagnetic Compatibility Measurements Procedure for Vehicle Components - Part 27: Immunity to Radiated Electromagnetic Fields - Mode Stir Reverberation Method
Auto/Vehicle	SAE	J1113/28	Electromagnetic Compatibility Measurements Procedure for Vehicle Components--Part 28--Immunity to Radiated Electromagnetic Fields--Reverberation Method (Mode Tuning)
Auto/Vehicle	SAE	J1113/4	Immunity to Radiated Electromagnetic Fields-Bulk Current Injection (BCI) Method
Auto/Vehicle	SAE	J1752/1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits-Integrated Circuit EMC Measurement Procedures-General and Definition
Auto/Vehicle	SAE	J1752/2	Measurement of Radiated Emissions from Integrated Circuits -- Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz

Category	Publisher	Number	Title
Auto/Vehicle	SAE	J1752/3	Measurement of Radiated Emissions from Integrated Circuits -- TEM/ Wideband TEM (GTEM) Cell Method; TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)
Auto/Vehicle	SAE	J1812	Function Performance Status Classification for EMC Immunity Testing
Auto/Vehicle	SAE	J2556	Radiated Emissions (RE) Narrowband Data Analysis--Power Spectral Density (PSD)
Auto/Vehicle	SAE	J2556	Radiated Emissions (RE) Narrowband Data Analysis–Power Spectral Density (PSD)
Auto/Vehicle	SAE	J2628	Characterization--Conducted Immunity
Auto/Vehicle	SAE	J2628	Characterization–Conducted Immunity
Auto/Vehicle	SAE	J551/15	Vehicle Electromagnetic Immunity--Electrostatic Discharge (ESD)
Auto/Vehicle	SAE	J551/16	Electromagnetic Immunity - Off-Vehicle Source (Reverberation Chamber Method) - Part 16 - Immunity to Radiated Electromagnetic Fields
Auto/Vehicle	SAE	J551/17	Vehicle Electromagnetic Immunity -- Power Line Magnetic Fields
Auto/Vehicle	SAE	J551/5	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz To 30 MHz
Auto/Vehicle	Scania	TB1400	EMC Requirements
Auto/Vehicle	Scania	TB1700	Load Dump Test
Auto/Vehicle	Smart	DE10005B	EMC requirements (electric aggregate and electronics in cars)
Auto/Vehicle	Toyota	TSC203G	Engineering standard (ABS-TRC computers)
Auto/Vehicle	Toyota	TSC7001G	Engineering standard (electric noise of electronic devices)
Auto/Vehicle	Toyota	TSC7001G-5.1	Power Supply Voltage Characteristic Test
Auto/Vehicle	Toyota	TSC7001G-5.2	Field Decay Test
Auto/Vehicle	Toyota	TSC7001G-5.3	Floating Ground Test
Auto/Vehicle	Toyota	TSC7001G-5.4	Induction Noise Resistance
Auto/Vehicle	Toyota	TSC7001G-5.5.3	Load Dump Test-1
Auto/Vehicle	Toyota	TSC7001G-5.5.4	Load Dump Test-2
Auto/Vehicle	Toyota	TSC7001G-5.5.5	Load Dump Test-3
Auto/Vehicle	Toyota	TSC7001G-5.6	Over Voltage Test
Auto/Vehicle	Toyota	TSC7001G-5.7.3	Ignition Pulse (Battery Waveforms) Test-1
Auto/Vehicle	Toyota	TSC7001G-5.7.4	Ignition Pulse (Battery Waveforms) Test-2
Auto/Vehicle	Toyota	TSC7001G-5.8	Reverse Voltage
Auto/Vehicle	Toyota	TSC7006G-4.4.2	Wide Band-Width Antenna Nearby Test (0.4 to 2 GHz)
Auto/Vehicle	Toyota	TSC7006G-4.4.3	Radio Equipment Antenna nearby Test (28 MHz ...)
Auto/Vehicle	Toyota	TSC7006G-4.4.4	Mobile Phone Antenna Nearby Test (835 MHz ...)
Auto/Vehicle	Toyota	TSC7018G	Static Electricity Test
Auto/Vehicle	Toyota	TSC7025G-5	TEM Cell Test (1 to 400 MHz)
Auto/Vehicle	Toyota	TSC7025G-6	Free Field Immunity Test (20 MHz to 1 GHz AM, 0.8 to 2 GHz PM)
Auto/Vehicle	Toyota	TSC7025G-7	Strip Line Test (20 - 400 MHz)
Auto/Vehicle	Toyota	TSC7026G-3.4	Narrow Band Emissions

Category	Publisher	Number	Title
Auto/Vehicle	Toyota	TSC7203	Voltage Drop / Micro Drops
Auto/Vehicle	Toyota	TSC7508G-3.3.1	Conductive Noise in FM and TV Bands
Auto/Vehicle	Toyota	TSC7508G-3.3.2	Conductive noise in LW, AM and SW Bands
Auto/Vehicle	Toyota	TSC7508G-3.3.3	Radiated Noise in FM and TV Bands
Auto/Vehicle	Toyota	TSC7508G-3.3.4	Radiated Noise in AM, SW, and LW Bands
Auto/Vehicle	Toyota	TXC7315G	Electrostatic Discharge (Gap Method)
Auto/Vehicle	Viston	ES-XU3F-1316-AA	Electronic Component - Subsystem Electromagnetic Compatibility (EMC) Requirements and Test Procedures
Auto/Vehicle	Volvo	N/A	EMC Requirements EMC requirements for 12V and 24V systems
Auto/Vehicle	VW	TL 801 01	Electric and electronic components in cars
Auto/Vehicle	VW	TL 820 66	Conducted Interference
Auto/Vehicle	VW	TL 821 66	EMC requirements of electronic components - bulk current injection (BCI)
Auto/Vehicle	VW	TL 823 66	Coupled Interference on Sensor Cables
Auto/Vehicle	VW	TL 824 66	Immunity Against Electrostatic Discharge
Auto/Vehicle	VW	TL 965	Short-Distance Interference Suppression
General	ANSI	S20.20	ESD Association Standard for the Development of and Electrostatic Discharge Control Program for the Protection of Electronic Parts, Assemblies, and Equipment
General	IEC	60050-161	International Electrotechnical Vocabulary. Chapter 161: Electromagnetic compatibility
General	IEC	60469	Transitions, pulses and related waveforms - Terms, definitions and algorithms
General	IEC	60940	Guidance information on the application of capacitors, resistors, inductors and complete filter units for electromagnetic interference suppression
General	IEC	61000-1-2	Electromagnetic compatibility (EMC) - Part 1-2: General - Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena
General	IEc	61000-2-10	Electromagnetic compatibility (EMC) - Part 2-10: Environment - Description of HEMP environment - Conducted disturbance
General	IEC	61000-2-11	Electromagnetic compatibility (EMC) - Part 2-11: Environment - Classification of HEMP environments
General	IEC	61000-2-12	Electromagnetic compatibility (EMC) - Part 2-12: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public medium-voltage power supply systems
General	IEC	61000-2-13	Electromagnetic compatibility (EMC) - Part 2-13: Environment - High-power electromagnetic (HPEM) environments - Radiated and conducted
General	IEC	61000-2-2	Electromagnetic compatibility (EMC) - Part 2-2: Environment - Compatibility levels for low-frequency conducted disturbances and signaling in public low-voltage power supply systems
General	IEC	61000-2-4	Electromagnetic compatibility (EMC) - Part 2-4: Environment - Compatibility levels in industrial plants for low-frequency conducted disturbances
General	IEC	61000-2-9	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 9: Description of HEMP environment - Radiated disturbance. Basic EMC publication
General	IEC	61000-5-5	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 5: Specification of protective devices for HEMP conducted disturbance. Basic EMC Publication

Category	Publisher	Number	Title
General	IEC	61000-5-7	Electromagnetic compatibility (EMC) - Part 5-7: Installation and mitigation guidelines - Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)
General	IEC	61000-5-8	Electromagnetic compatibility (EMC) - Part 5-8: Installation and mitigation guidelines - HEMP protection methods for the distributed infrastructure
General	IEC	61000-5-9	Electromagnetic compatibility (EMC) - Part 5-9: Installation and mitigation guidelines - System-level susceptibility assessments for HEMP and HPEM
General	IEC	62305-1	Protection against lightning - Part 1: General principles
General	IEC	62305-2	Protection against lightning - Part 2: Risk management
General	IEC	62305-3	Protection against lightning - Part 3: Physical damage to structures and life hazard
General	IEC	62305-4	Protection against lightning - Part 4: Electrical and electronic systems within structures
General	IEC	TR 61000-1-1	Electromagnetic compatibility (EMC) - Part 1: General - Section 1: Application and interpretation of fundamental definitions and terms
General	IEC	TR 61000-1-3	Electromagnetic compatibility (EMC) - Part 1-3: General - The effects of high-altitude EMP (HEMP) on civil equipment and systems
General	IEC	TR 61000-1-4	Electromagnetic compatibility (EMC) - Part 1-4: General - Historical rationale for the limitation of power-frequency conducted harmonic current emissions from equipment, in the frequency range up to 2 kHz
General	IEC	TR 61000-1-5	Electromagnetic compatibility (EMC) - Part 1-5: General - High power electromagnetic (HPEM) effects on civil systems
General	IEC	TR 61000-1-6	Electromagnetic compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty
General	IEC	TR 61000-1-7	Electromagnetic compatibility (EMC) - Part 1-7: General - Power factor in single-phase systems under non-sinusoidal conditions
General	IEC	TR 61000-2-1	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 1: Description of the environment - Electromagnetic environment for low-frequency conducted disturbances and signaling in public power supply systems
General	IEC	TR 61000-2-14	Electromagnetic compatibility (EMC) - Part 2-14: Environment - Overvoltages on public electricity distribution networks
General	IEC	TR 61000-2-3	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 3: Description of the environment - Radiated and non network-frequency-related conducted phenomena
General	IEC	TR 61000-2-5	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 5: Classification of electromagnetic environments. Basic EMC publication
General	IEC	TR 61000-2-6	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 6: Assessment of the emission levels in the power supply of industrial plants as regards low-frequency conducted disturbances
General	IEC	TR 61000-2-8	Electromagnetic compatibility (EMC) - Part 2-8: Environment - Voltage dips and short interruptions on public electric power supply systems with statistical measurement results
General	IEC	TR 61000-5-1	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication
General	IEC	TR 61000-5-2	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 1: General considerations - Basic EMC publication
General	IEC	TR 61000-5-3	Electromagnetic compatibility (EMC) - Part 5-3: Installation and mitigation guidelines - HEMP protection concepts

Category	Publisher	Number	Title
General	IEC	TR 61000-5-6	Electromagnetic compatibility (EMC) - Part 5-6: Installation and mitigation guidelines - Mitigation of external EM influences
General	IEC	TR-61000-2-7	Electromagnetic compatibility (EMC) - Part 2: Environment - Section 7: Low frequency magnetic fields in various environments
General	IEC	TS 61000-5-4	Electromagnetic compatibility (EMC) - Part 5: Installation and mitigation guidelines - Section 4: Immunity to HEMP - Specifications for protective devices against HEMP radiated disturbance. Basic EMC Publication
Generic	IEC	61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity standard for residential, commercial and light-industrial environments
Generic	IEC	61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity standard for industrial environments
Generic	IEC	61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
Generic	IEC	61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
Generic	IEC	61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for power station and substation environments
Generic	IEC	61000-6-6	Electromagnetic compatibility (EMC) - Part 6-6: Generic standards - HEMP immunity for indoor equipment
Generic	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
Medical	IEC	60601-1-1	Safety requirements for medical electrical systems
Medical	IEC	60601-1-10	Requirements for the development of physiologic closed-loop controllers
Medical	IEC	60601-1-11	Medical electrical equipment and medical electrical systems used in the home healthcare environment
Medical	IEC	60601-1-12	Medical electrical equipment and medical electrical systems used in the medical services environment
Medical	IEC	60601-1-2	Medical electrical equipment–Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests
Medical	IEC	60601-1-3	Radiation protection in diagnostic x-ray equipment
Medical	IEC	60601-1-6	General requirements for basic safety and essential performance – Usability
Medical	IEC	60601-1-8	General requirements for basic safety and essential performance - Alarm systems
Medical	IEC	60601-1-9	Requirements for environmentally conscious design
Medical	IEC	60601-2-2	Medical electrical equipment–Part 2-2: Particular requirements for the basic safety and essential performance of high frequency surgical equipment and high frequency surgical accessories
Medical	IEC	60601-4-2	Medical electrical equipment–Part 4-2: Guidance and interpretation - Electromagnetic immunity: performance of medical electrical equipment and medical electrical systems
Medical	IEC	TR 60601-4-2	Electromagnetic immunity performance
Medical	IEC	TR 60601-4-3	Considerations of unaddressed safety aspects in the third edition of IEC 60601-1
Medical	IEC	TR 62354	General testing procedures for medical electrical equipment
Medical	ISO	14708-1	Active implantable medical devices

Category	Publisher	Number	Title
MIL/Aero	AIAA	S-121	Electromagnetic Compatibility Requirements for Space Equipment and Systems, 2017
MIL/Aero	DoD	ADS-37A-PRF	Electromagnetic Environmental Effects (E3) Performance and Verification Requirements, 28 May 1996 (Army Aviation and Troop Command)
MIL/Aero	DoD	DoDD 4650.01	Policy and Procedures for Management and Use of the Electromagnetic Spectrum, 09 Jan 2009
MIL/Aero	DoD	DoDI 3222.03	DoD Electromagnetic Environmental Effects (E3) Program, Change Notice 2, 10 October 2017.
MIL/Aero	DoD	DoDI 6055.11	Protecting Personnel from Electromagnetic Fields, 19 Aug 2009
MIL/Aero	DoD	DOD-STD-1399-70	Section 070 Part 1 D.C. Magnetic Field Environment, (Notice 1 Validation, 30 Nov 1989)
MIL/Aero	DoD	MIL-HDBK-1195	Radio Frequency Shielded Enclosures, 30 Sep 1988
MIL/Aero	DoD	MIL-HDBK-1857	Grounding, Bonding and Shielding Design Practices, 27 Mar 1998
MIL/Aero	DoD	MIL-HDBK-2036	Preparation of Electronic Equipment Specifications, 1 November 1999
MIL/Aero	DoD	MIL-HDBK-235-1D	Military Operational Electromagnetic Environment Profiles Part 1D General Guidance, 03 April 2018
MIL/Aero	DoD	MIL-HDBK-237D	Electromagnetic Environmental Effects and Spectrum Certification Guidance for the Acquisition Process, 20 May 2005. (Notice 1 Validation 04 April 2013)
MIL/Aero	DoD	MIL-HDBK-240-1	Electromagnetic Environmental Effects to Ordnance Guide Part 1 General Guidance
MIL/Aero	DoD	MIL-HDBK-240-2	Electromagnetic Environmental Effects to Ordnance Guide Part 2 Hazards of Electromagnetic Radiation to Ordnance testing
MIL/Aero	DoD	MIL-HDBK-240-3	Electromagnetic Environmental Effects to Ordnance Guide Part 3 Electrostatic Discharge to Ordnance
MIL/Aero	DoD	MIL-HDBK-240-4	Electromagnetic Environmental Effects to Ordnance Guide Part 4 External Radio Frequency Electromagnetic Environments
MIL/Aero	DoD	MIL-HDBK-240-5	Electromagnetic Environmental Effects to Ordnance Guide Part 5 Lightning Effects to Ordnance (Notice 1 is administrative placeholder)
MIL/Aero	DoD	MIL-HDBK-240-6	Electromagnetic Environmental Effects to Ordnance Guide Part 6 Characterization of the Electromagnetic Environment for HERO
MIL/Aero	DoD	MIL-HDBK-240-7	Electromagnetic Environmental Effects to Ordnance Test Guide Part 7 Hazards of Electromagnetic Radiation to Ordnance Operational Guidance
MIL/Aero	DoD	MIL-HDBK-274A	Electrical Grounding for Aircraft Safety, 14 Nov 2011. (Notice 2 Validation 20 May 2021)
MIL/Aero	DoD	MIL-HDBK-335	Management and Design Guidance Electromagnetic Radiation Hardness for Air Launched Ordnance Systems, Notice 4, 08 Jul 2008. (Notice 5 Cancellation 01 August 2013)
MIL/Aero	DoD	MIL-HDBK-419A	Grounding, Bonding, and Shielding for Electronic Equipment and Facilities, 29 Dec 1987. (Notice 1 Validation 20 February 2014)
MIL/Aero	DoD	MIL-HDBK-454C	General Guidelines for Electronic Equipment
MIL/Aero	DoD	MIL-STD-1275E	Characteristics of 28 Volt DC Power Input to Utilization Equipment in Military Vehicles, 22 March 2013
MIL/Aero	DoD	MIL-STD-1310H	Shipboard Bonding, Grounding, and Other Techniques foe Electromagnetic Compatibility, Electeomagnetic Pulse (EMP) Mitigation, and Safety, 17 Sep 2009 (Notice 1 Validation 12 Aug 2014)
MIL/Aero	DoD	MIL-STD-1377	Effectiveness of Cable, Connector, and Weapon Enclosure Shielding and Filters in Precluding Hazards of EM Radiation to Ordnance; Measurement of, 20 Aug 1971 (Notice 1 Validation 19 Jan 2021)

Category	Publisher	Number	Title
MIL/Aero	DoD	MIL-STD-1399-300-1	Department of Defense Interface Standard Sectio 300, Part 1 Low Voltage Electric Power, Alternating Current
MIL/Aero	DoD	MIL-STD-1399-300-2	Department of Defense Interface Standard Sectio 300, Part 2 Medium Voltage Electric Power, Alternating Current
MIL/Aero	DoD	MIL-STD-1542B	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991
MIL/Aero	DoD	MIL-STD-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009 (Notice 1 Validation 12 Aug 2014)
MIL/Aero	DoD	MIL-STD-188-124B	Grounding, Bonding, and Shielding for Common Long Haul/Tactical Communications-Electronics Facilities and Equipment, 4 April 2013
MIL/Aero	DoD	MIL-STD-220C	Test Method Standard Method of Insertion Loss Measurement, 14 May 2009 (Notice 2 Validation 8 Oct 2019)
MIL/Aero	DoD	MIL-STD-331B	Fuze and Fuze Components, Environmental and Performance Tests for, 31 May, 2017
MIL/Aero	DoD	MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973 (Notice 2 Validation 4 Apr 2013)
MIL/Aero	DoD	MIL-STD-461G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015
MIL/Aero	DoD	MIL-STD-464D	Electromagnetic Environmental Effects Requirements for Systems, 24 Dec 2020
MIL/Aero	DoD	MIL-STD-704F	Aircraft Electric Power Characteristics, Change Notice 1, 05 December 2016 (Notice 3 Validation 17 Sep 2021).
MIL/Aero	DoD	TOP-01-2-511A	Protecting Personnel from Electromagnetic Fields, 19 Aug 2009
MIL/Aero	DoD	TOP-01-2-620	High-Altitude Electromagnetic Pulse (HEMP) Testing, 10 November 2011
MIL/Aero	DoD	TOP-01-2-622	Vertical Electromagnetic Pulse Testing, 11 September 2009
MIL/Aero	RTCA	DO-160G	Environmental Conditions and Test Procedures for Airborne Equipment (Change 1)
MIL/Aero	RTCA	DO-233	Portable Electronic Devices Carried on Board Aircraft
MIL/Aero	RTCA	DO-235B	Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band
MIL/Aero	RTCA	DO-292	Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band
MIL/Aero	RTCA	DO-294C	Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft
MIL/Aero	RTCA	DO-307A	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance
MIL/Aero	RTCA	DO-307A	Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance
MIL/Aero	RTCA	DO-357	User Guide Supplement to DO-160
MIL/Aero	RTCA	DO-363	Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft
MIL/Aero	RTCA	DO-364	Minimum Aviation System Performance Standards (MASPS) for Aeronautical Information/ Meteorological Data Link Services
MIL/Aero	SAE	ARP 5583A	Guide to Certification of Aircraft in a High Intensity Radiation (HIRF) Environment
MIL/Aero	SMC	SMC-S-008	Electromagnetic Compatibility Requirements For Space Equipment and Systems, 13 Jun 2008

Category	Publisher	Number	Title
Test	ANSI	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
Test	IEC	60060-1	International Electrotechnical Vocabulary. Chapter 161: Electromagnetic compatibility
Test	IEC	60060-2	High-voltage test techniques - Part 2: Measuring systems
Test	IEC	60060-3	High-voltage test techniques - Part 3: Definitions and requirements for on-site testing
Test	IEC	61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field immunity test
Test	IEC	61000-4-11	Electromagnetic compatibility (EMC) - Part 4-11: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations immunity tests
Test	IEC	61000-4-12	Electromagnetic compatibility (EMC) - Part 4-12: Testing and measurement techniques - Ring wave immunity test
Test	IEC	61000-4-13	Electromagnetic compatibility (EMC) - Part 4-13: Testing and measurement techniques - Harmonics and interharmonics including mains signaling at a.c. power port, low frequency immunity tests
Test	IEC	61000-4-14	Electromagnetic compatibility (EMC) - Part 4-14: Testing and measurement techniques - Voltage fluctuation immunity test
Test	IEC	61000-4-15	Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 15: Flickermeter - Functional and design specifications
Test	IEC	61000-4-16	Electromagnetic compatibility (EMC) - Part 4-16: Testing and measurement techniques - Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz
Test	IEC	61000-4-17	Electromagnetic compatibility (EMC) - Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test Electromagnetic compatibility (EMC) - Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test
Test	IEC	61000-4-18	Electromagnetic compatibility (EMC) - Part 4-17: Testing and measurement techniques - Ripple on d.c. input power port immunity test
Test	IEC	61000-4-19	Electromagnetic compatibility (EMC) - Part 4-19: Testing and measurement techniques - Test for immunity to conducted, differential mode disturbances and signalling in the frequency range 2 kHz to 150 kHz at a.c. power ports
Test	IEC	61000-4-2	Electromagnetic compatibility (EMC)–Part 4-2: Testing and measurement techniques - Electrostatic discharge immunity test
Test	IEC	61000-4-20	Electromagnetic compatibility (EMC) - Part 4-20: Testing and measurement techniques - Emission and immunity testing in transverse electromagnetic (TEM) waveguides
Test	IEC	61000-4-21	Electromagnetic compatibility (EMC) - Part 4-21: Testing and measurement techniques - Reverberation chamber test methods
Test	IEC	61000-4-22	Electromagnetic compatibility (EMC) - Part 4-22: Testing and measurement techniques - Radiated emissions and immunity measurements in fully anechoic rooms (FARs
Test	IEC	61000-4-23	Electromagnetic compatibility (EMC) - Part 4-23: Testing and measurement techniques - Test methods for protective devices for HEMP and other radiated disturbances
Test	IEC	61000-4-24	Electromagnetic compatibility (EMC) - Part 4-24: Testing and measurement techniques - Test methods for protective devices for HEMP conducted disturbance
Test	IEC	61000-4-25	Electromagnetic compatibility (EMC) - Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems

Category	Publisher	Number	Title
Test	IEC	61000-4-27	Electromagnetic compatibility (EMC) - Part 4-25: Testing and measurement techniques - HEMP immunity test methods for equipment and systems
Test	IEC	61000-4-28	Electromagnetic compatibility (EMC) - Part 4-28: Testing and measurement techniques - Variation of power frequency, immunity test
Test	IEC	61000-4-29	Electromagnetic compatibility (EMC) - Part 4-29: Testing and measurement techniques - Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests
Test	IEC	61000-4-3	Electromagnetic compatibility (EMC)–Part 4-3: Testing and measurement techniques - Radiated, radio-frequency, electromagnetic field immunity test
Test	IEC	61000-4-30	Electromagnetic compatibility (EMC) – Part 4-30: Testing and measurement techniques – Power quality measurement methods
Test	IEC	61000-4-31	Electromagnetic compatibility (EMC) - Part 4-31: Testing and measurement techniques - AC mains ports broadband conducted disturbance immunity test
Test	IEC	61000-4-33	Electromagnetic compatibility (EMC) - Part 4-33: Testing and measurement techniques - Measurement methods for highpower transient parameters
Test	IEC	61000-4-34	Electromagnetic compatibility (EMC) - Part 4-33: Testing and measurement techniques - Measurement methods for highpower transient parameters
Test	IEC	61000-4-36	Electromagnetic compatibility (EMC) - Part 4-36: Testing and measurement techniques - IEMI immunity test methods for equipment and systems
Test	IEC	61000-4-4	Electromagnetic compatibility (EMC)–Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test
Test	IEC	61000-4-5	Electromagnetic compatibility (EMC) - Part 4-5: Testing and measurement techniques - Surge immunity test
Test	IEC	61000-4-6	Electromagnetic compatibility (EMC) - Part 4-6: Testing and measurement techniques - Immunity to conducted disturbances, induced by radio-frequency fields
Test	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
Test	IEC	61000-4-8	Electromagnetic compatibility (EMC) - Part 4-8: Testing and measurement techniques - Power frequency magnetic field immunity test
Test	IEC	61000-4-9	Electromagnetic compatibility (EMC) - Part 4-9: Testing and measurement techniques - Impulse magnetic field immunity test
Test	IEC	61340-3-1	Electrostatics - Part 3-1: Methods for simulation of electrostatic effects - Human body model (HBM) electrostatic discharge test waveforms
Test	IEC	62153-10	Metallic communication cable test methods - Part 4-10: Electromagnetic compatibility (EMC) - Transfer impedance and screening attenuation of feed-throughs and electromagnetic gaskets - Double coaxial test method
Test	IEC	62153-11	Metallic communication cable test methods - Part 4-11: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of patch cords, coaxial cable assemblies, pre-connectorized cables - Absorbing clamp method
Test	IEC	62153-12	Metallic communication cable test methods - Part 4-12: Electromagnetic compatibility (EMC) - Coupling attenuation or screening attenuation of connecting hardware - Absorbing clamp method
Test	IEC	62153-13	Metallic communication cable test methods - Part 4-13: Electromagnetic compatibility (EMC) - Coupling attenuation of links and channels (laboratory conditions) - Absorbing clamp method

Category	Publisher	Number	Title
Test	IEC	62153-14	Metallic communication cable test methods - Part 4-14: Electromagnetic compatibility (EMC) - Coupling attenuation of cable assemblies (Field conditions) absorbing clamp method
Test	IEC	62153-15	Metallic communication cable test methods - Part 4-15: Electromagnetic compatibility (EMC) - Test method for measuring transfer impedance and screening attenuation - or coupling attenuation with triaxial cell
Test	IEC	62153-4	Metallic communication cable test methods - Part 4-0: Electromagnetic compatibility (EMC) - Relationship between surface transfer impedance and screening attenuation, recommended limits
Test	IEC	62153-4-1	Metallic communication cable test methods - Part 4-1: Electromagnetic compatibility (EMC) - Introduction to electromagnetic screening measurements
Test	IEC	62153-4-2	Metallic communication cable test methods - Part 4-2: Electromagnetic compatibility (EMC) - Screening and coupling attenuation - Injection clamp method
Test	IEC	62153-4-3	Metallic communication cable test methods - Part 4-3: Electromagnetic compatibility (EMC) - Surface transfer impedance - Triaxial method
Test	IEC	62153-4-4	Metallic communication cable test methods - Part 4-4: Electromagnetic compatibility (EMC) - Test method for measuring of the screening attenuation as up to and above 3 GHz, triaxial method
Test	IEC	62153-4-5	Metallic communication cables test methods - Part 4-5: Electromagnetic compatibility (EMC) - Coupling or screening attenuation - Absorbing clamp method
Test	IEC	62153-4-6	Metallic communication cable test methods - Part 4-6: Electromagnetic compatibility (EMC) - Surface transfer impedance - Line injection method
Test	IEC	62153-4-7	Metallic communication cable test methods - Part 4-7: Electromagnetic compatibility (EMC) - Test method for measuring of transfer impedance ZT and screening attenuation aS or coupling attenuation aC of connectors and assemblies up to and above 3 GHz - Triaxial tube in tube method
Test	IEC	62153-4-8	Metallic communication cable test methods - Part 4-8: Electromagnetic compatibility (EMC) - Capacitive coupling admittance
Test	IEC	62153-4-9	Metallic communication cable test methods - Part 4-9: Electromagnetic compatibility (EMC) - Coupling attenuation of screened balanced cables, triaxial method
Test	IEC	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
Test	IEC	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
Test	IEC	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
Test	IEC	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
Test	IEC	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
Test	IEC	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

Category	Publisher	Number	Title
Test	IEC	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
Test	IEC	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
Test	IEC	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
Test	IEC	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
Test	IEC	CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modeling - Measurement instrumentation uncertainty
Test	IEC	CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
Test	IEC	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
Test	IEC	CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
Test	IEC	CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modeling - Uncertainties in standardized EMC tests
Test	IEC	CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modeling - Statistical considerations in the determination of EMC compliance of mass-produced products
Test	IEC	CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modeling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
Test	IEC	CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modeling - Conditions for the use of alternative test methods
Test	IEC	CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
Test	IEC	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
Test	IEC	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
Test	IEC	TR 61000-4-32	Electromagnetic compatibility (EMC) - Part 4-32: Testing and measurement techniques - High-altitude electromagnetic pulse (HEMP) simulator compendium
Test	IEC	TR 61000-4-35	Electromagnetic compatibility (EMC) - Part 4-35: Testing and measurement techniques - HPEM simulator compendium
Test	IEC	TR 61000-4-37	Electromagnetic compatibility (EMC) - Part 4-36: Testing and measurement techniques - IEMI immunity test methods for equipment and systems

Category	Publisher	Number	Title
Test	IEC	TR 61000-4-38	Electromagnetic compatibility (EMC) - Part 4-38: Testing and measurement techniques - Test, verification and calibration protocol for voltage fluctuation and flicker compliance test systems
Test	IEC	TS 60816	Guide on methods of measurement of short duration transients on low-voltage power and signal lines
Wireless	ETSI EN	300 220	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25MHz to 1000MHz frequency range with power levels ranging up to 500mW
Wireless	ETSI EN	300 328	Electromagnetic compatibility and Radio Spectrum Matters (ERM); Wideband transmission systems; Data transmission equipment operating in the 2.4 GHz ISM band and using wide band modulation techniques; Harmonized EN covering essential requirements
Wireless	ETSI EN	300 330	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 9kHz to 25MHz frequency range and inductive loop systems in the 9kHz to 30MHz frequency range
Wireless	ETSI EN	300 440	Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 1GHz to 40GHz frequency range
Wireless	ETSI EN	301 489-17	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 17: Specific conditions for Wideband data and HIPERLAN equipment
Wireless	ETSI EN	301 489-3	Electromagnetic compatibility and Radio spectrum Matters (ERM); Electromagnetic Compatibility (EMC) standard for radio equipment and services; Part 3: Specific conditions for Short Range Devices (SRD) operating on frequencies between 9kHz and 40GHz
Wireless	ETSI EN	301 893	Broadband Radio Access Networks (BRAN); 5 GHz high performance RLAN; Harmonized EN covering essential requirements
Wireless	ETSI EN	303 413	GPS receivers
Wireless	ETSI EN	303 417	Wireless Power Transfer

EMC STANDARDS ORGANIZATIONS

American National Standards Institute (ANSI)
www.ansi.org

ANSI Accredited C63
www.c63.org

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

Bureau of Standards, Metrology and Inspection (BSMI)
http://www.bsmi.gov.tw/wSite/mp?mp=95

Canadian Standards Association (CSA)
www.csa.ca

Comité International Spécial des Perturbations Radioélectriques (CISPR)
http://www.iec.ch/dyn/www/f?p=103:7:0::::FSP_ORG_ID,FSP_LANG_ID:1298,25

China – Certification and Accreditation Administration (CNCA)
http://www.cnca.gov.cn/

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

Federal Communications Commission (FCC)
www.fcc.gov

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

International Electrotechnical Commission (IEC)
http://www.iec.ch

Institute of Electrical and Electronics Engineers (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

Radio Technical Commission for Aeronautics (RTCA)
https://www.rtca.org

Society of Automotive Engineers (SAE) EMC Standards Committee
www.sae.org

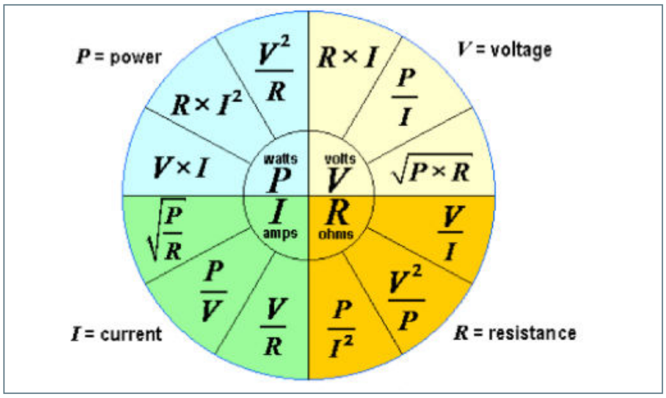
SAE EMC Standards
http://www.sae.org/servlets/works/committeeHome.do?comtID=TEVEES17

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

REFERENCES & TOOLS

COMMON EMC-RELATED EQUATIONS

OHMS LAW



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

BANDWIDTH VERSUS RISE TIME

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

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

BANDWIDTH VERSUS CLOCK FREQUENCY

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

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

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

PERIOD VERSUS FREQUENCY

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

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

25 nH/inch or 1 nH/mm
Example, a 1.5 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: 11.8 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 Z1,Z2 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

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

RETURN LOSS, GIVEN VSWR

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

Return Loss, given reflection coefficient (ρ)

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

TEMPERATURE CONVERSIONS

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

REFERENCES & TOOLS

E-FIELD FROM DIFFERENTIAL-MODE CURRENT

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

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

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

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)

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

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

ANTENNA (FAR FIELD) RELATIONSHIPS

(continued)

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

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

REFERENCES & TOOLS

DBM, DBMV, DBMA (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

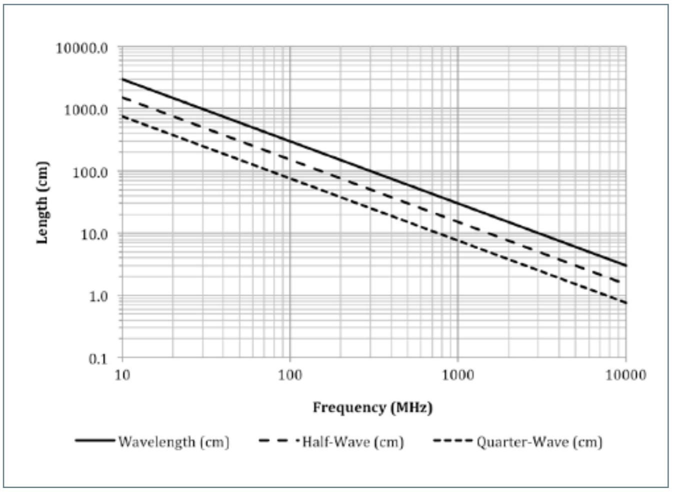
A common formula for converting default spectrum analyzer amplitudes (dBm) to the limits as shown in the emissions standards (dBμV):

dBm to dBμV, use: dBμV = dBm + 107

WAVELENGTH EQUATIONS (FREE SPACE)

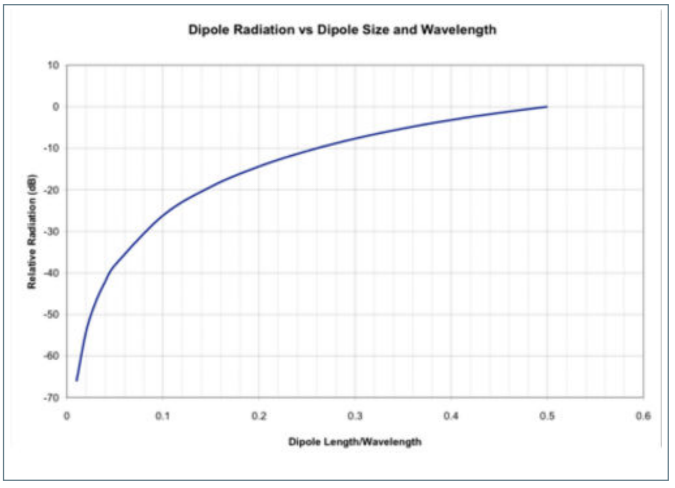
Wavelength(m) = 300/f(MHz)
Half-wavelength(ft.) = 468/f(MHz)

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. 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. Image Source: Bruce Archambeault.

COMMON SYMBOLS

A	Amperes, unit of electrical current
AC	Alternating Current
AM	Amplitude modulated
dBm	dB with reference to 1 mW
dBμA	dB with reference to 1 μA
dBμV	dB with reference to 1 μV
DC	Direct Current
E	"E" is the electric field component of an electromagnetic field.
E/M	Ratio of the electric field (E) to the magnetic field (H), in the far-field this is the characteristic impedance of free space, approximately 377 Ω
EM	Electromagnetic
EMC	Electromagnetic compatibility
EMI	Electromagnetic Interference
FM	Frequency modulated
GHz	Gigahertz, one billion Hertz (1,000,000,000 Hertz)
H	"H" is the magnetic field component of an electromagnetic field.
Hz	Hertz, unit of measurement for frequency
I	Electric current
kHz	Kilohertz, one thousand Hertz (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.
ANSI	American National Standards Institute
BCI	(Bulk Current Injection) - An EMC test where common-mode currents are coupled onto the power and communications cables of an EUT.
BEV	Battery Electric Vehicle
CE	(Conducted Emissions) - The RF energy generated by electronic equipment, which is conducted on power cables.
CE Marking	The marking signifying a product meets the required European Directives.
CENELEC	French acronym for the “European Committee for Electrotechnical Standardization”.
CI	(Conducted Immunity) - A measure of the immunity to RF energy coupled onto cables and wires of an electronic product.
CISPR	French acronym for “Special International Committee on Radio Interference”.
Conducted	Energy transmitted via cables or PC board connections.
Coupling Path	A structure or medium that transmits energy from a noise source to a victim circuit or system.
CS	(Conducted Susceptibility) - RF energy or electrical noise coupled onto I/O cables and power wiring that can disrupt electronic equipment.
CW	(Continuous Wave) - A sinusoidal waveform with a constant amplitude and frequency.
EMC	(Electromagnetic Compatibility) - The ability of a product to coexist in its intended electromagnetic environment without causing or suffering disruption or damage.
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.
HEV	Hybrid Electric Vehicle
IEC	International Electrotechnical Commission

ISM	(Industrial, Scientific and Medical equipment) - A class of electronic equipment including industrial controllers, test & measurement equipment, medical products and other scientific equipment.
ITE	(Information Technology Equipment) - A class of electronic devices covering a broad range of equipment including computers, printers and external peripherals; also includes, telecommunications equipment, and multi-media devices.
LISN	(Line Impedance Stabilization Network) - Used to match the 50-Ohm impedance of measuring receivers to the power line.
MLCC	(Multi-Layer Ceramic Capacitor) - A surface mount capacitor type often used as decoupling or energy storage capacitors in a power distribution network.
Near Field	When you are close enough to a radiating source that its field is considered spherical rather than planar.
Noise Source	A source that generates an electromagnetic perturbation or disruption to other circuits or systems.
OATS	(Open Area Test Site) - An outdoor EMC test site free of reflecting objects except a ground plane.
PDN	(Power Distribution Network) - The wiring and circuit traces from the power source to the electronic circuitry. This includes the parasitic components (R, L, C) of the circuit board, traces, bypass capacitance and any series inductances.
PHEV	Plug-in Hybrid Electric Vehicle
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.
PLT	(Power Line Transient) - A sudden positive or negative surge in the voltage on a power supply input (DC source or AC line).
Radiated	Energy transmitted through the air via antenna or loops.
RFI	Radio Frequency Interference) - The disruption of an electronic device or system due to electromagnetic emissions at radio frequencies (usually a few kHz to a few GHz). Also EMI.
RE	(Radiated Emissions) - The energy generated by a circuit or equipment, which is radiated directly from the circuits, chassis and/or cables of equipment.
RI	Radiated Immunity) - The ability of circuits or systems to be immune from radiated energy coupled to the chassis, circuit boards and/or cables. Also Radiated Susceptibility (RS).
RF	(Radio Frequency) - A frequency at which electromagnetic radiation of energy is useful for communications.
RS	(Radiated Susceptibility) - The ability of equipment or circuits to withstand or reject nearby radiated RF sources. Also Radiated Immunity (RI).
SAR	(Specific Absorption Rate) Measure of the rate of RF energy absorbed by the body.
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

2024 EMC Fundamentals Guide
The Fundamentals Guide and keep your project running smoothly by better understanding how to address EMI and EMC in the early design phases.
https://learn.interferencetechnology.com/2024-emc-fundamentals-guide

2023 EMC Testing Guide
This guide offers insights and tools needed to plan for and prevent EMC failures before even entering the testing lab.
https://learn.interferencetechnology.com/2023-emc-testing-guide/

2023 IoT, Wireless, 5G EMC Guide
This guide includes content and reference material focused on providing the information required for designing and testing EMI-free wireless devices.
https://learn.interferencetechnology.com/2023-iot-wireless-5g-emc-guide/

2023 Military & Aerospace EMC Guide
This guide provides up-to-date information on a range of mil/aero technologies and EMC standards like MIL-STD-461G and DO-160, ensuring cost-effective design and testing.
https://learn.interferencetechnology.com/2023-military-and-aerospace-emc-guide/

2021 Automotive EMC Guide
This guide features technical articles, reference materials, and a company directory focused on the EMI challenges that result from today's complex connected automotive systems.
https://learn.interferencetechnology.com/2021-automotive-emc-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.

Adamczyk,
Foundations of EMC with Practical Applications

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.

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

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

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

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

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.

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

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

Montrose,
EMC Made Simple
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.

Wiley, 2000. **Kimmel and Gerke,**
Electromagnetic Compatibility in Medical Equipment
IEEE Press, 1995. Good general product design information.

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.

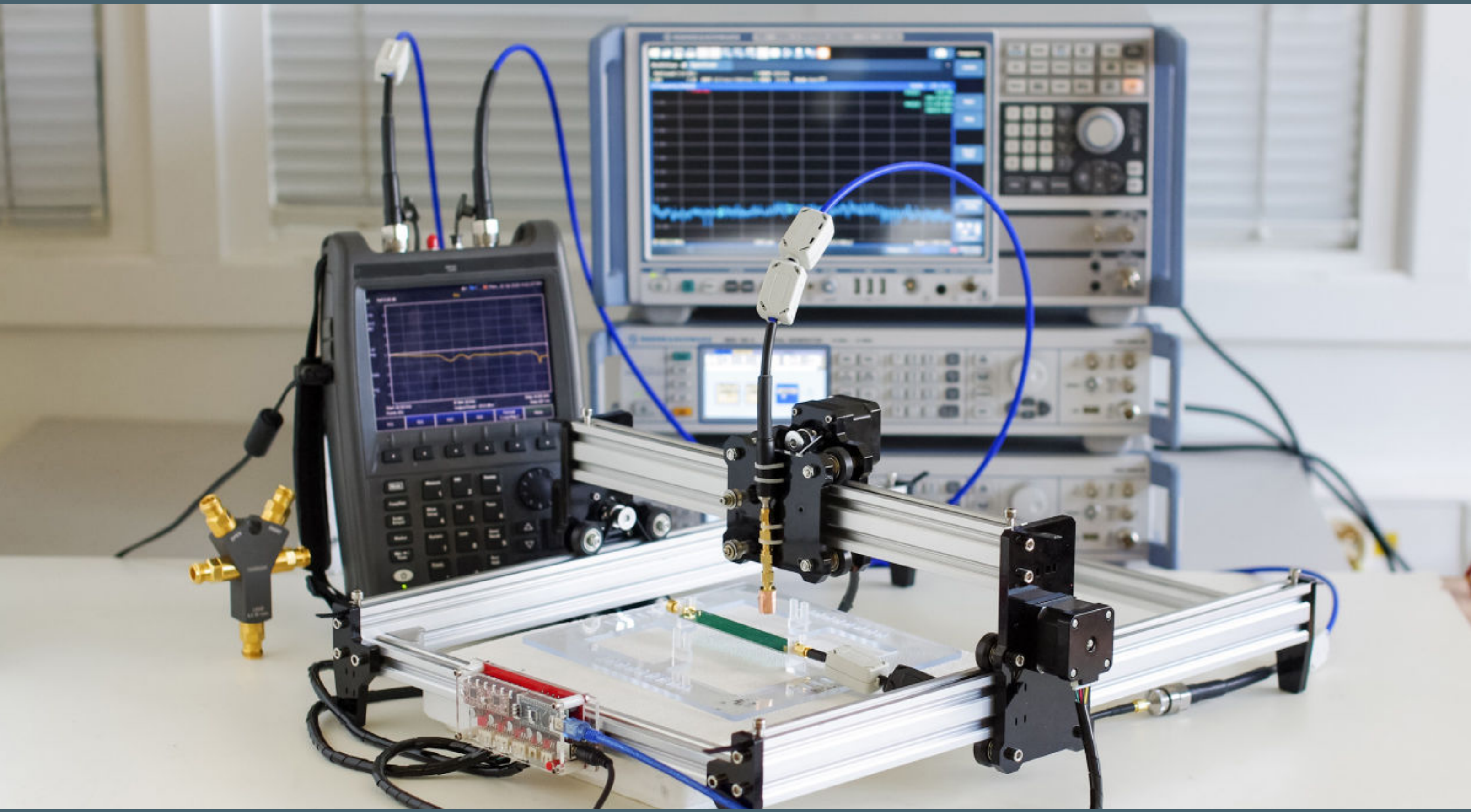
Wyatt and Gruber,
Radio Frequency (RFI) Pocket Guide
SciTech Publishing, 2015. A handy pocket-sized reference guide to radio frequency interference.

LINKEDIN GROUPS

For Industry Specific LinkedIn Groups, please see the Featured Industry sections on Wireless/5G/IoT, Automotive, and Military/Aerospace.

Electromagnetic Compatibility Forum
Electromagnetics and Spectrum Engineering Group
EMC - Electromagnetic Compatibility
EMC Experts
EMC Troubleshooters
ESD Experts
Signal & Power Integrity Community
EMI/EMC Testing
IEEE EMC Society
iNARTE

EMC FUNDAMENTALS



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

COMMERCIAL STANDARDS

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

FCC

https://www.ecfr.gov

Electronic Code of Federal Regulations (e-CFR)

CFR 47 - Part 15 (Radio Frequency Devices)

ANSI

http://webstore.ansi.org

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

IEC

https://webstore.iec.ch

Document Number	Title
IEC 60601-1-2	Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests
IEC 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 61000-4-4	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 61000-4-7	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 61000-4-10	Electromagnetic compatibility (EMC) - Part 4-10: Testing and measurement techniques - Damped oscillatory magnetic field 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 61000-6-5	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

CISPR

https://webstore.iec.ch

Document Number	Title
CISPR 12	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of off-board receivers
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 16-1-5	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 16-4-1	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 32	Electromagnetic compatibility of multimedia equipment - Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY STANDARDS

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

CISPR (AUTOMOTIVE EMISSIONS REQUIREMENTS)

https://webstore.iec.ch

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

ISO (AUTOMOTIVE IMMUNITY REQUIREMENTS)

https://www.iso.org

Document Number	Title
ISO 7637-2	Road vehicles – Electrical disturbances from conduction and coupling – Part 2: Electrical transient conduction along supply lines only
ISO/TR 10305-1	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 1: Devices for measurement of electromagnetic fields at frequencies > 0 Hz
ISO/TR 10305-2	Road vehicles – Calibration of electromagnetic field strength measuring devices – Part 2: IEEE standard for calibration of electromagnetic field sensors and probes, excluding antennas, from 9 kHz to 40 GHz
ISO/TS 21609	Road vehicles – (EMC) guidelines for installation of aftermarket radio frequency transmitting equipment
ISO 11452-7	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 7: Direct radio frequency (RF) power injection
ISO 11452-10	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 10: Immunity to conducted disturbances in the extended audio frequency range

SAE (AUTOMOTIVE EMISSIONS AND IMMUNITY)

http://standards.sae.org

Document Number	Title
J1113/1	Electromagnetic Compatibility Measurement Procedures and Limits for Components of Vehicles, Boats (Up to 15 M), and Machines (Except Aircraft) (50 Hz to 18 Ghz)
J1113/4	Immunity to Radiated Electromagnetic Fields-Bulk Current Injection (BCI) Method
J1113/11	Immunity to Conducted Transients on Power Leads
J1113/12	Electrical Interference by Conduction and Coupling - Capacitive and Inductive Coupling via Lines Other than Supply Lines
J1113/13	Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Part 13: Immunity to Electrostatic Discharge
J1113/26	Electromagnetic Compatibility Measurement Procedure for Vehicle Components - Immunity to AC Power Line Electric Fields
J1113/27	Electromagnetic Compatibility Measurements Procedure for Vehicle Components - Part 27: Immunity to Radiated Electromagnetic Fields - Mode Stir Reverberation Method
J1752/1	Electromagnetic Compatibility Measurement Procedures for Integrated Circuits-Integrated Circuit EMC Measurement Procedures-General and Definition
J1752/2	Measurement of Radiated Emissions from Integrated Circuits – Surface Scan Method (Loop Probe Method) 10 MHz to 3 GHz
J1752/3	Measurement of Radiated Emissions from Integrated Circuits – TEM/Wideband TEM (GTEM) Cell Method; TEM Cell (150 kHz to 1 GHz), Wideband TEM Cell (150 kHz to 8 GHz)
J551/5	Performance Levels and Methods of Measurement of Magnetic and Electric Field Strength from Electric Vehicles, Broadband, 9 kHz To 30 MHz
J551/15	Vehicle Electromagnetic Immunity–Electrostatic Discharge (ESD)
J551/16	Electromagnetic Immunity - Off-Vehicle Source (Reverberation Chamber Method) - Part 16 - Immunity to Radiated Electromagnetic Fields
J551/17	Vehicle Electromagnetic Immunity – Power Line Magnetic Fields
J1812	Function Performance Status Classification for EMC Immunity Testing
J2628	Characterization–Conducted Immunity
J2556	Radiated Emissions (RE) Narrowband Data Analysis–Power Spectral Density (PSD)

GM

https://global.ihs.com

Document Number	Title
GMW3091	General Specification for Vehicles, Electromagnetic Compatibility (EMC)-Engl; Revision H; Supersedes GMI 12559 R and GMI 12559 V
GMW3097	General Specification for Electrical/Electronic Components and Subsystems, Electromagnetic Compatibility-Engl; Revision H; Supersedes GMW12559, GMW3100, GMW12002R AND GMW12002V

FORD

https://www.fordemc.com

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

DaimlerChrysler

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

Automotive Electromagnetic Compatibility Standards From

https://cecas.clemson.edu/cvel/emc/

MEDICAL STANDARDS

COLLATERAL STANDARDS

https://www.webstore.iec.ch

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

OTHER RELEVANT STANDARDS

https://www.webstore.iec.ch

Document Number	Title
IEC 60601-1	General requirements for basic safety and essential performance
IEC TR 62354	General testing procedures for medical electrical equipment
ISO 14708-1	Active implantable medical devices

For more extensive listings of medical standards, download the 2020 Medical EMC Guide:
https://learn.interferencetechnology.com/2020-medical-emc-guide/

COMMON WIRELESS STANDARDS

ETSI STANDARDS

https://www.etsi.org

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

COMMON MILITARY RELATED DOCUMENTS AND STANDARDS

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

Document Number	Title
MIL-HDBK-235-1	Military Operational Electromagnetic Environment Profiles Part 1C General Guidance, 1 Oct 2010
MIL-HDBK-1857	Grounding, Bonding and Shielding Design Practices, 27 Mar 1998
MIL-STD-220C	Test Method Standard Method of Insertion Loss Measurement, 14 May 2009
MIL-STD-449D	Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973
MIL-STD-461F	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 10 Dec 2007
MIL-STD-461G	Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment, 11 Dec 2015
MIL-STD-464C	Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010
MIL-STD-1541A	Electromagnetic Compatibility Requirements for Space Systems, 30 Dec 1987
MIL-STD-1542B	Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991
MIL-STD-1605A	Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009
DoDI 3222.03	DoD Electromagnetic Environmental Effects (E3) Program, 24 Aug 2014

AEROSPACE STANDARDS

AIAA STANDARDS

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

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

RTCA STANDARDS

www.rtca.org/

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

SAE STANDARDS

www.sae.org/

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

REFERENCES

EMC STANDARDS ORGANIZATIONS

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

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

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

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

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

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

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

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

IEC
https://www.iec.ch/homepage

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

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

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

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

RTCA
https://www.rtca.org

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

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

RECOMMENDED BOOKS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Sandler
Power Integrity - Measuring, Optimizing, and Troubleshooting Power Related Parameters in Electronics Systems

McGraw-Hill, 2014. The latest information on measurement and design of power distribution networks and how the network affects stability and EMC.

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

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

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

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

RECOMMENDED GUIDES FROM *INTERFERENCE TECHNOLOGY*

2024 EMC Fundamentals Guide
https://learn.interferencetechnology.com/2024-emc-fundamentals-guide

2023 EMC Testing Guide
https://learn.interferencetechnology.com/2023-emc-testing-guide/

2023 EMC Fundamentals Guide
https://learn.interferencetechnology.com/2023-emc-fundamentals-guide

2023 Military & Aerospace EMC Guide
https://learn.interferencetechnology.com/2023-military-and-aerospace-emc-guide/

2023 IoT, Wireless, 5G EMC Guide
https://learn.interferencetechnology.com/2023-iot-wireless-5g-emc-guide/

2023 EMC SI & PI Guide
https://learn.interferencetechnology.com/2023-signal-and-power-integrity-guide/

2022 EMC Testing Guide
https://learn.interferencetechnology.com/2022-emc-testing-guide//

2022 Military & Aerospace EMC Guide
https://learn.interferencetechnology.com/2022-military-and-aerospace-emc-guide/

2022 IoT, Wireless, 5G EMC Guide
https://learn.interferencetechnology.com/2022-iot-wireless-5g-emc-guide/

2021 Automotive EMC Guide
https://learn.interferencetechnology.com/2021-automotive-emc-guide/

OTHER WEBSITES

Doug Smith
http://emcesd.com

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

Henry Ott
https://hotelelconsultants.net/bio/

Interference Technology
https://interferencetechnology.com

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

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

Patrick André
http://andreconsulting.com

Silent Solutions
https://silent-solutions.com/

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

University of Oklahoma EMC
https://www.ou.edu/tulsa/wecad

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

LIST OF LINKEDIN GROUPS

- Aircraft and Spacecraft ESD/EMI/EMC Issues
- Automotive EMC Troubleshooting Experts
- Electromagnetic Compatibility Forum
- Electromagnetics and Spectrum Engineering Group
- EMC - Electromagnetic Compatibility
- EMC Experts
- EMC Troubleshooters
- ESD Experts
- Signal & Power Integrity Community

DEMYSTIFYING THE MATH OF EMC

Interference Technology Editorial Board

As we progress through the fold of technological developments, be it in commercial products, military advancements, automotive electronics, or any of the other industries where electromagnetic devices are developed, EMI will be present and EMC testing will be required.

For those technical personnel who are walking into a laboratory for the first time, learning EMC because their boss said so, or are taking up an interest in the industry, a few simple yet fundamental math lessons need to be known to understand how things are calculated in an EMC laboratory environment.

This article is intended for the beginner or anybody who needs a refresher on the beautiful math of the EMC world.

OHM'S LAW AND IMPEDANCE

Any electrical engineer knows Ohm's Law. If not, a refund should be issued from the institution attended, because it's literally the first thing learned in an electrical engineering class. Ohm's law is utilized to derive power (Watts), voltage (Volts), current (Amperes), and resistance/impedance (Ohms). Two simple equations are given to find any of the above values:

Power (Watts) = Voltage (Volts) x Current (Amperes)
*Voltage (Volts) = Current (Amperes) x Impedance (Ohms)**

**RF, including EMC Testing, typically uses 50 Ohms as the defining impedance*

From these two equations, we can find any of the above values utilizing simple algebra. Once we know how to get from Power to Volts to Amps to Ohms or any combination in between, we can start talking about more important things we might see.

BRING ON THE DECIBEL

EMC testing, including limits, field strengths, transfer functions, shielding effectiveness, and a myriad of other measurements and notations are almost always noted utilizing the decibel (dB). The decibel is a way of expressing units of measurement in a logarithmic notation. This is a very useful way of expressing numbers that are increasing quickly (exponentially) as they relate to what is happening in an EMC system or during an EMC test.

In many EMC test and measurements, the results are often very large or very small, and the dB gives a very convenient way of presenting the data. If two very dissimilar numbers need to be shown on a graph, the dB is a good way of doing it.

For example, looking at power:

- 1 Watt = 30 dBm
- 10 Watts = 40 dBm
- 1 Kilowatt = 60 dBm

Seeing those values should beg the question of how they are derived. Converting between the dB values of power, voltage, and current is pretty simple. Remember that our impedance is 50 Ohms, so it's a constant in these equations.

And you really only need to know 3:
Power (dBm) = 10*log(power in milliwatts(mW))
Voltage (dBuV) = 20*log(Voltage in microvolts (uV))
Current (dBuA) = 20*log(current in microamperes(uA))

Since this is a 50 Ohm system, we also need to remember what the impedance of 50 Ohms is in logarithmic terms:
Impedance (dBOhms) = 20log(impedance) = 20log(50) = 33.979 = 34

Something to remember is that we can't just add and subtract these logarithmic terms like we would linear terms. In fact, adding and subtracting in logarithmic terms is the same as multiplying and dividing in linear terms.

For example:
13 dBuV + 44 dBuV = 57 dBuv

If we convert these terms back to linear and perform the inverse of the Voltage equation above:

$uV = 10^{(dBuv/20)}$
$uV = 10^{(13/20)} = 4.47$ uV and $uV = 10^{(44/20)} = 158.49$ uV

4.47 uV * 158.49 uV = 708.45 uV
20*log(708.45) = 57.01 dBuV

Conversely, subtracting in logarithms is the same as dividing in linear:
dB1 - dB2 = Linear1/Linear2

HOW TO CONVERT BETWEEN DBUA, DBM, AND DBUV

Often enough, an engineer will need to convert between current, voltage, and power for several different reasons, whether it be converting limits, measurements, or understanding data. Simple addition and subtraction will get us wherever we want to go.

Remembering that our impedance is 50 Ohms:
Impedance (dBOhms) = 20 log (50) = 33.979 = 34

dBm = dBuV - 107	dBuV = dBm + 107
dBuV = dBuA + 34	dBuA = dBuV - 34
dBm = dBuA + 73	dBm = dBuA - 73

As a quick exercise, let's convert 0 dBm to dBuV:

0 dBm = x dBuV
0 dBm = 0.001 Watts or 1 mW
0 dBm = 0.224V
0.001W = $(Volts^2)$/50 Ohms
0.001W x 50 Ohms = $Volts^2$
Sqrt(0.001Wx50Ohms) = Volts = 0.224V = 0.224×10^6 uV Volts
20 log (0.224×10^6 uV) = 106.987 dBuV

DECADES AND OCTAVES

Decades and octaves are typically used in frequency ranges, which are found throughout the EMC sphere. A good understanding of these will enable you to read limits and graphs when looking at data.

An octave is defined as a doubling or halving of a value. So if we are at 1 GHz, an increase of 1 octave is 2 GHz. an octave above 2 GHz is 4 GHz, and so on.

A decade is defined as ten times (or a tenth) of any value. If we are at 1 GHz, an increase of 1 decade is 10 GHz. A decade above that is 100 GHz and so on.

Limits will sometimes be expressed in terms of decades. For example, an emissions limit might be expressed as "starting at 10 kHz and increasing 10 dB per decade to 1 GHz."

A dB IS A dB

When you convert linear terms to logarithmic terms (dB), you've created a situation where all of the units are relatable. This is important to note because as power levels increase and voltage levels increase, an engineer might be interested to know how much power it takes to get to a certain field level.

To increase an octave in Voltage (or field level), you need to add 6 dB. To increase an octave in power, you need to add 3 dB. And this is where this knowledge becomes important.

If we have a field level in a test of 100 V/m, and we need to increase that to 200 V/m, we need to add 6 dB. Well, that goes for our power also. We need to increase the power by 6 dB coming from our test system, mainly our amplifier.

So, for example, let's say we need 150 Watts (51.76 dBm) to reach 100 V/m (163.52 dBuB/m) in our system. Since we need to add 6 dB to the field, we also need to add 6 dB to the amplifier, so we need 51.76 + 6 = 57.76 dBm. From what we've learned so far, that's:
$10^{(57.76/10)}$ = 597,035 mW = 597 Watts, which is a big difference from 150 Watts.

STORY TIME

Given everything above, and with a little practice, the simple math of EMC can be learned and applied in different ways. During my time in the laboratory, a customer thought they knew ways to get their device to "pass" by applying some of the math above, albeit incorrectly.

While testing CE101, the measurement was 3 dB above the limit for current harmonics. All measurement system integrities were verified, and we were able to see the measurement on an analyzer. The customer representative asked us to "subtract out our ambient" since the laboratory could have been noisy. While we agreed, we reminded the customer that actually subtracting the dBuA levels was inappropriate and the numbers MUST be converted to linear terms.

The limit level was 100 dBuA, and the measurement was approximately 103.50 dBuA. The noise floor of the analyzer when everything was connected was about 73 dBuA.

So, we showed the customer the following math.

Measurement → $10^{(103.5/20)}$ = 149,623.56 uA
Ambient → $10^{(73/20)}$ = 4,466.84 uA

Subtracting → 149,623.56 uA - 4,466.84 uA = 145,156.72 uA

Go back to dB → 20log(145,156.72) = 103.24

STILL 3 dB ABOVE THE LIMIT

So, just remember how to apply things correctly, and you'll have success in any EMC laboratory you may walk into.

FUNDAMENTALS OF ELECTROMAGNETIC COMPATIBILITY

Ed Sveda
Spectrum Control

INTRODUCTION

Electromagnetic Compatibility (EMC) ensures that multiple electronic devices can function acceptably within the same electromagnetic environment by not interfering with each other.

This article is intended to provide the reader with a basic understanding of EMC standards, test methods, and mitigation techniques.

ELECTROMAGNETIC INTERFERENCE

Electromagnetic Interference (EMI) is an electromagnetic emission that causes interference in another electronic device. EMI encompasses the entire electromagnetic spectrum but is most applicable to modern electronic devices over the frequency range of 10 kHz to 10 GHz. EMI can be from intentional or unintentional sources, continuous or intermittent, and at a single frequency or across a broad range of frequencies.

Unintentional EMI sources include switch-mode power supplies (SMPS), digital devices, brushed DC motors, high-voltage ignition systems, and fluorescent lighting. SMPS are the most common unintentional EMI source; since they are now used almost exclusively in LED light bulbs, digital devices, and battery chargers for cell phones and laptops.

Intentional EMI sources are most commonly radio frequency transmitters, whose emissions are often referred to as Radio Frequency Interference (RFI). This includes AM radio, FM radio, television, cell phones, Wi-Fi, Bluetooth, and many other fixed and mobile radio communication systems used by aviation, emergency services, police, and the military.

Intermittent EMI includes transients that can cause catastrophic damage to electronics including electrostatic discharge, lightning, inductive kickback, and electromagnetic pulse events (EMP).

EMI COUPLING

EMI coupling from the source to the receptor can be conducted through wires, radiated through the air, or both. Radiated emissions become more difficult to mitigate at higher frequencies because higher frequencies have shorter wavelengths that are more effectively radiated by typical wire lengths. Radiated emissions readily penetrate non-conductive materials such as air, space, plastic, wood, and insulators.

Figure 1: EMC Components

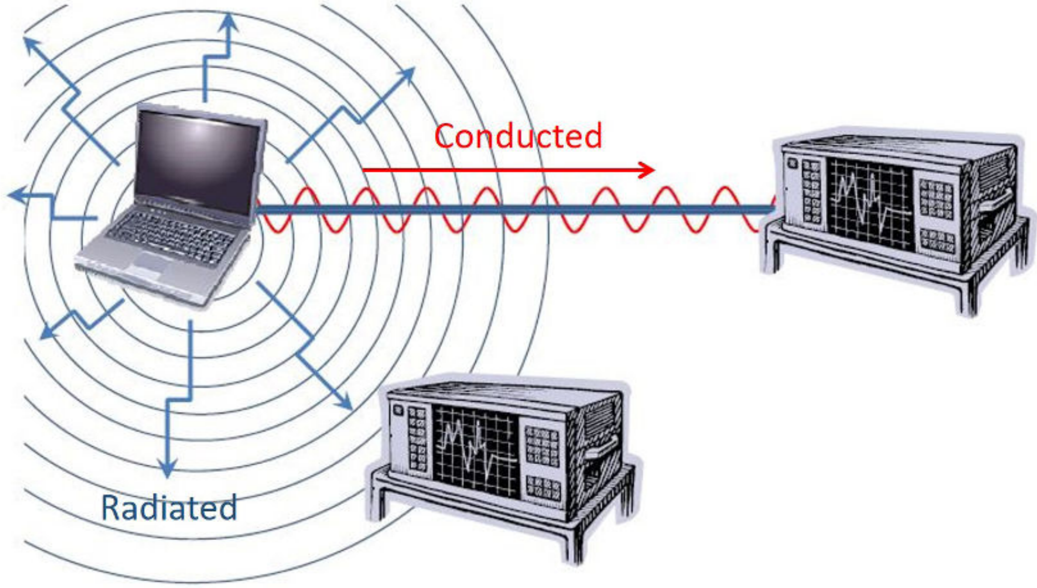


Figure 2: Coupling Mechanisms

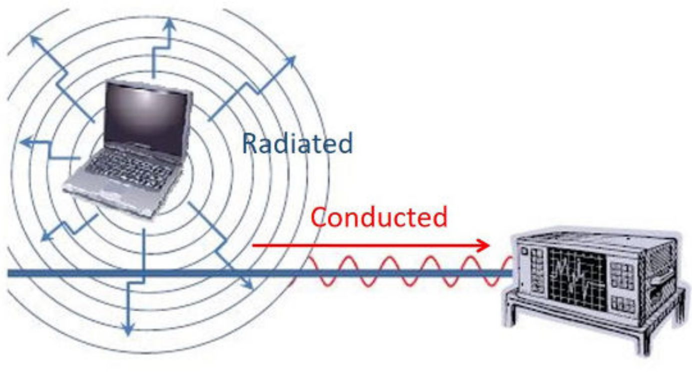


Figure 3: Radiation → Conduction

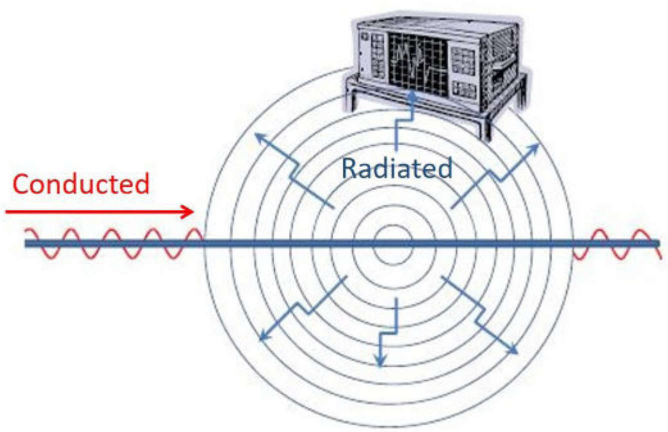


Figure 4: Conduction → Radiation

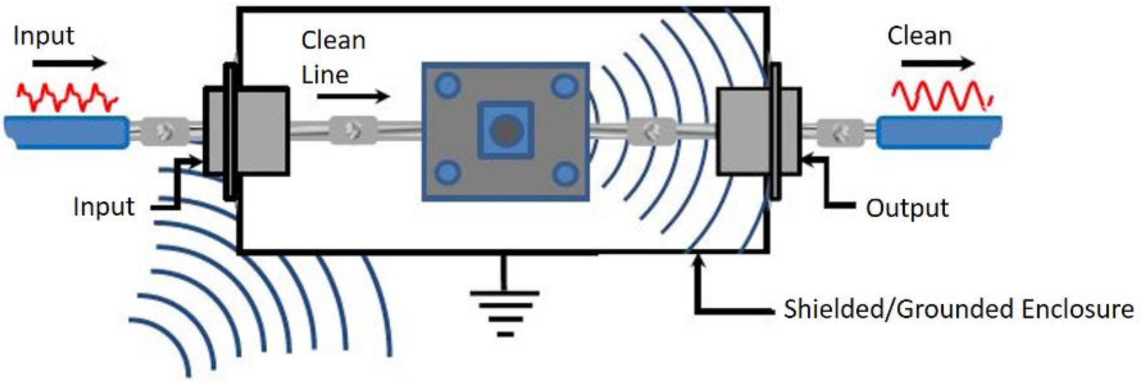


Figure 5: Basic EMI Compliant System

Real-world EMI situations are often a combination of both conducted and radiated emissions, with any or all wires and cables acting as receiving or transmitting antennas.

EMI SUPPRESSION

EMC requires proper grounding, filtering, and shielding, i.e. you can't simply increase filtering to make up for a bad ground or ineffective shielding.

Radiated EMI often requires shielding electronic components inside a metallic enclosure, and maintaining that shield requires cables and wires to be filtered at the point of entry. Filters reduce conducted EMI on wires and cables into and out of the enclosure. Point of entry feedthrough filters require low-impedance coaxial connections to the metal enclosure to function correctly.

COMPLIANCE TESTING

The two types of EMC testing are emissions and immunity. Emission testing verifies the frequency and amplitude of a device's emissions are below standardized limits. Immunity testing verifies the acceptable functionality of a device when exposed to standardized EMI levels.

Emissions are measured using a Line Impedance Stabilization Network (LISN), current probe, or antenna connected to an EMI receiver that scans the desired frequency range. Emissions under the limit are passing and emissions over the limit are failing.

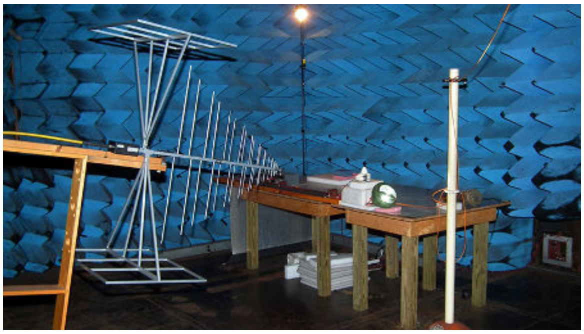
Immunity is performed by injecting EMI through a Coupling/Decoupling Network (CDN), current probe, or antenna and verifying the functionality of the device under test. The pass and fail indications are not seen on the EMC test equipment but are determined by monitoring the functionality of the device being tested while it is exposed to EMI.

Emission and immunity testing are further broken down into the four basic EMC tests 1) Conducted Emissions, 2) Radiated Emissions, 3) Conducted Immunity, and 4) Radiated Immunity. Conducted emissions and conducted immunity testing does not use an antenna, whereas radiated emissions and radiated immunity testing use antennas. If there is an antenna in the setup radiated emissions or radiated immunity test is being performed.

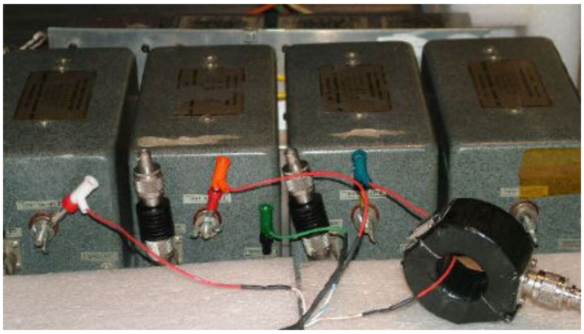
REAL WORLD CONSIDERATIONS

The typical difference between EMI emission limits and immunity test levels is 100,000 to 1 or 100 dB.Is this a 100 dB safety margin? If electronic devices in a given environment are limited to such low levels of emissions, then why are these same devices required to handle such high levels for

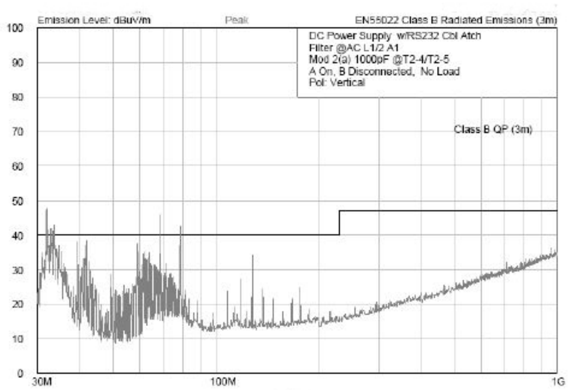
Figure 6: Emissions Testing



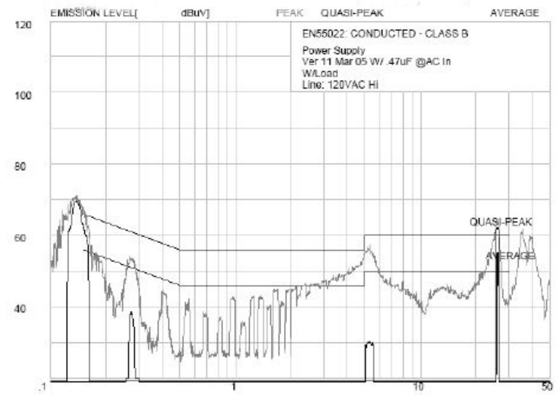
Radiated Emissions Test Setup



Conducted Emissions Test Setup



Radiated Emissions Test Data



Conducted Emissions Test Data

immunity? The reason is that electronic devices must operate in close proximity to both radio transmitters and radio receivers. Radio transmitters generate high-level RFI to communicate over great distances. Radio receivers are very sensitive in order to detect these signals. Immunity test levels simulate the energy levels that electronic devices will be exposed to when they are operated nearby radio transmitters. Emission limits unsure that a device's EMI emissions will not interfere with the reception of nearby radio receivers.

NOTES

- Equipment expected to operate in close proximity to radio transmitters must be immune to EMI levels in excess of 10 V or 140 dBμV.
- Equipment expected to operate in close proximity to radio receivers typically limit EMI emission levels to less than 0.0001 V or 40 dBμV.

STANDARDS AND SPECIFICATIONS

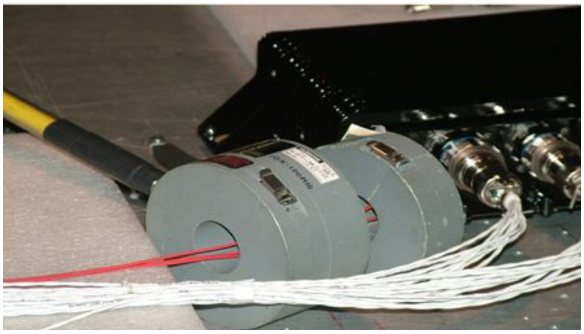
From a global perspective, most governments have rules and regulations related to the control of EMI and call out specific standards for testing devices to ensure EMC compliance.

In the U.S., EMC guidelines for commercial equipment are handled by the Federal Communications Commission (FCC). The Code of Federal Regulations (CFR) section 47 Parts 15, 18, and 68 contain relevant information that all engineers should be aware of when designing class A and B devices.

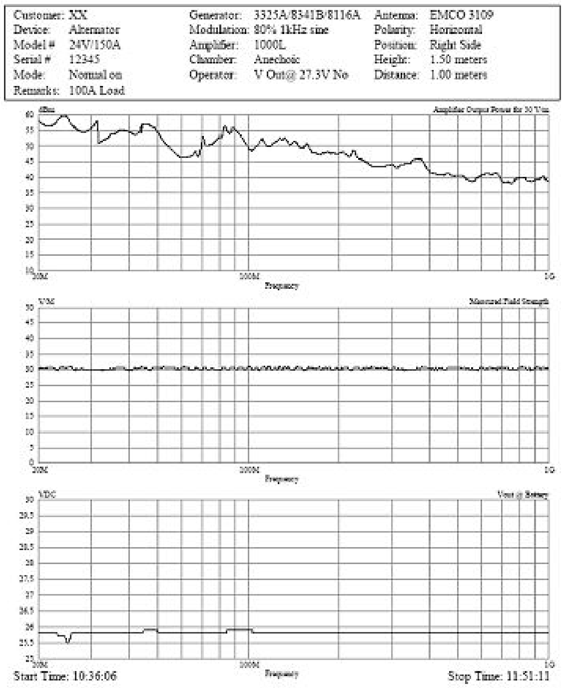
The US Military has its own standards, which are significantly more stringent. These guidelines are detailed in a wide range of military standards, such as MIL-STD-461 and MIL-STD-464.

Figure 7: Immunity Testing

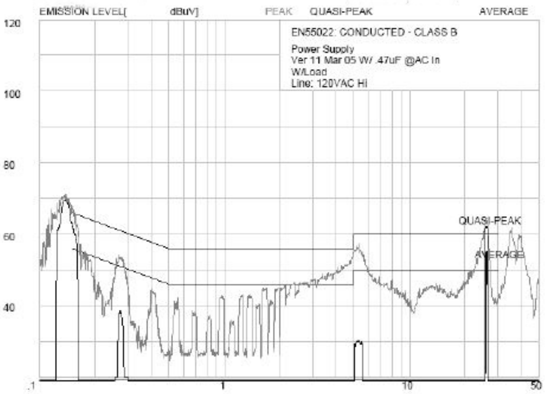
Radiated Immunity Test Setup



Conducted Immunity Test Setup



Radiated Immunity Test Data



Conducted Immunity Test Data

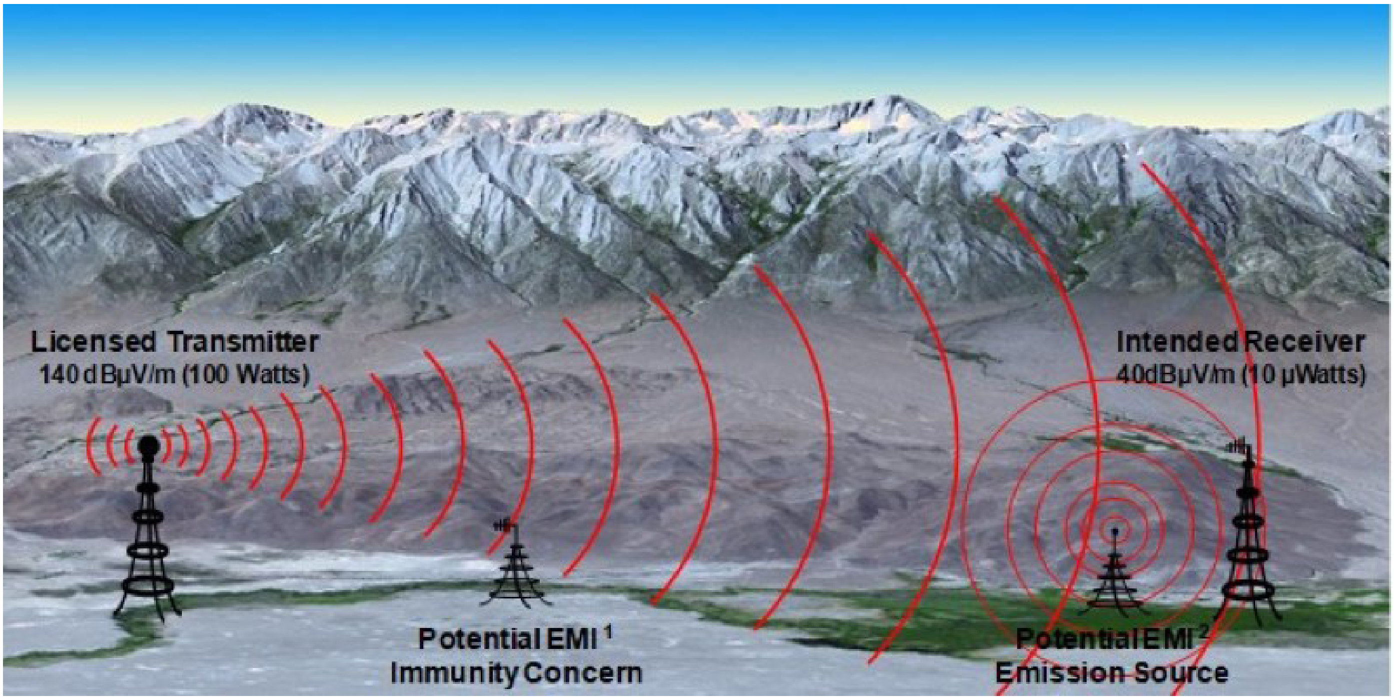


Figure 8

The International Electrotechnical Commission (IEC), via its International Special Committee on Radio Interference (CISPR), creates globally accepted EMC standards.

Test capability at Spectrum Control is extensive and covers a large number of requirements related to the FCC, US Military, and the IEC. Some test capabilities are listed below, but this list continues to evolve and expanded in support of market expectations.

Commercial
- FCC Part 15 Emissions
- CISPR 11, 14, 22 Emissions
- CISPR 25 Emissions
- IEC 1000 4 x Immunity

International
- EN55011/CISPR 11
- EN55014/CISPR 14
- EN55022/CISPR 22
- EN61000-4-2 Electrostatic Discharge
- EN61000-4-3 Radiated RF Immunity
- EN61000-4-4 Electrical Fast Transient
- EN61000-4-5 Surge
- EN61000-4-6 Conducted RF Immunity

Medical
- EN 55011
- EN 55022

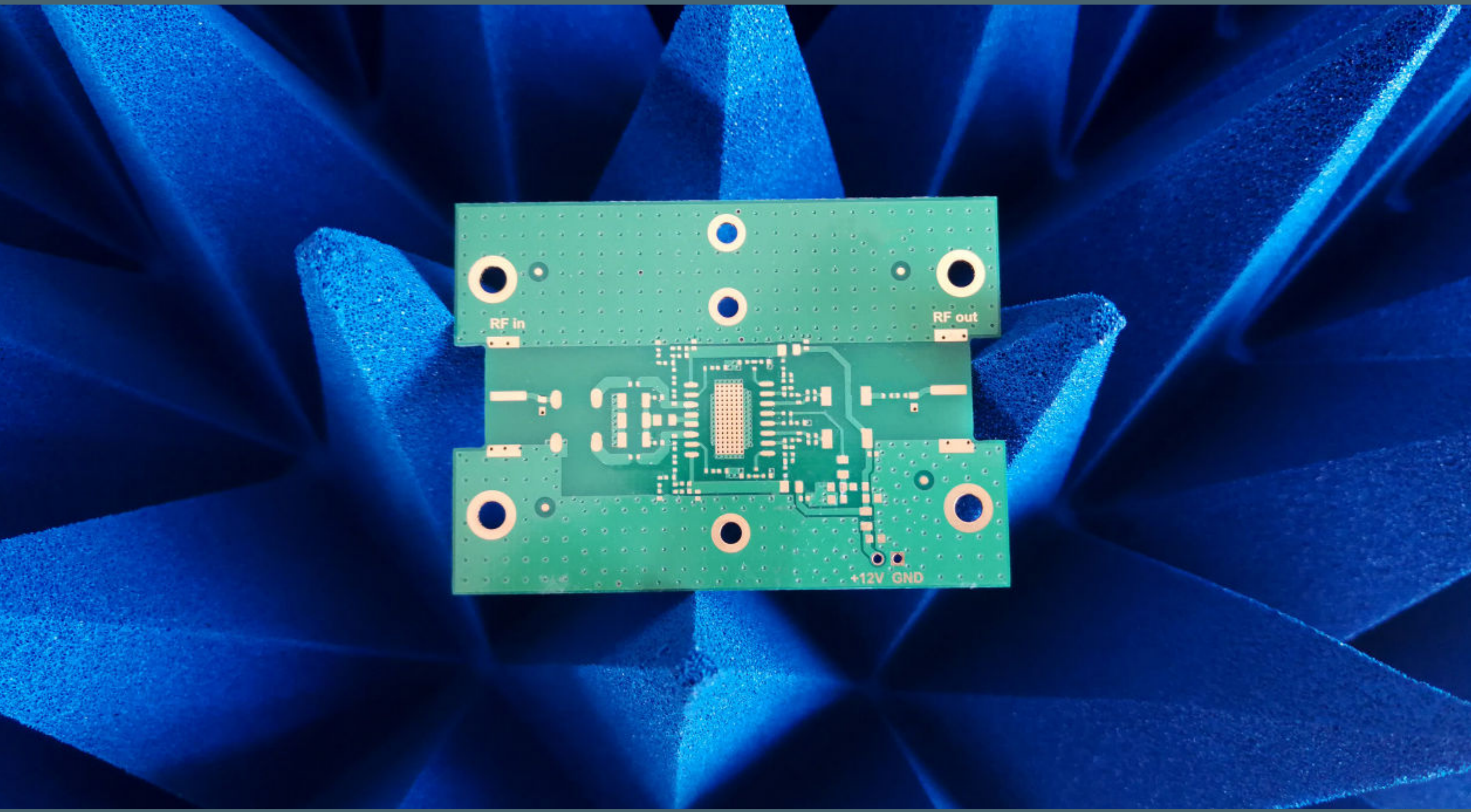
Military
- MIL-STD-461 A/B/C/D/E/F/G
- MIL-STD-1399
- MIL-STD-704
- MIL-STD-1275

CONCLUSION

Electromagnetic Compatibility has become an important aspect in the design of electronic equipment and systems. Equipment manufacturers must stay up to date with continually evolving EMC legislation. It is important to understand EMC since equipment failures at the compliance level can lead to delayed product deliveries and increased development costs. EMC failures at the user level can mean returned equipment, loss of future business, and potential hazards in critical applications.

Please contact Spectrum Control for additional information.

EMC TESTING



COMMON COMMERCIAL EMC STANDARDS

Commercial Electromagnetic Compatibility (EMC) Standards

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

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

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

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

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

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

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

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

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

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

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

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

USEFUL EMC TESTING REFERENCES

RECOMMENDED BOOKS & JOURNALS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY (EMC) STANDARDS

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

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

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

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

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

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

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

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

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

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

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

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

MILITARY RELATED DOCUMENTS & STANDARDS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MIL-STD-464D Electromagnetic Environmental Effects Requirements for Systems, 24 Dec 2020.

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

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

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

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

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

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

MILLIMETER WAVE APPLICATIONS AND PROMISE

Mike Violette, P.E.
President, Washington Laboratories

Imagine a radio frequency wavelength about the thickness of your pinky nail. This is a new area for technology applications.

A growing area in spectrum development is exploding. For many decades, very high frequencies (millimeter waves) have been the playground of radio-astronomers to image our solar system, stars and galaxies. This space is "new" fertile ground for sensing and communications in terrestrial (and extra-terrestrial) use.

The millimeter wave space is opening up for these applications, which promise enormous multi-gigahertz bandwidths for innovation across many sectors.

Typically reserved for passive sensing of the mysteries of the Earth and our galactic environment, the 100+ GHz spectrum is, in a way, "off to the races." Radar applications for mobile devices (automobile and other) are being allocated on an increased basis. The applications are numerous, and the challenges are unique. Because of the physics of dealing with these high frequencies, the use of these frequencies is confined to very focused applications, requiring precision and tight control on propagation between the devices that transmit and receive mmWave energy.

In the industry, the mmWave Coalition (mmwavecoalition.org) works on these new areas, monitoring and focusing on the allocations mandated by The Federal Communications Commission (FCC) and other regulatory bodies. Tossed in the salad of interests are incumbent users of this spectrum (NASA, radio-astronomy users, research institutions as mentioned before) and a host of Earth- and space-based sensing systems.

What is tricky is the reasonable parsing of these new spectrum spaces. As terahertz (THz) applications are borne and deployed, there is a balance that must be considered for the use and protection of the incumbents without stifling innovation from other interests. This is doubly necessary as the existing and future roles of terahertz technologies include Earth observations of weather and climate.

The radiometry applications (sensing at a distance based on the "temperature" of the Earth's surface, as measured by wide-band sensors) are critical. Additional clutter and noise in the GHz frequencies can clog and distort the science that is necessary to predict winds, waves, ocean, Earth's surface temperature and other weather and physical phenomena that give eyes to what is happening on our planet. Something as mundane as the nightly weather report is dependent on good satellite data for small and large weather patterns that affect daily life, crop predictions, safety and incident prediction. Other applications use radiometers to predict surface winds, all important for naval and ocean-going navigation and planning (see: Tropical Rainfall Measurement Mission https://gpm.nasa.gov/missions/trmm). As NASA explains: "TRMM provided much needed information on rainfall and its associated heat release that helps to power the global atmospheric circulation that shapes both weather and climate. In coordination with other satellites in NASA's Earth Observing System."

1. Various groups are very interested in this particularly large chunk of the spectrum. For the present, the FCC's allocations end at 90GHz and the radio frequency spectrum, challenged and fiercely protected by research and other groups, is being weighed as new applications arise.
2. Members of the mmWave Coalition include several applications-based organizations that are learning to capitalize and expand on mmWave capabilities. One member, for instance, equipment manufacturer Virginia Diodes, can expand sensing and measurements and, with their extension modules can detect, measure and synthesize frequencies in excess of 1000 GHz, which is remarkable.

According to the commonly used equation, the wavelength of an RF signal is equal to *c/f* (speed of light divided by frequency), or 300*10^8/1000X10^9. This means that the wavelengths are on the order of 0.3 millimeters, or about the thickness of your pinky nail. What is amazing is the high frequencies allow for multi-GHz wide bandwidths, which allow for tremendous gains in communication operating data rates.

With these very small wavelengths, the physical structure of antennas and associated waveguides are attendantly small (we are talking pin-head small), precisely machined and carefully aligned. Care is required for connecting waveguide structures — no dirt and grime and grit, or the game is off.

The real challenges arise in making and sensing these frequencies because a few hindrances need to be noted and properly dealt with, namely the directionality of these mmWaves and the propagation losses associated with these very high frequencies. In addition, the beamwidths of these high frequency phenomena are extremely tight. No longer can a large and lopey broadband antenna be used to measure this energy properly. Laser-like precision is necessary to collect and quantify these quantities. We have worked on a system that used a 275 GHz operating frequency to sense and image packages for safety and security measures. Automotive radar applications at ~60 GHz are now commonplace.

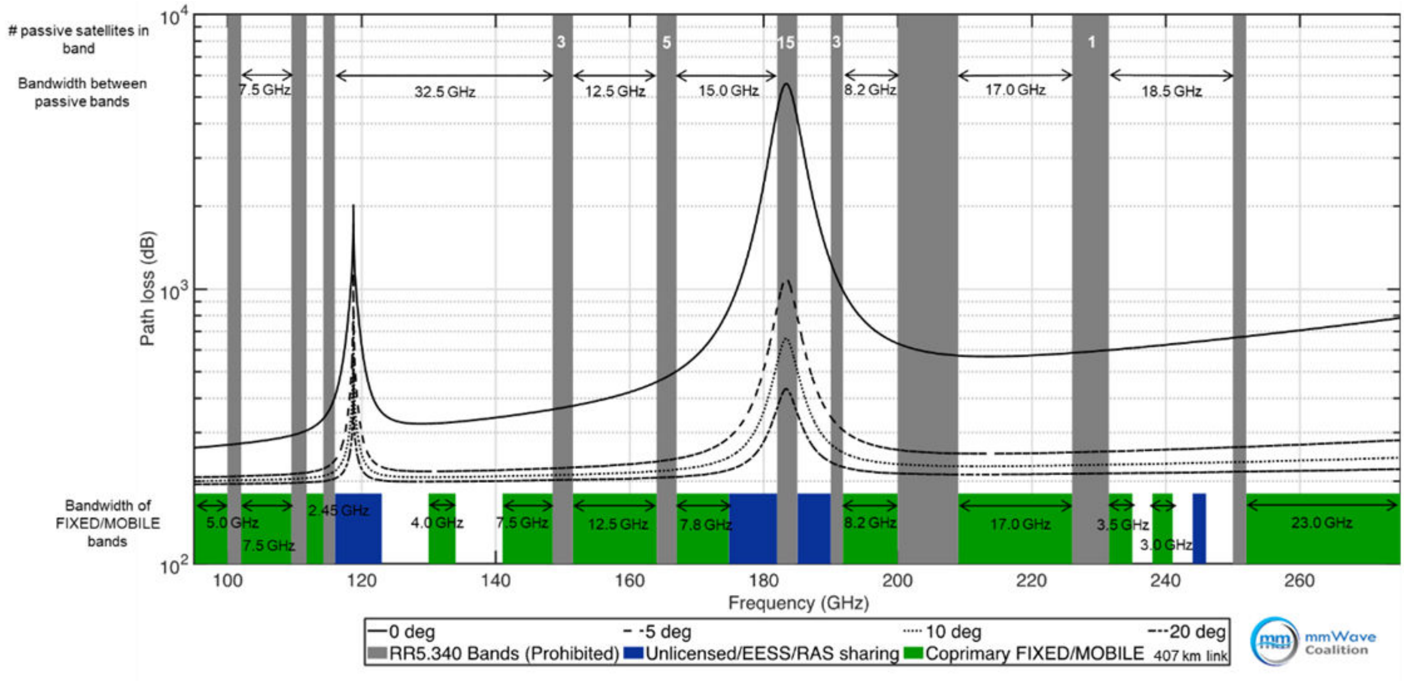
PROPAGATION LOSSES

The propagation losses are extremely high, which limits the practical range for these applications. The Free-Space Propagation Losses (FSPL) are well-known. The FSPL are a function of frequency, fundamentally, and can be calculated according to the following equation:

$$\mathbf{FSPL = 20\log(d) + 20\log(f) + 20\log(4\pi/c) - G_{Tx} - G_{Rx}}$$

Where d is the distance, in meters, f is frequency in Hertz and G_{Tx} and G_{Rx} are the transmit and receive gain of the antennas, respectively. *c* is the speed of light in m/s and π is my favorite irrational constant.

All other terms aside, the driving function in the above equation is the frequency of the RF energy, so the loss monotonically increases with frequency. At 100 GHz, the losses are 40 dB higher than at 1 GHz, which is a significant increase in propagation loss. But there are derived benefits from this naturally occurring FSPL, namely, there are isolation losses that occur as a result and, in addition, the tight beamwidths tend to allow more isolation between devices that may be



Source: mmWave Coalition

sharing the same spectrum, thus, much of the communications and sensing applications are point-to-point and necessarily so.

There are naturally occurring losses in the atmosphere, due to water vapor absorption — and these losses are substantial (see the figure below, note the large losses at ~100 GHz and l85 GHz). This is not at all a “bad” thing because one can take advantage of these deep losses to put sensitive communications in those bands.

For laboratory applications, it is critical that measurement personnel understand these physical realities and the correct use of measurement instruments be well-applied. This demands that spectrum/receiver extension modules be correctly reasoned and applied. For example, most spectrum analyzer have baseband measurement input that can extend to 50GHz (or so). Above that frequency extension modules use mixer-based extensions that “use” the local oscillator (LO) of the analyzer and beat the incoming signal to be measured against various harmonics of the LO. This produces an input Intermediate Frequency (IF) that the analyzer can recognize and produce a display that, using conversion gains associated with the external mixer (from nominally 10 to 40 dB), can produce a calibrated response. Again, a little tricky, but not impossible.

As allocations increase, applications for mmWave are expanding. As the frequencies increase, the phenomena of RF communications begins to be more light-like and the crossover between RF and optics become less hazy.

Innovative companies, such as those associated with the mmWave Coalition, are working to implement a balanced approach to use of these high frequency/short wavelength physics.

For the immediate future, the allocations for these devices are going to be negotiated and settled.

Stay tuned.

WIRELESS / 5G / IOT

WIRELESS GROUPS & ORGANIZATIONS

MAJOR WIRELESS LINKEDIN GROUPS

- Wireless Telecommunications Worldwide
- Wireless and Telecom Industry Network
- Cellular, Wireless & Mobile Professionals
- Wireless Communications & Mobile Networks
- 802.11 Wireless Professionals
- Wireless Consultant
- Telecom & Wireless World

WIRELESS ASSOCIATIONS AND ORGANIZATIONS

ALLIANCE FOR TELECOMMUNICATIONS INDUSTRY SOLUTIONS

https://www.atis.org/

As a leading technology and solutions development organization, the Alliance for Telecommunications Industry Solutions (ATIS) brings together the top global ICT companies to advance the industry's business priorities.

APCO INTERNATIONAL

https://www.apcointl.org

APCO International is the world's oldest and largest organization of public safety communications professionals and supports the largest U.S. membership base of any public safety association. It serves the needs of public safety communications practitioners worldwide — and the welfare of the general public as a whole — by providing complete expertise, professional development, technical assistance, advocacy and outreach.

ALLIANCE FOR TELECOMMUNICATIONS INDUSTRY SOLUTIONS (ATIS)

http://www.atis.org

In a rapidly changing industry, innovation needs a home. ATIS is a forum where the information and communications technology (ICT) companies convene to find solutions to their most pressing shared challenges.

BLUETOOTH SPECIAL INTEREST GROUP

https://www.bluetooth.com

Join thousands of the world's most innovative companies already developing and influencing Bluetooth technology.

BROADBAND FORUM

https://www.broadband-forum.org/

The Broadband Forum is an industry-driven global standards development organization helping operators, application providers, and vendors deliver better, services-led broadband.

COMPETITIVE CARRIERS ASSOCIATION (CCA)

https://www.ccamobile.org/

CCA advocates on behalf of its members' interests and works to educate policymakers on the key issues that impact its members' ability to compete, survive, and thrive.

CTIA - THE WIRELESS ASSOCIATION

http://www.ctia.org

CTIA is an international nonprofit membership organization that has represented the wireless communications industry since 1984. The association's members include wireless carriers, device manufacturers, suppliers as well as apps and content companies.

EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE (ETSI)

http://www.etsi.org

We produce globally applicable standards for Information & Communications Technologies including fixed, mobile, radio, broadcast, internet, aeronautical, and other areas.

GLOBAL MOBILE SUPPLIERS ASSOCIATION (GSA)

https://gsacom.com/about-gsa/

GSA is a not-for-profit industry organization representing companies across the worldwide mobile ecosystem who are engaged in the supply of infrastructure, semiconductors, test equipment, devices, applications and mobile support services.

IEEE STANDARDS ASSOCIATION

https://standards.ieee.org/

IEEE Standards Association (IEEE SA) is a leading consensus building organization that nurtures, develops and advances global technologies, through IEEE. It brings together a broad range of individuals and organizations from a wide range of technical and geographic points of origin to facilitate standards development and standards related collaboration.

INTERNATIONAL ELECTROTECHNICAL COMMISSION (IEC)

https://www.iec.ch/homepage

Founded in 1906, the IEC is the world's leading organization for the preparation and publication of international standards for all electrical, electronic and related technologies. These are known collectively as "electrotechnology."

INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

https://iso.org/home.html

ISO, the International Organization for Standardization, brings global experts together to agree on the best way of doing things – for anything from making a product to managing a process. As one of the oldest non-governmental international organizations, ISO has enabled trade and cooperation between people and companies the world over since 1946. The International Standards published by ISO serve to make lives easier, safer and better.

INTERNATIONAL TELECOMMUNICATION UNION (ITU)

https://www.itu.int/en/Pages/default.aspx

ITU is the United Nations specialized agency for information and communication technologies (ICTs). The Organization is made up of a membership of 193 Member States and more than 1000 companies, universities and international and regional organizations. Headquartered in Geneva, Switzerland, and with regional offices on every continent, ITU is the oldest agency in the UN family – connecting the world since the dawn of the telegraph in 1865.

INTERNET ENGINEERING TASK FORCE (IETF)

https://www.ietf.org/

IETF, founded in 1986, is the premier standards development organization (SDO) for the Internet. The IETF makes voluntary standards that are often adopted by Internet users, network operators, and equipment vendors, and it thus helps shape the trajectory of the development of the Internet. But in no way does the IETF control, or even patrol, the Internet.

NATIONAL ASSOCIATION OF BROADCASTERS (NAB)

http://nab.org

NAB is the voice for the nation's radio and television broadcasters. As the premier trade association for broadcasters, NAB advances the interests of our members in federal government, industry and public affairs; improves the quality and profitability of broadcasting; encourages content and technology innovation; and spotlights the important and unique ways stations serve their communities.

NATIONAL ASSOCIATION OF TOWER ERECTORS (NATE)

https://natehome.com/

NATE is a non-profit trade association providing a unified voice for tower erection, maintenance and service companies. NATE is headquartered in Watertown, South Dakota with a staff of fourteen people who administer to the day-to-day operations of the association. As a member driven association, NATE is led by its Board of Directors. These individuals come from all types and sizes of companies located throughout the United States.

RURAL WIRELESS ASSOCIATION (RWA)

https://ruralwireless.org/

RWA is a trade association representing rural wireless carriers who each serve fewer than 100,000 subscribers. RWA's members have joined together to speed delivery of new, efficient, and innovative wireless technologies to the populations of remote and underserved sections of the country.

SATELLITE INDUSTRY ASSOCIATION (SIA)

http://www.sia.org

SIA is a Washington D.C. based trade association representing the leading global satellite operators, service providers, manufacturers, launch services providers, and ground equipment suppliers.

TELECOMMUNICATIONS INDUSTRY ASSOCIATION (TIA)

http://www.tiaonline.org

TIA is the leading trade association representing the global information and communications technology (ICT) industry through standards development, policy initiatives, business opportunities, market intelligence and networking events. With support from hundreds of members, TIA enhances the business environment for companies involved in telecom, broadband, mobile wireless, information technology, networks, cable, satellite, unified communications, emergency communications, and the greening of technology.

Wi-Fi ALLIANCE

https://www.wi-fi.org/

Wi-Fi Alliance drives global Wi-Fi adoption and evolution through thought leadership, spectrum advocacy, and industry-wide collaboration. Their work includes the development of innovative technologies, requirements, and test programs that help ensure Wi-Fi provides users the interoperability, security, and reliability they have come to expect.

WIRELESS BROADBAND ALLIANCE (WBA)

https://wballiance.com/

WBA is the global organization that connects people with the latest Wi-Fi initiatives. Founded in 2003, the vision of the WBA is to drive seamless, interoperable service experiences via Wi-Fi within the global wireless ecosystem. WBA's mission is to enable collaboration between service providers, technology companies, cities, regulators and organizations to achieve that vision.

WIRELESS COMMUNICATIONS ALLIANCE (WCA)

https://wca.org/

WCA exists to enable collaboration between technology companies, solution and service providers, early adopters, and academia to drive the successful implementation of wireless products and services within the global wireless ecosystem.

WIRELESS INFRASTRUCTURE ASSOCIATION (WIA)

http://wia.org

The Wireless Infrastructure Association represents the businesses that develop, build, own, and operate the nation's wireless infrastructure.

WIRELESS INNOVATION FORUM

http://www.wirelessinnovation.org

WInnForum members are dedicated to advocating for the innovative use of spectrum and advancing radio technologies that support essential or critical communications worldwide. Through events, committee projects, and initiatives the Forum acts as the premier venue for its members to collaborate to achieve these objectives, providing opportunities to network with customers, partners and competitors, educate decision makers, develop and expand markets, and advance relevant technologies.

WIRELESS INTERNET SERVICE PROVIDERS ASSOCIATION (WISPA)

https://www.wispa.org/

WISPA – Broadband Without Boundaries was founded in 2004 to promote the development, advancement, and unification of the WISP industry, with WISP defined as “an Internet service provider that utilizes wireless, fiber optics, or other technologies to distribute broadband or related Internet Protocol-derived services.”

WiMAX FORUM

https://wimaxforum.org/

The WiMAX Forum® is an industry-led, not-for-profit organization that certifies and promotes the compatibility and interoperability of broadband wireless products based upon IEEE Standard 802.16. The WiMAX Forum's primary goal is to accelerate the adoption, deployment and expansion of WiMAX, AeroMACS, and WiGRID technologies across the globe while facilitating roaming agreements, sharing best practices within its membership and certifying products.

WTA

https://w-t-a.org/

WTA is a member-driven association strengthening the ability of its members to provide affordable, advanced broadband and communications services in rural America through advocacy and education.

ZIGBEE ALLIANCE

csa-iot.org/all-solutions/zigbee/

Our innovative standards are custom-designed by industry experts to meet the specific market needs of businesses and consumers. These market leading standards give product manufacturers a straightforward way to help their customers gain greater control of, and even improve, everyday activities.

USEFUL WIRELESS REFERENCES

WIRELESS WORKING GROUPS

802.11 Working Group
The 802.11 Working Group is responsible for developing wireless LAN standards that provide the basis for Wi-Fi.
http://grouper.ieee.org/groups/802/11/

802.15 Working Group
The 802.15 Working Group is responsible for developing wireless PAN standards that provide the basis for Bluetooth and ZigBee.
http://www.ieee802.org/15/

802.16 Working Group
The 802.16 Working Group is responsible for developing wireless MAN standards that provide the basis for WiMAX.
http://grouper.ieee.org/groups/802/16/

Bluetooth SIG
The Bluetooth SIG is responsible for developing wireless PAN specifications.
https://www.bluetooth.com

Cellular Telecommunications and Internet Association (CTIA)
The CTIA represents cellular, personal communication services, mobile radio, and mobile satellite services over wireless WANs for service providers and manufacturers.
http://www.ctia.org

Federal Communications Commission (FCC)
The FCC provides regulatory for RF systems in the U.S.
https://www.fcc.gov

GSM Association
The GSM Association participates in the development of development of the GSM platform - holds the annual 3GSM World Congress.
http://www.gsmworld.com

Wi-Fi Alliance
The Wi-Fi Alliance develops wireless LAN (“Wi-Fi”) specifications based on IEEE 802.11 standards and provides compliance testing of Wi-Fi products.
http://www.wi-fi.org

WiMAX Forum
The WiMAX Forum develops wireless MAN standards based on IEEE 802.16 standards and provides compliance testing of WiMAX products.
http://wimaxforum.org

ZigBee Alliance
The ZigBee Alliance develops standards for low-power wireless monitoring and control products.
http://www.zigbee.org

USEFUL WEBSITES

ARRL RFI Information
http://www.arrl.org/radio-frequency-interference-rfi

Jim Brown has several very good articles on RFI, including: A Ham’s Guide to RFI, Ferrites, Baluns, and Audio Interfacing.
www.audiosystemsgroup.com

FCC
http://www.fcc.gov

FCC, Interference with Radio, TV and Telephone Signals
http://www.fcc.gov/guides/interference-defining-source

IWCE Urgent Communications
http://urgentcomm.com has multiple articles on RFI

Jackman, Robin, Measure Interference in Crowded Spectrum, Microwaves & RF Magazine, Sept. 2014.
http://mwrf.com/test-measurement-analyzers/measure-interference-crowded-spectrum

RFI Services (Marv Loftness) has some good information on RFI hunting techniques
www.rfiservices.com

TJ Nelson, Identifying Source of Radio Interference Around the Home, 10/2007
http://randombio.com/interference.html

USEFUL BOOKS

The RFI Book (3rd edition)
Gruber, Michael
ARRL, 2010.

AC Power Interference Handbook (2nd edition)
Loftness, Marv
Percival Publishing, 2001.

Transmitter Hunting: Radio Direction Finding Simplified
Moell, Joseph and Curlee, Thomas
TAB Books, 1987.

USEFUL BOOKS (CONTINUED)

Interference Handbook
Nelson, William
Radio Publications, 1981.

Electromagnetic Compatibility Engineering
Ott, Henry W.
John Wiley & Sons, 2009.

Platform Interference in Wireless Systems - Models, Measurement, and Mitigation
Slattery, Kevin, and Skinner, Harry
Newnes, 2008.

Spectrum and Network Measurements, (2nd Edition)
Witte, Robert
SciTech Publishing, 2014.

Radio Frequency Interference (RFI) Pocket Guide
Wyatt and Gruber
SciTech Publishing, 2015.

USEFUL FORMULAS AND REFERENCE TABLES

E-Field Levels versus Transmitter Pout			
Pout (W)	V/m at 1m	V/m at 3m	V/m at 10m
1	5.5	1.8	0.6
5	12.3	4.1	1.2
10	17.4	5.8	1.7
25	27.5	9.2	2.8
50	38.9	13.0	3.9
100	55.0	18.3	5.5
1000	173.9	58.0	17.4

Assuming the antenna gain is numerically 1, or isotropic, and the measurement is in the far field and greater than 100 MHz.

Using Decibels (dB)
The decibel is always a ratio…

- Gain = P_{out}/P_{in}, where P = power
- Gain(dB) = 10log(P_{out} / P_{in}), where P = power
- Gain(dB) = 20log(V_{out}/V_{in}), where V = voltage
- Gain(dB) = 20log(I_{out}/I_{in}), where I = current

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
Multiplying power by a factor of 2 corresponds to a 3 dB increase in power. This also corresponds to a 6 dB increase in voltage or current.

Commonly Used Power Ratios (dB)		
Ratio	Power	Voltage or Current
0.1	-10 dB	-20 dB
0.2	-7.0 dB	-14.0 dB
0.3	-5.2 dB	-10.5 dB
0.5	-3.0 dB	-6.0 dB
1	0 dB	0 dB
2	3.0 dB	6.0 dB
3	4.8 dB	9.5 dB
5	7.0 dB	14.0 dB
7	8.5 dB	16.9 dB
8	9.0 dB	18.1 dB
9	9.5 dB	19.1 dB
10	10 dB	20 dB
20	13.0 dB	26.0 dB
30	14.8 dB	29.5 dB
50	17.0 dB	34.0 dB
100	20 dB	40 dB
1,000	30 dB	60 dB
1,000,000	60 dB	120 dB

Multiplying power by a factor of 10 corresponds to a 10 dB increase in power. Multiplying a voltage or current by 10 is a 20 dB increase. Dividing by a factor of 10 corresponds to a 10 dB reduction in power, or 20 dB for voltage and current.

COMMON WIRELESS FREQUENCY BANDS (LINKS)

GSM Bands:
https://en.wikipedia.org/wiki/GSM_frequency_bands

UMTS Bands:
https://en.wikipedia.org/wiki/UMTS_frequency_bands

LTE Bands:
https://en.wikipedia.org/wiki/LTE_frequency_bands

MMDS:
https://en.wikipedia.org/wiki/Multichannel_Multipoint_Distribution_Service

V Band (40 to 75 GHz):
https://en.wikipedia.org/wiki/V_band

DECT and DECT 6.0 (wireless phones and baby monitors):
https://en.wikipedia.org/wiki/Digital_Enhanced_Cordless_Telecommunications

Comparison of wireless internet standards:
https://en.wikipedia.org/wiki/Comparison_of_mobile_phone_standards

Wi-Fi Protocols (From Intel):
http://www.intel.com/content/www/us/en/support/network-and-i-o/wireless-networking/000005725.html

LINKS TO MANUFACTURER'S WHITE PAPERS

Interference Hunting With The R&S FSH (Rohde & Schwarz):
https://www.rohde-schwarz.com/us/applications/interference-hunting-with-r-s-fsh-application-note_56280-77764.html

Interference Hunting / Part 1 (Tektronix):
http://www.tek.com/blog/interference-hunting-part-1-4-get-insight-you-need-see-interference-crowded-spectrum

Interference Hunting / Part 2 (Tektronix):
https://in.tek.com/blog/interference-hunting-part-2-4-how-often-interference-happening

Interference Hunting / Part 3 (Tektronix):
http://www.tek.com/blog/interference-hunting-part-3-4-use-mask-search-automatically-discover-when-interference-happenin

Interference Hunting / Part 4 (Tektronix):
https://www.tek.com/en/blog/interference-hunting-part-4-4-storing-and-sharing-captures-interference-hunter%E2%80%99s-safety-net

USE OF FERRITE-LOADED ABSORBER TO REDUCE WIRELESS SELF-INTERFERENCE

Kenneth Wyatt
Wyatt Technical Services

Self-generated EMI from DC-DC converters, as well as digital and video processing has long plagued designers of wireless and IoT devices, especially since physical sizes have trended smaller. The broadband harmonic content often extends up through 1.5 GHz, which includes most wireless protocols, cellular LTE and GPS/GNSS bands.

One new mitigation technique I've been trying lately is the use of ferrite-loaded RF absorber. These come in flexible sheets of varying thickness with adhesive on one side. In my past designs of microwave modules, these could be stuck to the inside of shield covers to reduce structural resonances due to cavities.

Today, I'm starting to use them to reduce the electromagnetic field level of IC packages and flex cables. The material is made by several manufacturers, such as 3M, Parker-Chomerics, NEC and Würth Elektronik. They are primarily designed as near field communication (NFC) shields or microwave absorbers.

Often, I need something effective in the LTE cellular frequency range of 650 to 860 MHz and it seems very few absorber materials are very effective in this range. I needed a quick way to characterize the many absorber materials I had at hand.

Unfortunately, manufacturers of these materials rarely show the absorptive properties versus frequency, but rather the permeability curves. While higher permeability materials usually mean better shielding at lower frequencies, EMC engineers are more interested in specific absorption (in dB) versus frequency, such information makes it easier to specify the correct material, depending on the application.

Würth Elektronik has a useful application note, ANP022, "Selection and Characteristics of WE-FSFS (Flexible Sintered Ferrite Sheet)" that shows a simple measurement technique for determining the insertion loss versus frequency (Reference 1). I've made these absorption measurements and present my results here. *Figure 1* shows the tested samples.

Figure 1: My collection included a variety of ferrite absorber sheets from different manufacturers

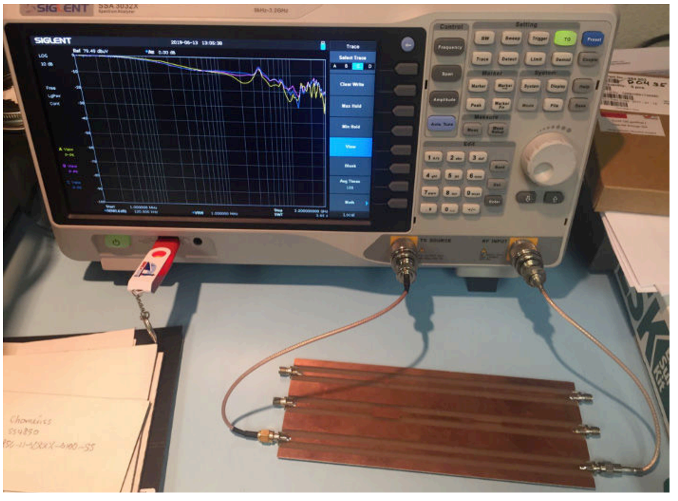


Figure 2: The test setup showing the spectrum analyzer and tracking generator connected to each end of the 50-Ohm transmission line

The overall test setup was simple enough, just requiring a spectrum analyzer with tracking generator (Siglent SSA3032X) and a 50-Ohm microstrip transmission line

(*Figure 2*). Once the transmission line is normalized as a straight line to eliminate basic transmission line variances with frequency, we merely place and hold the sample absorber on top of the microstrip. Generally, I measured from 100 MHz to 3.2 GHz (*Figure 3*).

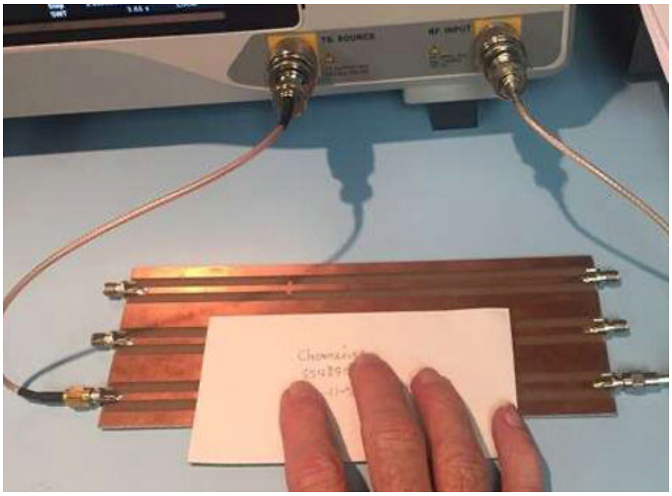


Figure 3: Measuring ferrite absorber sheets using the microstrip attenuation method

Flexible ferrite absorber sheets are generally good for only 5 to 20 dB absorption, but let's see what the measurements reveal. The Arc-Tech WXA-series had excellent insertion loss of 10 to 40 dB above 1 GHz and should prove useful for applications in the cellular, GPS, and 2.4 GHz Wi-Fi bands (*Figure 4*). Unfortunately, Arc-Tech closed their business and transferred the technology to others and this material is no longer available through U.S. distributors.

The Chomerics material is unique in that it has substantial absorption properties starting around 20 MHz and increasing to 20 dB insertion loss above 1 GHz. As you can see, I had to greatly expand the frequency span in order to capture the whole picture (*Figure 5*).

NEC has their R4N(01) material that has good absorbance in the cellular through GPS frequencies (blue trace in *Figure 6*).

CASE STUDY - BODY-WORN WIRELESS DEVICE

I had a chance to use this type material on a body-worn device a few years ago. The product included cellular, Wi-Fi, Bluetooth and GPS. It also included a video camera that produced a high amount of EMI on its connecting flex cable. During characterization measurements, I identified the DRAM, power management IC (PMIC) and video cable as the highest energy sources of interference. This self-interference was blocking reception in LTE Band 5 (and others).

Placing small squares of WAVE-X 20 absorber on top of the DRAM, PMIC and video cable (red "X"s in *Figure 7*) were

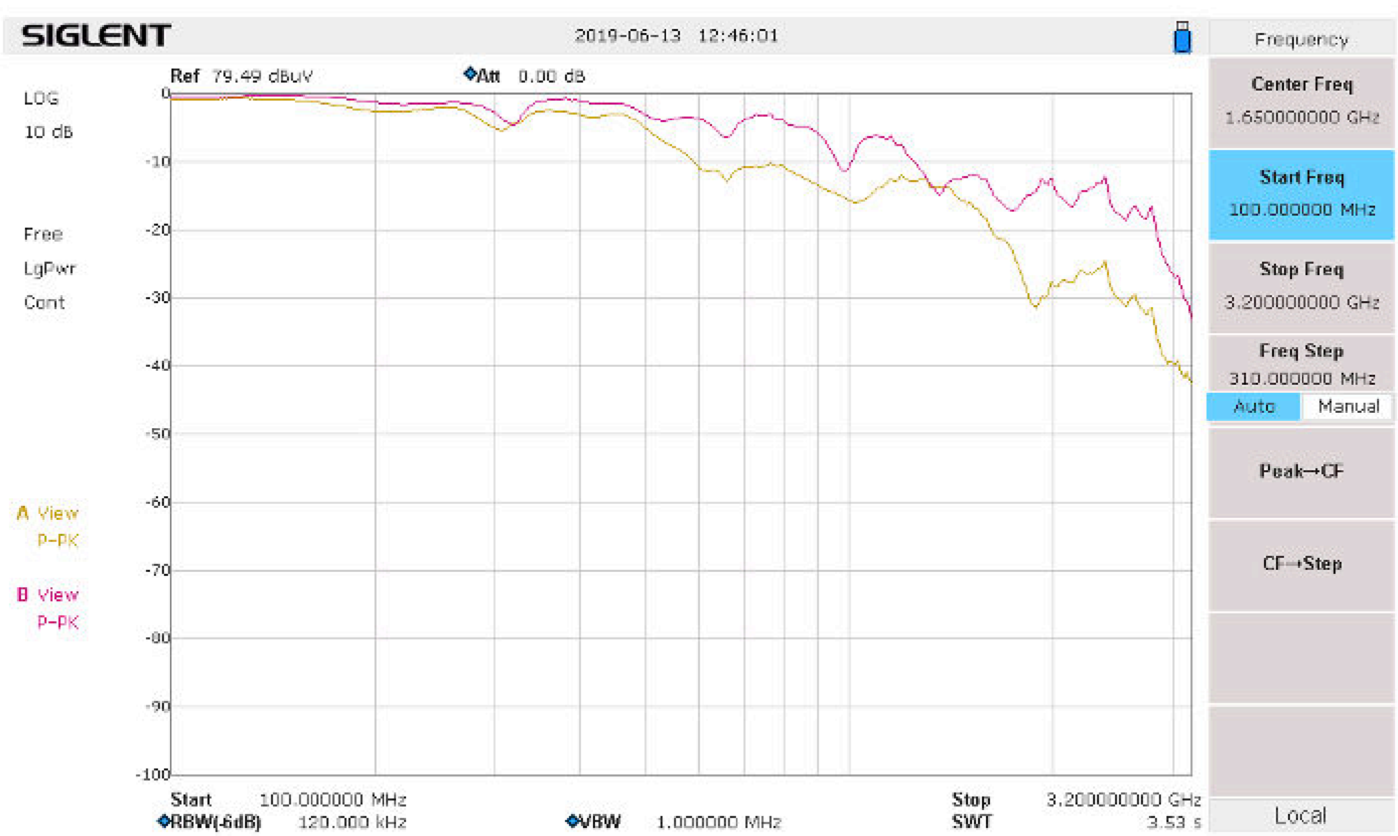


Figure 4: Arc-Tech's WAVE-X P/N WXA10 (yellow) and WXA20 (violet). Sample size: 15 x 15 cm

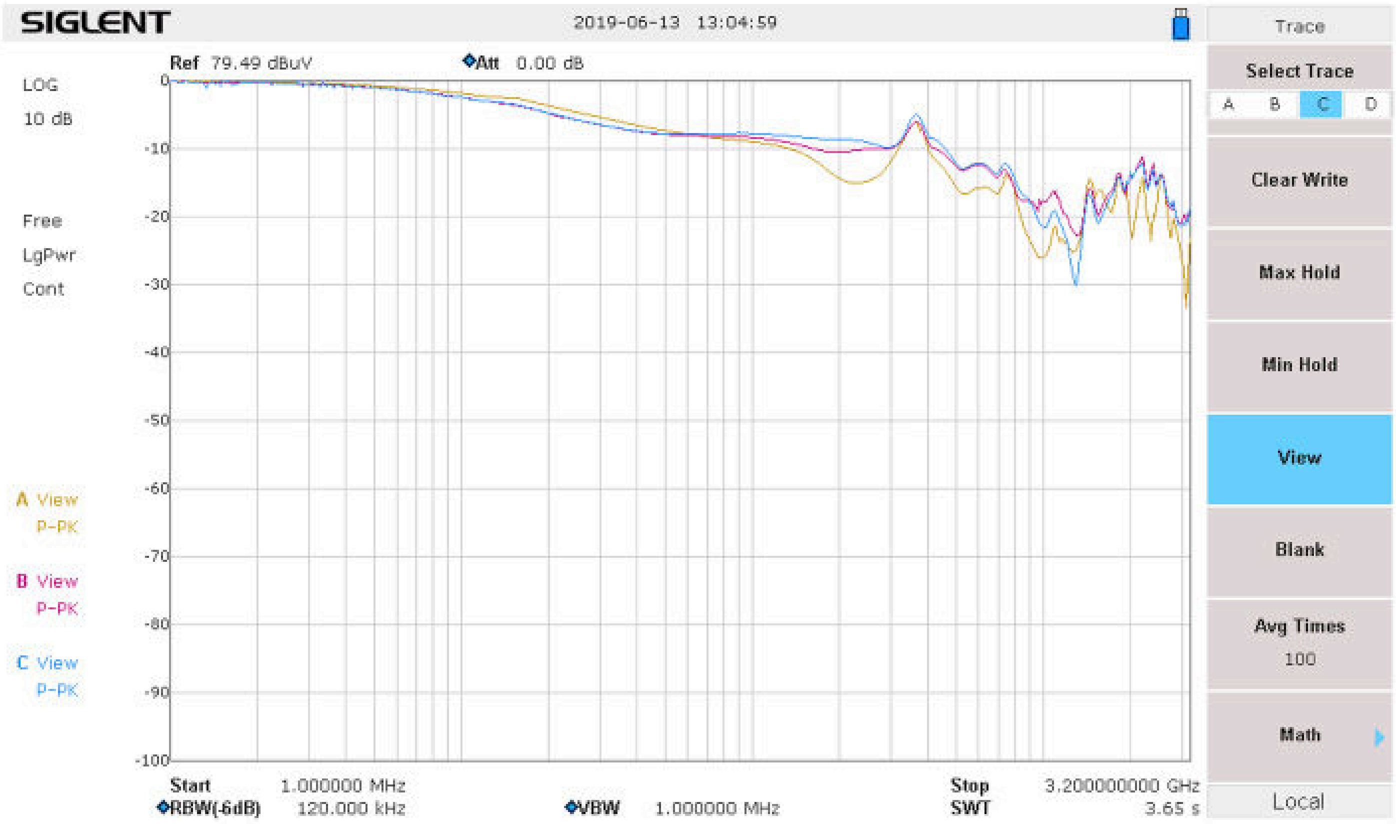


Figure 5: Chomerics P/N SS4850-0100 (yellow), SS4850-0150 (violet), and SS4850-0300 (blue). Sample size: 6.5 x 13, 12 x 13, and 12 x 13 cm, respectively

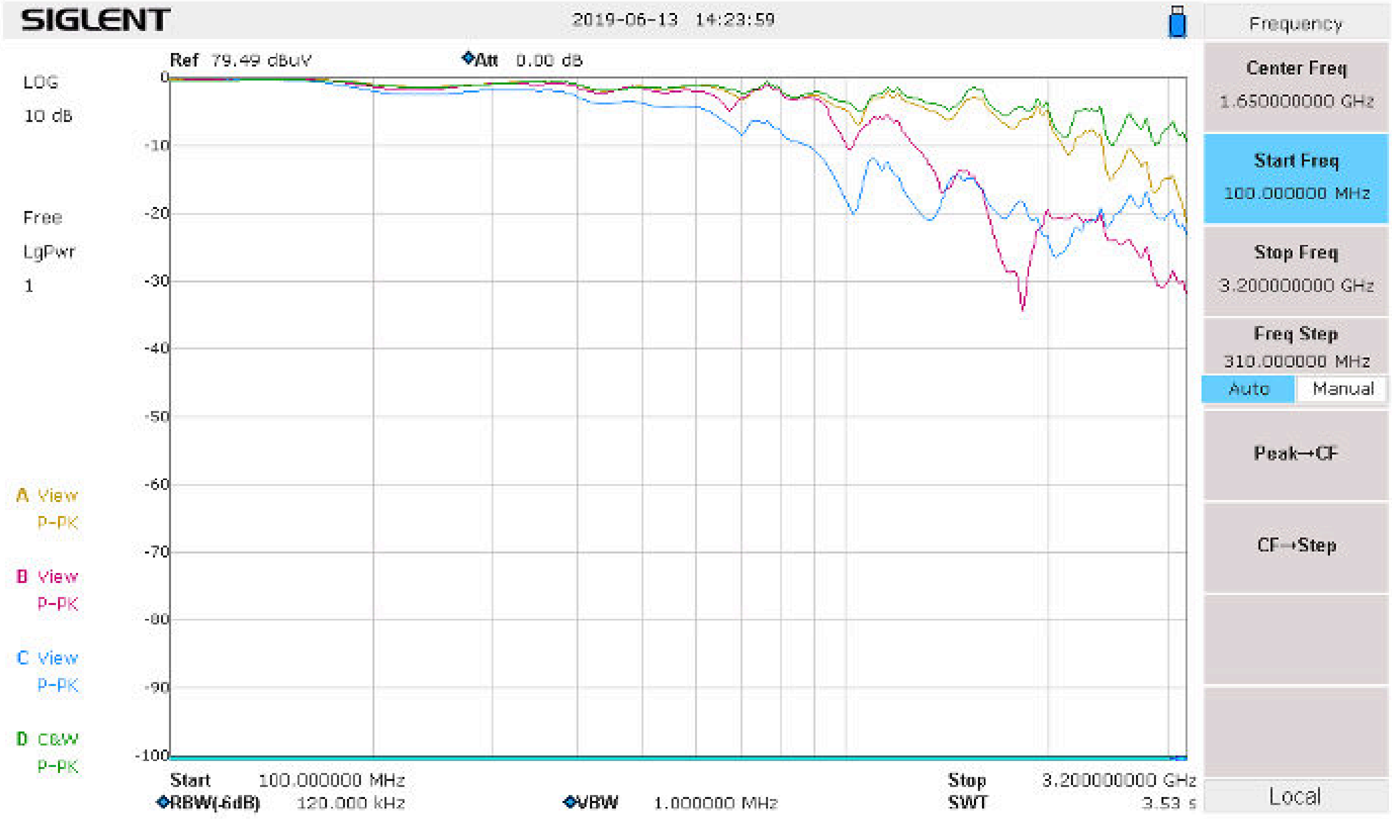


Figure 6: Plot showing the measured ferrite absorbers from NEC. NEC P/N EFR(01) in yellow, FK2(03) in violet, 3TG(04) in green, and R4N(01) in blue. The measured samples were all 8 × 8 cm

effective in reducing the self-generated EMI primarily affecting the various cellular receiver (downlink) bands.

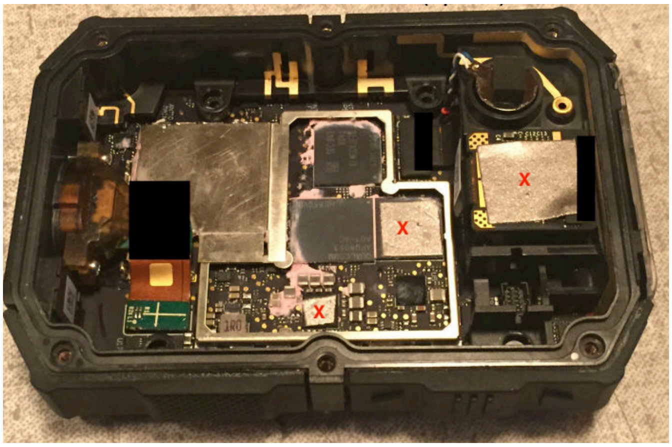


Figure 7: A wireless device showing three places where ferrite absorber was placed

In *Figure 8*, I'm measuring the near field emissions with a small antenna at the PC board edge close to where the cellular antenna is located embedded in the case. Examining the LTE Band 5 downlink, we observe several signals that could be the cause of low receive sensitivity, including a large video harmonic (*Figure 9*).

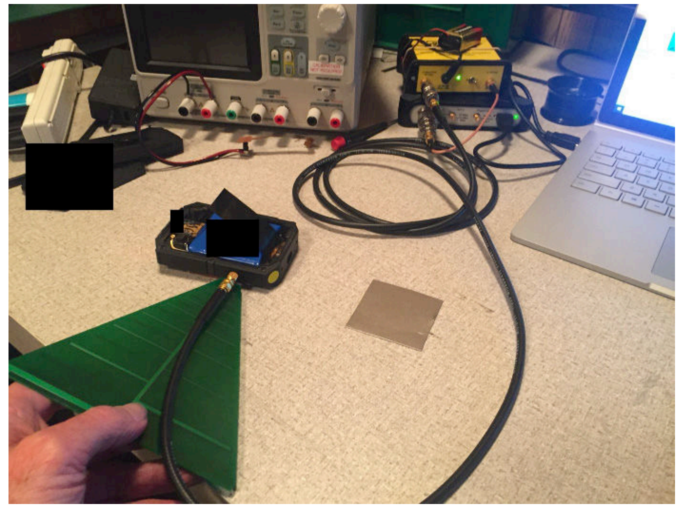


Figure 8: Characterizing the self-generated EMI using a close-spaced antenna

Remeasuring the emissions, we see a 15-dB reduction in the video harmonic and the three narrowband signals have disappeared into the noise floor (*Figure 10*). The result was greatly improved reception on Band 5.

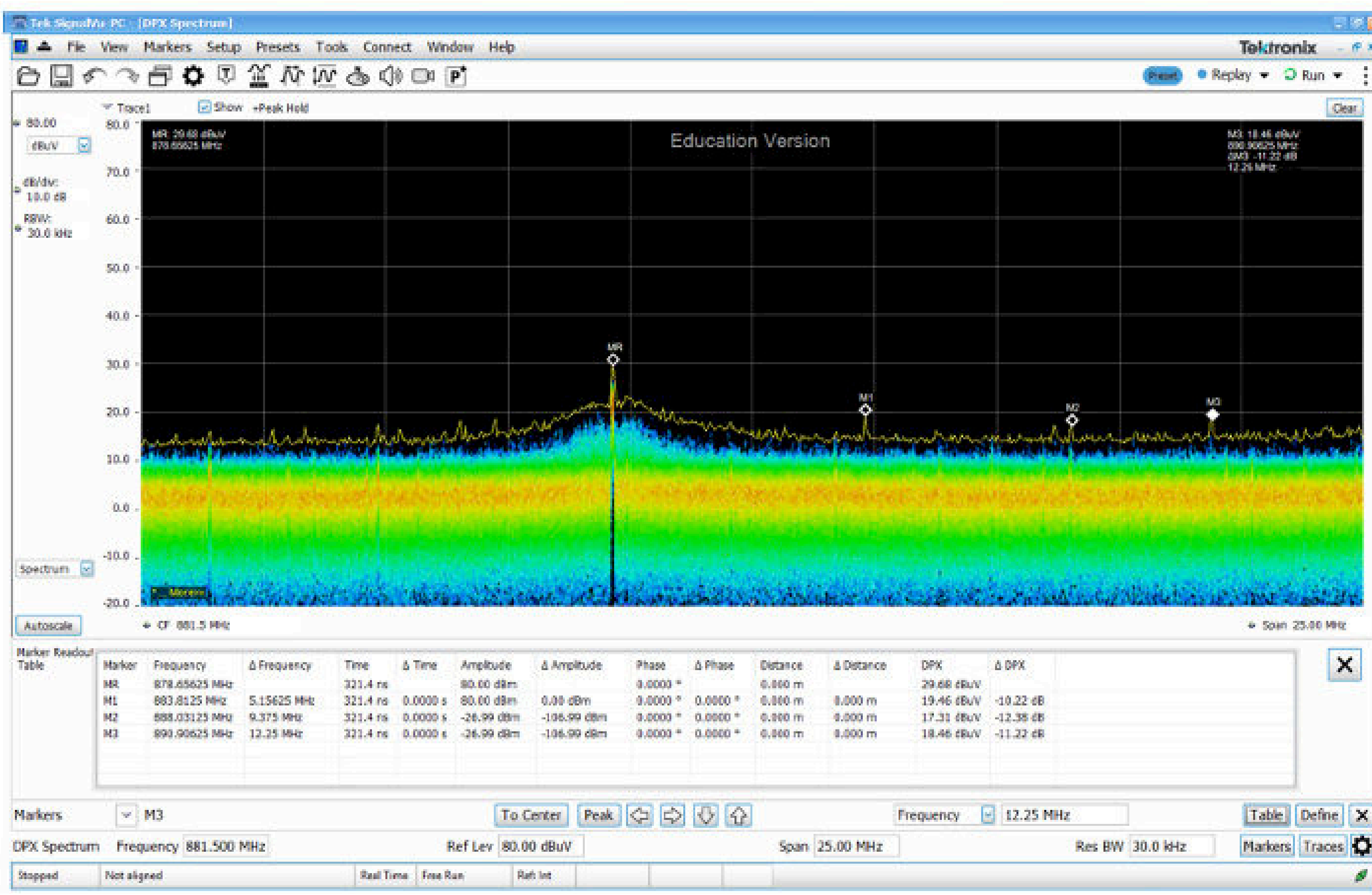


Figure 9: Looking at the LTE Band 5 downlink (869-894 MHz) showing a strong video harmonic with several narrowband harmonics before the ferrite absorber was added

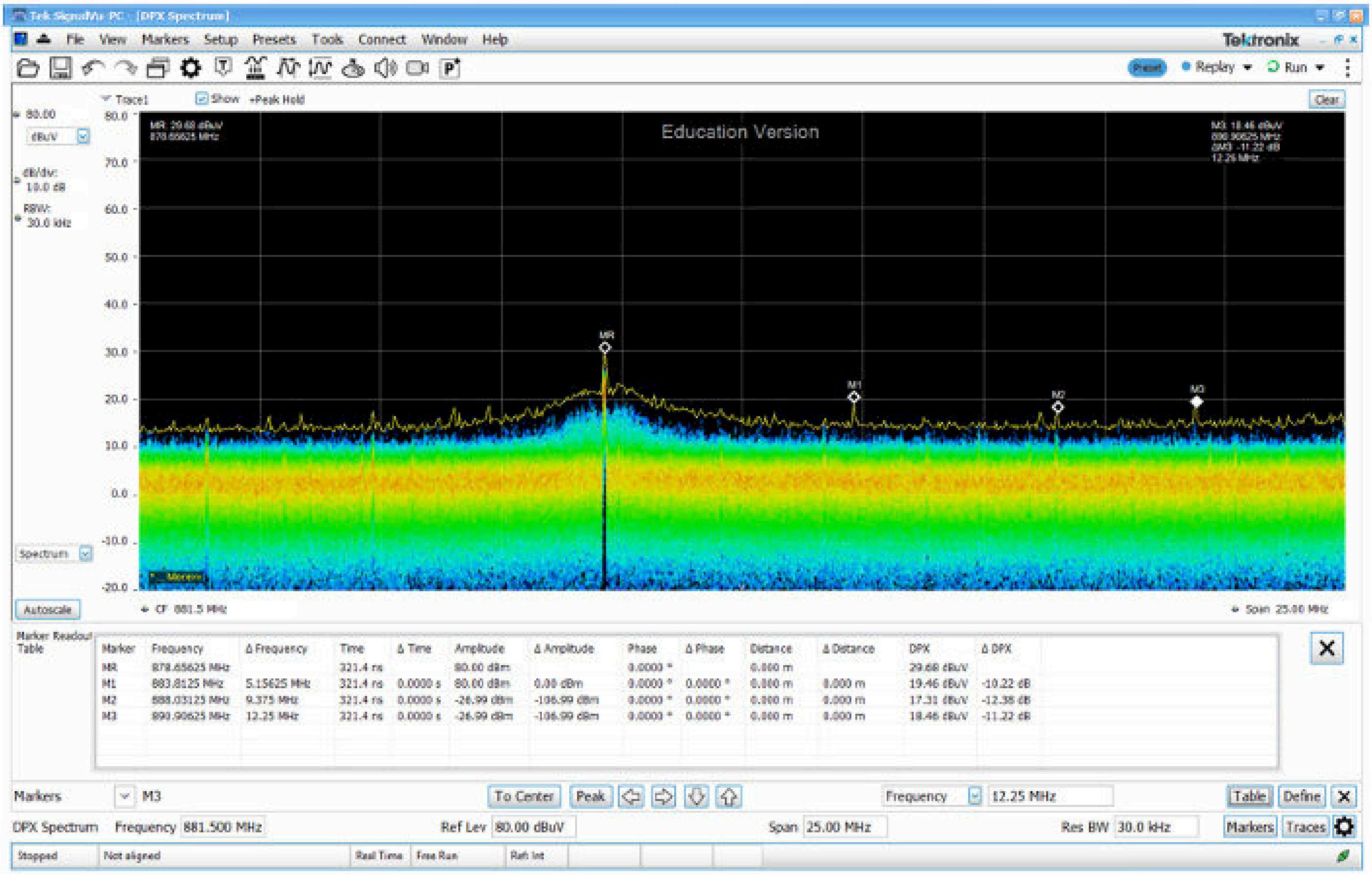


Figure 10: Looking at the LTE Band 5 downlink (869-894 MHz) with ferrite absorbers installed. The video signal was reduced by 15 dB. The narrowband harmonics were gone

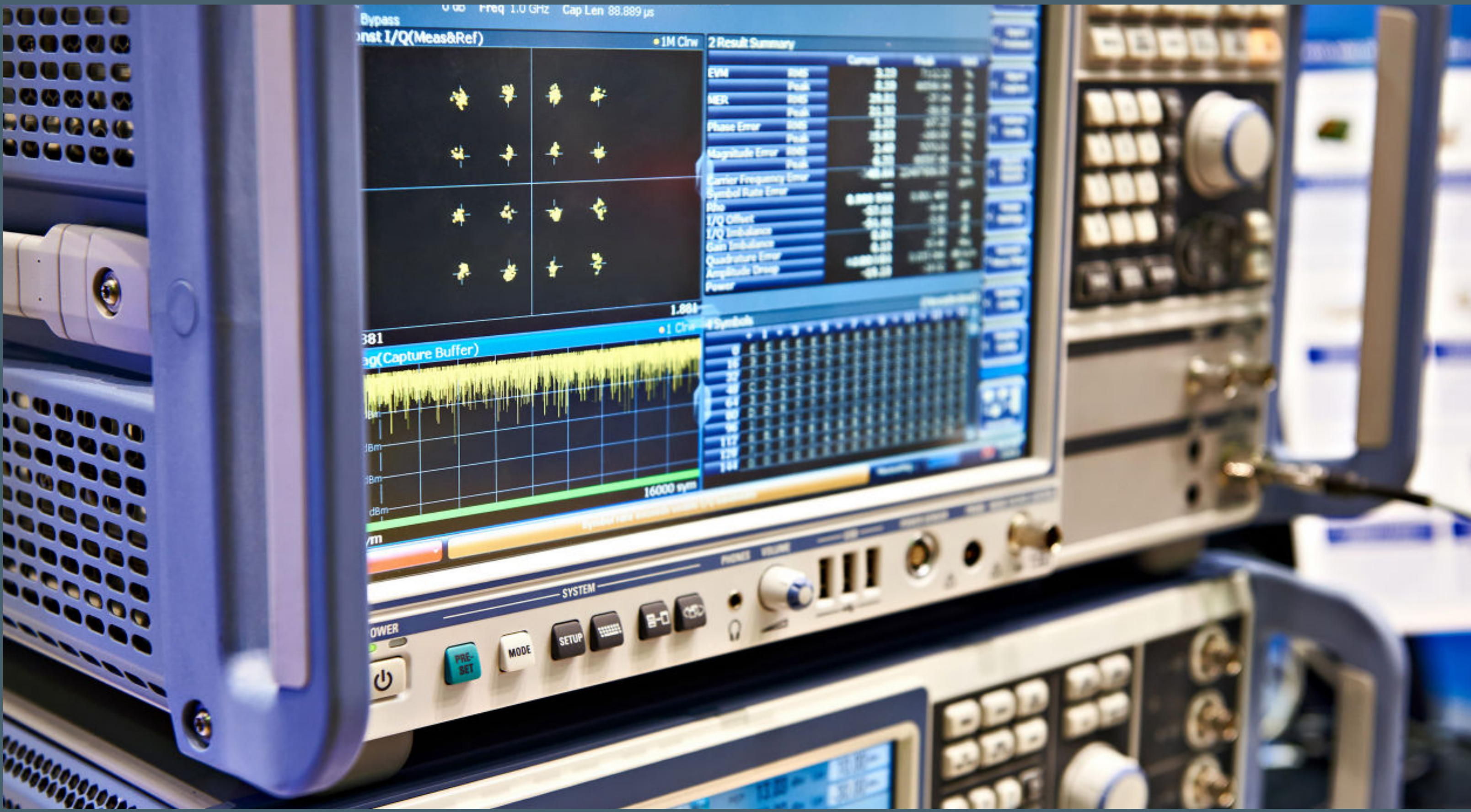
SUMMARY

I hope this information is useful to you as you're designing smaller wireless products, where every bit of shielding and attenuation of self-generated EMI is important. The use of small bits of ferrite-loaded absorber applied to known EMI sources appears to be a cost-effective solution to reducing self-interference affecting wireless receiver performance. It also did not appear to affect the RF or video performance of the device. While WAVE-X 20 is no longer available in the U.S., there are other manufacturers that make equally good materials. Würth Elektronik described some alternative ways of characterizing ferrite absorber sheets, but the microstrip method was quick and easy.

REFERENCES

1. Würth Elektronik Applications Note ANP022, Selection and Characteristics of WE-FSFS. https://www.we-online.de/web/en/electronic_components/produkte_pb/application_notes/auswahlundeigenschaftenvonwefsfs.php
2. Würth Elektronik, Trilogy of Magnetics (5th Edition). https://www.we-online.de/web/en/electronic_components/produkte_pb/fachbuecher/fachbuecher.php
3. Kenneth Wyatt, Platform Interference - Measurement and Mitigation. https://interferencetechnology.com/platform-interference-measurement-mitigation/

EMI, SI & PI


Bypass
Freq 1.0 GHz
Cap Len 88.889 µs
2 Result Summary
EVM
MER
Phase Error
Magnitude Error
Carrier Frequency Error
Symbol Rate Error
Rho
I/Q Offset
I/Q Imbalance
Gain Imbalance
Quadrature Error
Amplitude Droop
Power
4 Symbols
16000 sym
SYSTEM
PRE-SET
MODE
SETUP

SI METRICS THAT HAVE TAKEN US TO 224G

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

In the world of signal integrity, we rely on many important metrics to qualify high-speed channel designs, both before prototyping and during prototype testing. There is a common group of signal integrity metrics that appear in high-speed digital interface standards and which need to be implemented in printed circuit boards and packages. These signal integrity metrics have helped guide the way from Gbps interfaces all the way up to the fastest interface implementations we see today, running at 224G PAM-4 per lane.

This article will give readers an overview of these important signal integrity metrics, each of which may be examined at the interconnect level or the system level.

LIST OF SIGNAL INTEGRITY METRICS

Although interfaces with faster data rates are clearly more advanced in terms of their function and evaluation, they rely on the same set of signal integrity metrics as used long ago, before Gbps interfaces became common. What has become more advanced is the analysis and interpretation of the results, as well as the resulting changes to PCB or package layouts in order to improve signal integrity.

Whether looking at low speed interfaces at ~1 Gbps NRZ or ultra-fast interfaces at 224G PAM-4, we are often trying to answer the following questions when examining signal integrity:

- Does the channel provide the minimum required quasi-TEM bandwidth?
- Is there excessive loss (absorption or reflection) during propagation?
- Is crosstalk from nearby interconnects within acceptable limits?
- Do losses, crosstalk, and bandwidth limiting create excess bit errors?

S-parameters

The workhorse of signal integrity measurements and analysis is S-parameters, which collectively define transmission and loss of signal between the input and output ports of an interconnect. There are multiple ways to use or formulate S-parameters in order to quantify other important signal integrity metrics. Thus, most signal integrity metrics will reference S-parameters when looking in the frequency domain.

Depending on the number of ports in your system and what the S-parameters are meant to represent physically, we can have several different definitions for signal integrity metrics. The table below provides port numbering and some metrics which are qualified with these S-parameter definitions specifically for transmission lines.

Note that *Table 1* addresses transmission lines, but technically the S-parameter definitions for any DUT (either single-ended or differential) would follow the exact same table.

At its root, the S-parameters quantify the input impedance of an interconnect between two terminated ports; this is then related to the characteristic impedance of the DUT or the coupling impedance between two coupled DUTs, e.g., coupling impedance that determines crosstalk. Once an impedance is known, the propagation constant (and thus losses) is known. From there all other signal integrity metrics can be simulated or calculated by hand.

Crosstalk and mode conversion are two sets of signal integrity metrics for differential interconnects; aside from the newest versions of DDR, many high-speed interfaces are differential, including 112G/224G SerDes lanes. Crosstalk has always been a signal integrity metric at lower frequencies and is normally qualified by comparing the relevant S-parameter spectrum against an S-parameter mask.

Time Domain Reflectometry

Because impedance is the core signal integrity metric that influences all other metrics, we have a simple method to measure impedance by looking at reflection against a reference value. This is where time-domain reflectometry (TDR) is

Interconnect type	Number of ports	What is quantified with S-parameters
1 single-ended transmission line	2	• Reflection • Power loss
2 coupled transmission lines	4	• Reflection • Power loss • Crosstalk
Differential transmission line	4 (2 common mode, 2 differential mode)	• Reflection • Power loss • Mode conversion
2 coupled differential transmission lines	8 (4 common mode, 4 differential mode)	• Reflection • Power loss • Differential crosstalk • Mode conversion
1 single-ended line and 1 differential line	6 (2 common mode, 2 differential mode, 2 single-ended)	• Reflection • Power loss • Mixed-mode crosstalk • Mode conversion

Table 1

used as it overcomes an important drawback of S-parameter measurements, most notably S11.

In S11 (reflection) measurements, a VNA provides a frequency domain view of reflection due to an impedance mismatch, but it does not say where the major mismatch is which will lead to reflection. This is overcome with a TDR measurement, which will show where the impedance mismatch is located along an interconnect, as well as whether there is excess capacitance or excess inductance.

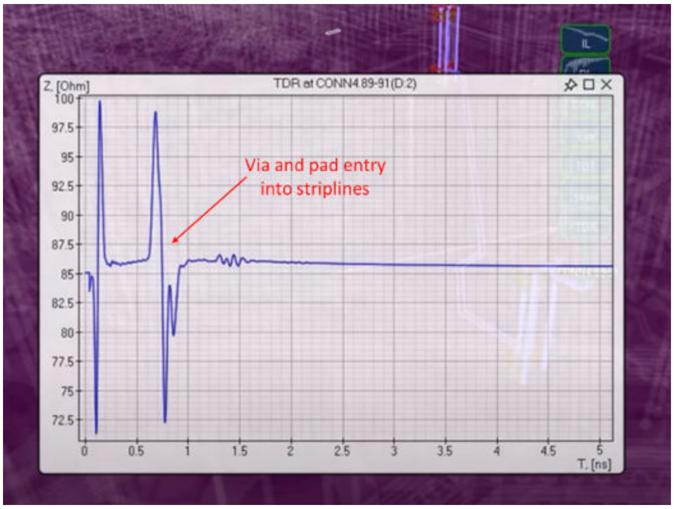


Figure 1

An example from Simbeor is shown in *Figure 1*. Here the peaks in a TDR trace can be used to identify specific points along the length of the interconnect based on the corresponding propagation time; the peaks correspond to impedance discontinuities, which may illustrate excess parasitic capacitance or excess inductance. Here we have a TDR spectrum for a PCIe lane routed as striplines, which shows the effects of the pad and via arrangement right at the input of the interconnect.

Do these peaks really matter? If they are noticed within your required channel bandwidth in the S-parameter spectrum, then the answer is “yes” and these features would need to be redesigned.

Physically smaller discontinuities along interconnects become more noticeable as the required channel bandwidth increases, i.e., as the data rate increases. This occurs because physically smaller deviations create noticeable reflections only at higher frequencies. This means very small PCB or package features like pads/antipads and vias will create reflections that become noticeable in 224G PAM-4 interconnects, which require at least 56 GHz of bandwidth. These very specific features can be identified in a TDR plot and selected for design modification if they create excess reflection.

A related test that is performed in simulation is the impulse response of an interconnect; when the impulse response for an isolated transmission line is simulated, it is equivalent to a TDR simulation. The goal is to qualify a linear network model for your interconnect or DUT in terms of causality, loss, and reflection leading to intersymbol interference.

Eye Diagrams

The last mile in qualification of a channel design is to generate an eye diagram. This is the closest representation you will

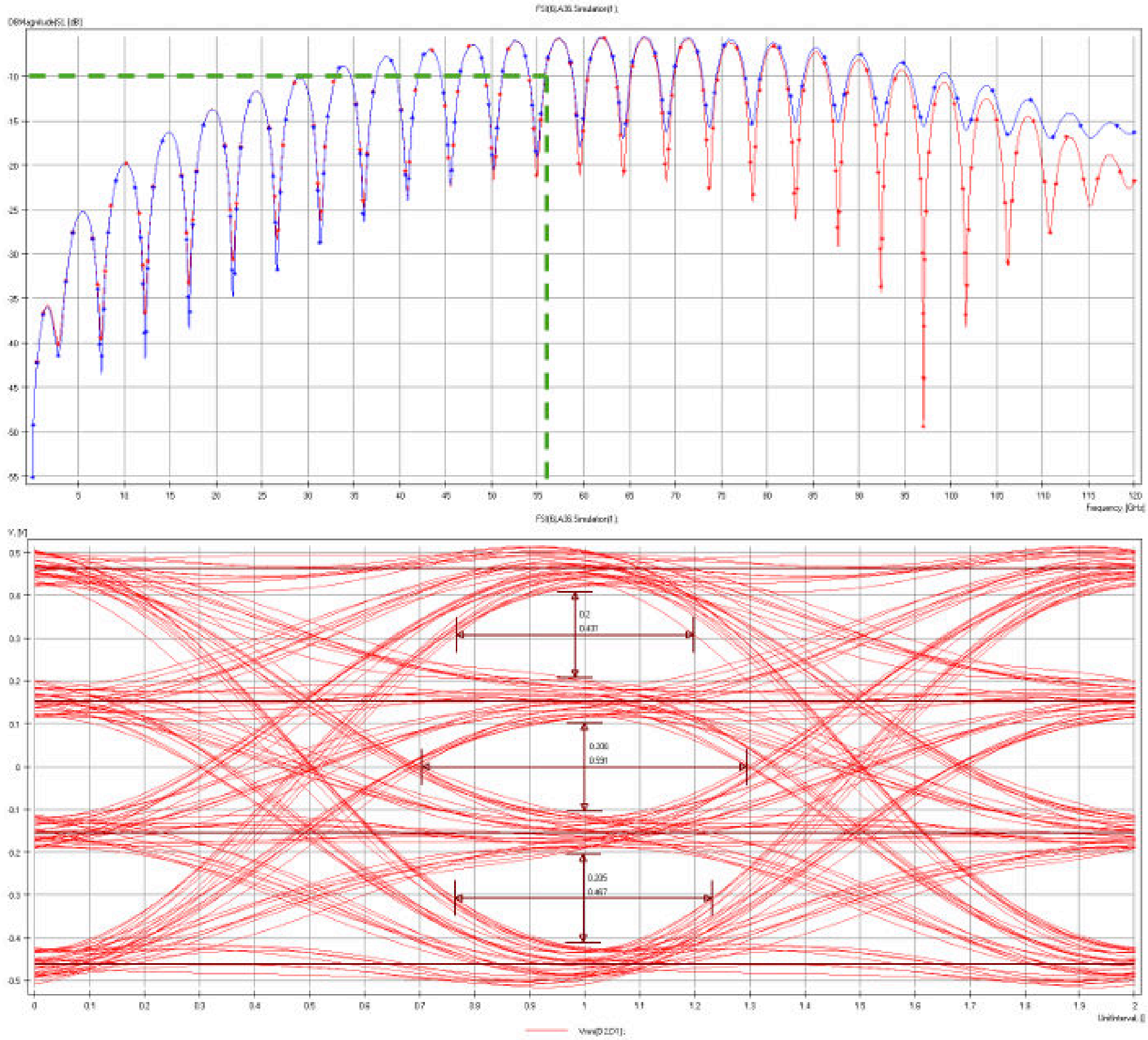


Figure 2

get to real operation before you take measurements of your system. An eye diagram is a simulation where a pseudorandom bitstream is used to examine the bit error rate (BER), a summative metric that allows one to determine whether cumulative signal integrity problems will cause a channel to exhibit unacceptably high data errors.

An example is shown in Simbeor above (*Figure 2*). In this image, any bit errors are determined by comparing with an eye diagram mask, or through automatic calculation. The corresponding S11 spectrum for this differential interconnect illustrates a spot check limit at -10 dB which would be the maximum acceptable return loss. As can be seen, the S11 plot rises above -10 dB before the channel bandwidth requirement of 56 GHz is reached, indicating there is excess impedance mismatch that will impact channel compliance.

In PAM-4 channels, the difficulty increases due to losses extending to higher bandwidths, reduced distance between signal levels, and greatly reduced skew budgets, all of which contribute to eye closure. In these channels where high losses and excess jitter can cause eye closure, equalization or pre-emphasis might be used to bolster signal strength and recover the signal from the noisy bitstream. These measures can be further examined in the eye diagram to ensure the incoming data can be resolved by a receiver.

Although the world is potentially reaching the end of wideband copper interconnects as we near the 56 GHz channel bandwidth requirement, the above metrics will continue to be the yardsticks against which we measure signal integrity. Whatever trick is exploited to get to the next doubling of data rates, these metrics will continue to be used to qualify signal integrity in these more advanced channels.

WHEN DO YOU NEED LOW-Dk PCB LAMINATES?

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

Designers looking to build more advanced systems operating at higher data rates and bandwidths tend to rely on materials with low dielectric constant values, i.e., low-Dk materials. It has gotten to the point where every high-speed PCB design guide implies that high-speed and RF designs will not function without a low-Dk material like Rogers or Arlon.

The reality is that the use of a low-Dk material in a PCB, or in more advanced substrate and package designs, is an engineering decision just like any other. In PCBs, low-Dk materials provide benefits in terms of manufacturability, particularly in HDI designs, and the material selection is not always related to the electrical functionality of a product. In packaging, the common materials used for substrate buildup tend to have lower Dk than organic PCB materials, but this extends channel bandwidths for certain high-speed interfaces.

Low-Dk materials come in a range of options and commercial products, and this article will outline the main factors driving the usage of a lower Dk laminate. As we will see, you don't always need a high-performance PTFE laminate, but there are times where the additional laminate cost can be a lifesaver for signal integrity and could reduce the overall cost of the product.

WHY EVERYONE THINKS THEY NEED LOW-DK PCB MATERIALS

There are two very common reasons why basic design guides will recommend low-Dk PCB materials. These two common reasons have to do with signal integrity:

- **Justification #1**: Lower Dk laminates have faster signal propagation speed, thus it increases the critical length beyond which transmission line impedance calculations are needed.
- **Justification #2**: Lower Dk laminates create lower losses that are desirable in advanced systems.

The first statement is correct from a physics standpoint: signals traveling in lower Dk materials do have faster propagation speeds, and that would increase the critical length. It is also true that commercially available lower Dk PCB laminates tend to have lower loss tangent, but this only affects dielectric loss, and the reverse of this statement is not universally true. These are not the best justifications for using low Dk materials from a signal integrity perspective.

Lower Propagation Speed Does Not Matter

First, let's address point number one. If you are building a system that is deemed "advanced," then you should not look for an excuse not to calculate impedances. It is extremely simple to calculate transmission line characteristic impedance or differential impedance for differential interfaces. This is thanks to a wealth of simulation tools built into CAD programs and online calculators for determining impedance. The difficulty of calculating impedance is, therefore, a non-issue. Furthermore, as I showed in a prior article, the value of a "critical length" is arbitrary and requires calculating the impedance to implement correctly.

High-Dk Laminates Can Also Have Low Loss

While it is true that lower Dk PCB materials tend to have low loss tangent, the reverse is not true for higher Dk materials. For example, consider a Rogers 3010 laminate, with Dk = 10.2 and Df = 0.0022 at 10 GHz. Compared to basic FR4 with Dk = 4.4 and Df = 0.02 at 10 GHz, the FR4 laminate has 4x the dielectric loss as the Rogers 3010 laminate despite its lower Dk value. We can see this as follows:

- Rogers 3010 dielectric loss $\propto$ (10.2)×(0.0022) = 0.02244
- Basic FR4 dielectric loss $\propto$ (4.4)×(0.02) = 0.088

The factor 4 difference in dielectric loss is very clear. The real difference in total loss when Df values are very low (0.001 or less) comes from differences in conductor size and conductor roughness in a given stackup, it is not just about the laminate's Dk and Df values. This is because, at low Df values, the copper loss becomes dominant starting from 5 GHz and exceeding 50 GHz (depending on material constants). This is especially the case in more advanced designs where layers are thinner, and thus the traces are thinner.

REAL REASONS TO USE LOW-DK LAMINATES

Manufacturability in Thin Laminates

The first reason to use thin laminates is for manufacturability reasons, particularly when manufacturing designs with impedance controlled buses. The requirement of fixed impedance on certain traces sets the trace width to a specific value, which is also a function of dielectric thickness and substrate Dk value. If the laminate is too thin and the resulting trace width is too thin, the copper etching process will become more expensive. Eventually, at very small linewidths, the processing requirement switches to additive.

Figure 1 summarizes the trend on thin laminates, and as we can see from the graph, it is possible to maintain fabrication in the subtractive regime, which carries lower costs.

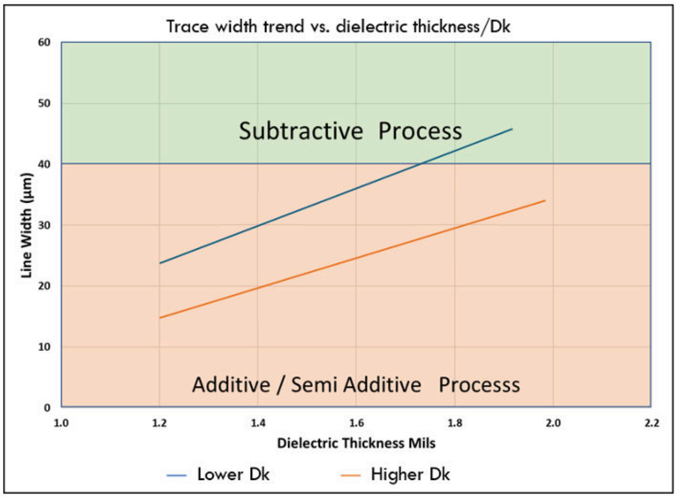


Figure 1

Another reason to stay in the subtractive range is availability of fabrication capacity. Additive copper deposition on PCBs at scale is currently only available in China and Taiwan, which may be a non-starter for some military and aerospace products. Staying in the subtractive range expands the number of available locations where fabrication capacity can be accessed, which will be inclusive of capacity in the US and Europe.

Reducing the Dominant Copper Loss

As was mentioned above, copper losses become dominant when Df values are sufficiently low. These losses are determined by the skin effect and the roughness of the copper foil used to fabricate the PCB. For microstrips, the plating material used on the surface layers will also impact the copper losses as they can further roughen the copper or create magnetic losses (such as in platings with nickel seed layers).

Using a low-Dk laminate will require a larger conductor cross section in order to hit an impedance target, as shown in the above graph. This then reduces skin effect losses at high frequencies, which is very important in digital signals with bandwidths in the multi-GHz range. Further reductions in conductor losses can be achieved by using alternative surface platings, using smoother copper foils, and preferring microstrip routing where possible.

Reduced Crosstalk and Mode Conversion

One consequence of the lower dielectric constant and the ability to use thinner dielectrics is more control over crosstalk. When crosstalk occurs, it is mediated by ratio of mutual capacitance (Cm) between two traces to the self capacitance (Cs), and this capacitance ratio is dependent on the Dk value of the dielectric; the same idea applies to mutual and self inductances. Using a lower Dk value provides smaller Cm/Cs ratio in the following ways:

- Fixed trace width, smaller laminate thickness: this allows Cs to be larger for a given trace width and spacing.
- Larger width → smaller trace spacing: When the width is made larger, a smaller crosstalk penalty would be seen when using a low Dk value compared to a high Dk value.

The first option gives a simple way to keep trace widths constant when swapping a laminate in the PCB stackup. The second option enables HDI design but with smaller crosstalk penalty compared to the case of a higher Dk laminate.

A related signal integrity issue in differential interfaces, which is also mediated by mutual capacitance and mutual inductance, is mode conversion. In some ways, mode conversion in differential channels is a form of loss as it increases differential SNR values by converting some differential signal to common-mode signal, which is then canceled by the differential receiver. For a given trace-to-trace spacing and width in a differential pair, a smaller Dk value will also decrease the mutual capacitance, which decreases mode conversion.

THE RESULT: INCREASED CHANNEL BANDWIDTH

In total, these effects surrounding low-Dk values serve to increase the TEM bandwidth of channels for digital signals. Channel bandwidth becomes limited by losses and excitation of non-TEM propagation modes at sufficiently high frequencies. The effects on losses are outlined above and it should be very clear that low Dk manifests its benefits beyond a simple reduction in dielectric loss.

The other mechanism of increasing bandwidth is very important as the fastest digital interfaces start to extend their required channel bandwidths to 56 GHz, corresponding to 224G PAM-4 signaling. This limit was previously reached in 112G NRZ channels, and further bandwidth extensions have only occurred by shifting from NRZ to PAM-4. More advanced components and complex via structures in high density PCBs and packages can extend the bandwidths beyond 56 GHz by using higher density ballouts and low Dk materials in packaging and PCBs.

MILITARY & AEROSPACE EMC

MILITARY RELATED DOCUMENTS AND STANDARDS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

MIL-STD-331C Fuze and Fuze Components, Environmental and Performance Tests for, 22 Jun 2009.

MIL-STD-449D Radio Frequency Spectrum Characteristics, Measurement of, 22 Feb 1973.

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

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

MIL-STD-464D Electromagnetic Environmental Effects Requirements for Systems, 24 Dec 2020.

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

MIL-STD-1275E Characteristics of 28 Volt DC Input Power to Utilization Equipment in Military Vehicles, 22 March 2013 (MIL-STD-1275F expected in 2021)
http://everyspec.com/MIL-STD/MIL-STD-1100-1299/MIL-STD-1275E_45886/

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

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

MIL-STD-1399 Section 300 Part 2 Medium Voltage Electric Power, Alternating Current 25 September 2018
http://everyspec.com/MIL-STD/MIL-STD-1300-1399/

MIL-STD-1542B Electromagnetic Compatibility and Grounding Requirements for Space System Facilities, 15 Nov 1991. MIL-STD-1605 Procedures for Conducting a Shipboard Electromagnetic Interference (EMI) Survey (Surface Ships), 08 Oct 2009.

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

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

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

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

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

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

AEROSPACE STANDARDS

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

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

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

DO-160G, Environmental Conditions and Test Procedures for Airborne Equipment

DO-160G Change 1, Environmental Conditions and Test Procedures for Airborne Equipment

DO-233, Portable Electronic Devices Carried on Board Aircraft

DO-235B, Assessment of Radio Frequency Interference Relevant to the GNSS L1 Frequency Band

DO-292, Assessment of Radio Frequency Interference Relevant to the GNSS L5/E5A Frequency Band

DO-294C, Guidance on Allowing Transmitting Portable Electronic Devices (T-PEDs) on Aircraft

DO-307, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

DO-307A, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

DO-357, User Guide: Supplement to DO-160G

DO-363, Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft

DO-364, Minimum Aviation System Performance Standards (MASPS) for Aeronautical Information/Meteorological Data Link Services

DO-363, Guidance for the Development of Portable Electronic Devices (PED) Tolerance for Civil Aircraft

DO-307A, Aircraft Design and Certification for Portable Electronic Device (PED) Tolerance

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

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

REFERENCES

CONFERENCE DIRECTORIES

AFCEA Events:
www.afcea.org/site/

ASCE Events:
www.asce.org/communities/institutes-and-technical-groups/aerospace-engineering/conferences-and-events/

ASD Events:
https://www.asdevents.com/shopcontent.asp?type=aerospace_defence

Aviation Week Event Calendar:
www.events.aviationweek.com/current/Public/Enter.aspx

Defense Conferences:
www.defenseconference.com/

Global Edge (MSU):
www.globaledge.msu.edu/industries/aerospace-and-defense/events/

IEEE AESS Events:
www.ieee-aess.org/conferences

Jane's Events:
www.janes.com/events

LINKEDIN GROUPS

- Aerospace and Defense Subcontractor and Suppliers
- Aerospace and Security and Defence Technology and Business (Defence spelled correctly)
- Defense and Aerospace
- EMP Defense Council
- High Intensity RF (HIRF) Professionals
- Radio, Microwave, Satellite, and Optical Communications
- RF/Microwave Aerospace and Defense Applications
- RF and Microwave Community

SIMULTANEOUS OPERATIONS (SIMOPS) OF RADIO SYSTEMS DUE TO ANTENNA TO ANTENNA COUPLING ON AN AIRCRAFT

David A. Weston
EMC Consulting Inc.

Although specifically dealing with aircraft systems, the methods described in this article are applicable for other platforms where a number of antennas are in close proximity. The number of antennas in use and in close proximity on mission specific aircraft are as many as 22 on a small search and rescue aircraft.

ANALYSIS METHODS

The methods of coupling analysis include electromagnetic analysis programs, measurements on a 1/10th scale aircraft, a full-scale mockup of a part of the aircraft fuselage and wing, as an example, and provisionally mounting antennas on the actual aircraft. All these methods mean that the analysis can be performed before installation of antennas on the aircraft and thus the location of antennas can be modified, or mitigation techniques employed if a coupling problem exists. All of the analysis techniques have advantages and disadvantages. For example, the antennas and antenna drive element would be too small on the 1/10th scale model at 93.75MHz and test equipment for 93.7GHZ would almost certainly not be available. Ideally the electromagnetic analysis programs alone would be good enough. However, in two articles, reference 1 and 2, and in an upcoming paper comparing the accuracy of the four methods, we see that that is not true.

The 1/10th scale model is shown in *Figure 1* and the FEKO program model of the aircraft in *Figure 2*.

Figure 1: 1/10th scale model

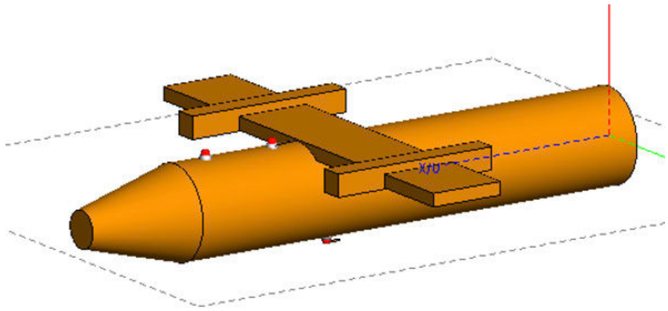


Figure 2: FEKO model

In-Band Coupling

For transmitter receiver pairs that are in band (i.e., transmitter and receiver frequency the same) a simultaneous operations (SIMOPS) red case (non SIMOPS possibility) is obvious. A possibility for acceptable in-band performance at low frequency may be achieved with an in-band cancellation circuit shown in reference 3.

Out of Band Coupling

Most antennas do not function as an effective filter and pass "out of band" frequencies with often little attenuation. When a high-level source of electromagnetic radiation is close to an antenna, and the receiver does not contain a band pass filter at the input, then the signal present at the input of the receiver can result in cross modulation (where the interferer modulates the intentional signal). Also, when the transmitter frequency is close to the receiver IF bandwidth or the edges of the receiver bandwidth.

With high input levels desensitization/compression of the receiver can occur, which means the gain of the receiver reduces. Alternatively, the high RF level can be demodulated by a semiconductor in the receiver resulting in a dc level which can effectively saturate the front end. High input levels can result in a spurious response in the receiver which may be in band. If the induced power is too high, a voltage or current can be applied to an input semiconductor, resulting in breakdown or overheating and stressing. To reduce high levels, a series of band pass, band stop, high pass, and low pass filters have been designed and built from 30MHz to 9.375GHz, described in references 4 and 5.

Passive Intermodulation

A source of in band interference is Passive intermodulation (PIM). Intermodulation products are generated when two or more signals mix in a structure with nonlinear junctions or ferrous metal. When these intermodulation products fall in band for a co-located receiver, a SIMOPS red case may exist.

Passive Intermodulation may occur in any metal structure in proximity to a receiving antenna, such as the antenna structure, railings, towers, or other metallic surfaces. Reference 4 describes PIM in more detail. One common source of a nonlinear junction is either a loose joint or oxidization of metal. A structure that includes ferrous materials (which has a nonlinear magnetic hysteresis) or carbon fiber (which has a nonlinear resistivity) may also exhibit PIM, and this is, perhaps surprisingly, an order of magnitude higher than the joint generated PIM.

On the aircraft, the ferrous material is typically in the landing gear, flap rods/tracks, and door handles, with the landing gear, flap rods/track the most likely source. *Figure 3* shows an example of the incident and PIM fields.

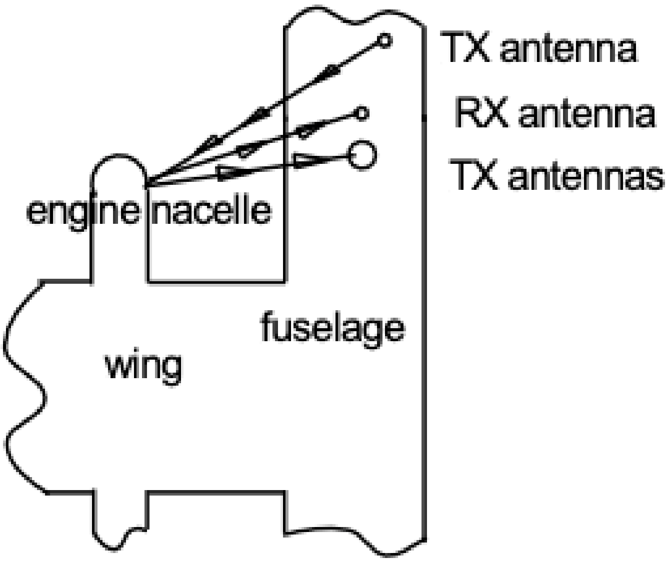


Figure 3

Some of the sources of PIM which have been experienced are:

- Poor alignment of parts
- Moving structures which are not adequately bonded
- Insufficient or incomplete cleaning of parts
- Contaminated plating bath
- Poor plating adhesion
- Dissimilar metals in direct contact
- Plating non uniformly applied and on insufficient thickness (high resistance)
- Material which has not been in the plating bath long enough (high resistance)
- Oxidization

Luckily the reradiated PIM level is usually at a low level.

Another source of in-band noise may be the broad band noise from a high-power transmitter which is in band.

Receiver and frequency (MHz)	Transmitter and frequency (MHz)	Frequency over lap	Received level (dBm)
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#2 Cockpit HF 2-30	At 30MHz	-11
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#3 Mission HF R&S 1.5 - 30	At 30MHz	15.5
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#3 Mission V/HF R&S V/UHF 100-512	225-400	-13
#1 Cockpit V/UHF 30-88 18-174 225-400 400-600	#5 Cockpit VHF Comm. VHF#2 118- 137	118 - 137	18
#6 Acoustics VHF Sonobuoy VHF 136-173.5	#3 Mission V/HF R&S V/UHF 100-512	136-173.5	1.1
#6 Acoustics VHF Sonobuoy VHF 136-173.5	#5 Cockpit VHF Comm. VHF#2 136 -173.5	136-173.5	28

Table 1: In-band coupling example

In-Band Coupling Analysis Sheet (example)
An example of an in-band coupling sheet is provided in *table 1* with some of these coupled levels being a clear possibility for a red case of SIMOPS.

The effect on the receivers can best be provided by the receiver manufacturer. However, this may not be provided. Another possibility is that the input circuit of the receiver is available, in which case the effect of the level on the circuit can be modelled using a circuit model program. If neither is possible then the assumption can be made that the 15.5dBm and 18dBm levels will cause a problem.

An Example of Antenna Coupling
The aircraft has a Side Looking Airborne Radar (SLAR) antenna mounted on the sides operating at 9375MHz. Underneath the fuselage is a Maritime Search Radar also operating at 9375MHz. The antennas transmit and receive a vertically polarized wave.

A creeping wave will be generated from the SLAR antenna to the Maritime Search Radar and vice versa, but due to the high frequency the power will be at a low level. The use of a 1/10th scale model is not practical, nor is the use of one of two analysis computer programs, again because of the high frequency. Neither the SLAR antenna nor the Search Radar Antenna were available. Instead, an E plane sectional horn antenna was built and calibrated.

Figure 4 shows the gain plot of the SLAR and the sectional horn, and it can be seen that they have a good correlation.

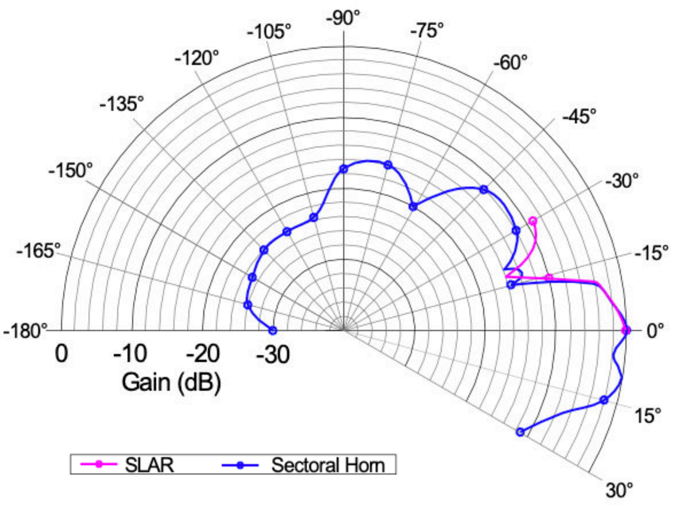


Figure 4: The SLAR antenna plot versus the sectional antenna plot

A parabolic dish antenna was used in place of the maritime search radar. It was angled 5.6 degrees in the H plane and 60 degrees in the E plane to the side of the fuselage. The sidelobe of the radar is minimum 36dB down on the main lobe, and so the sidelobe is 31-36 = -5dB. The parabolic dish gain is 28dB and at 90 degrees it is 27dB. So 27dB-28 = -1dB, and that is the gain used in the analysis.

Figure 5 shows the coupling path from the SLAR to the radar.

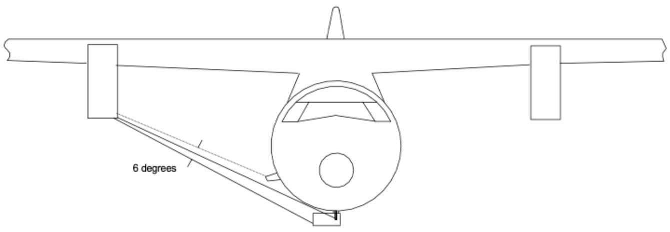


Figure 5: SLAR to radar coupling

The SLAR output power is 25,000W. The power into the sectional horn is 10W and in the analysis the power received by the parabolic dish was corrected accordingly, along with the gain correction.

A full-scale section of the fuselage, wing and nacelle were built with a copper foil covering and the horn and parabolic dish antennas were mounted at the appropriate location. The ground under the mockup was covered in absorber with high absorption at 9375MHz.

The predicted level induced into the Maritime Search Receiver is 42.3dBm.

The SLAR generates a 50nS wide pulse at a repetition rate of 50Hz. This means that the Maritime Search Radar will only see an interfering signal for a short time at a low repletion rate, and may be able to identify it and ignore this level. Because the level is so high (16W) damage to the receiver may be possible. If the SLAR generates a blanking pulse, the Maritime Search Radar may be able to use this to protect the receiver input.

CONCLUSIONS
Lack of SIMOPS between transmitters and receivers on a platform can have many causes, including in-band coupling; out of band coupling with high levels at the receiver; and PIM. The mitigation of lack of SIMOPS may be achieved by locating transmitting and receiving antennas on opposite sides of the fuselage (the higher the frequency the more effective this is); moving antennas down the aircraft to minimize reflections from structures such as engines and wings and reduce PIM; signal filters at the antenna end of the receiver cable; in-band cancellation at lower frequencies (See reference 5). Blanking receivers when a transmitter operates may reduce cross modulation, generation of spurious emissions, and receiver damage.

REFERENCES

1. Antenna to Antenna Coupling on an Aircraft Using a 1/10th Scale Model with Results Compared to the FEKO Electromagnetic Analysis Program.
   IEEE EMC Europe 2010.
   D. A. Weston

2. Electromagnetic ambient inside an aircraft from transmitting antennas mounted on the outside compared to safety levels and radiated susceptibility test levels.
   D. A. Weston.
   IEEE International Symposium 2013.

3. Website: emcconsultinginc.com

4. Electromagnetic Compatibility Methods, Analysis, Circuits, and measurement.
   1,150 pages. Third Edition. D. A. Weston
   CRC press 2017.

5. Antenna to Antenna coupling on an aircraft: Mitigation techniques.
   Interference Technology magazine. EMC Directory and Design Guide 2012.

2024 INDEX OF ADVERTISERS

Request Information From Our Advertisers. When you contact our advertisers, please remember to tell them you saw their ad in *Interference Technology*.

A.H. Systems
e: sales@ahsystems.com
w: www.AHSystems.com
page: 3

Coilcraft Inc.
e: sales@coilcraft.com
w: www.coilcraft.com
pages: 86, 108

Exodus Advanced Communications
e: sales@exoduscomm.com
w: www.exoduscomm.com
page: 2

Fair-Rite Products Corp.
e: ferrites@fair-rite.com
w: www.fair-rite.com
page: 11

Interference Technology
e: info@interferencetechnology.com
w: www.interferencetechnology.com
page: 110

LECTRIX
e: info@lectrixgroup.com
w: www.lectrixgroup.com
pages: 116

R&K Company Limited
e: info@rkco.jp
w: www.rk-microwave.com/index.php
page: 10

Spectrum Control
e: leonardo.marsala@spectrumcontrol.com
w: www.spectrumcontrol.com
page: 6


Break the same old pattern.
Problem First. Product Last.
Strategy | Content | Data | Technology
LECTRIX®
Digital Marketing for the B2B Electronics Industry
1.484.688.0300 | info@lectrixgroup.com
www.lectrixgroup.com