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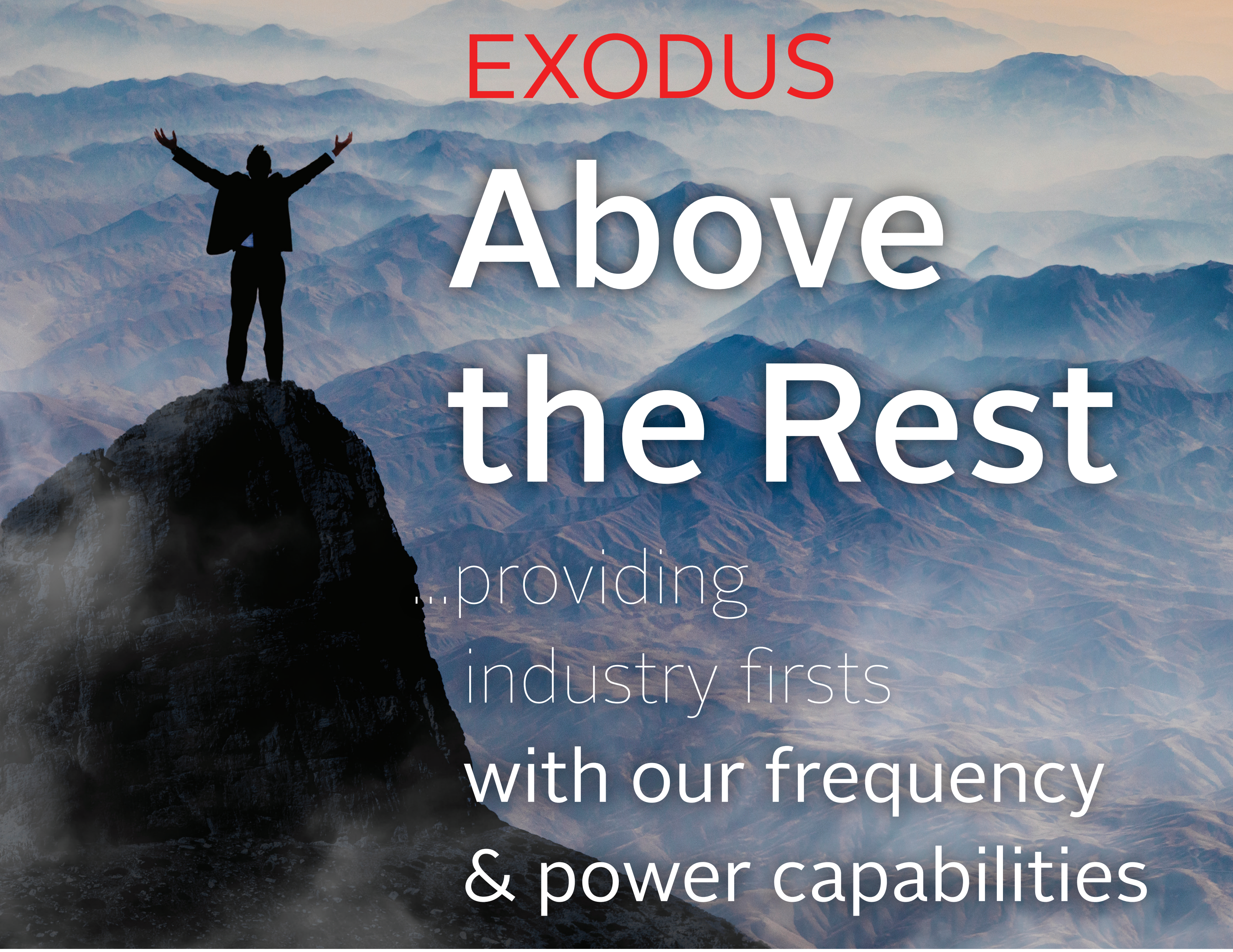

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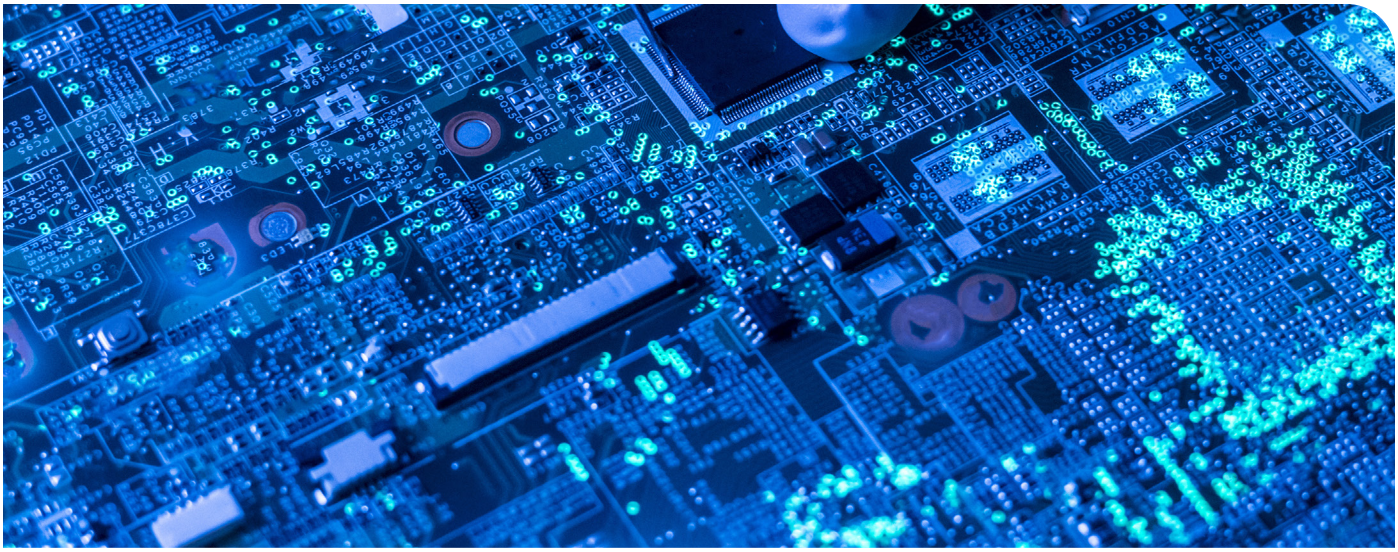

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PATRICK ANDRE

iNARTE CERTIFIED MASTER DESIGN ENGINEER

Patrick G. André received his physics degree in 1982 from Seattle University, with post graduate work in Electrical Engineering and Physics. He has worked in the Electromagnetic Compatibility (EMC) field over 35 years. He is an iNARTE Certified Engineer in both EMC (Electromagnetic Compatibility – EMC-001335-NE) and ESD (Electrostatic Discharge – ESD-00078-NE). He was honored as an iNARTE Certified Master Design Engineer - EMCD-00053-ME.

He has worked in the military and aerospace environment for his entire career and worked with commercial electronics for over 25 years. Projects worked on vary from semiconductors, satellite equipment, industrial and test equipment, cellular installations, to writing the procedures and reports, and performing or supervising EME testing of many panels for the flight deck of several aircraft. He has successfully worked with, and given input to, all branches of the military, NASA, the RTCA, the FAA, as well as several of their subcontractors. He has a strong ability in the test, measurement, and troubleshooting of EMC, and is president of André Consulting, Incorporated.

He is a third-party auditor for local governments and has provided expert opinions on the use of cellular transmitters, including health and safety concerns. Patrick has published numerous articles for a variety of magazines. He is the coauthor of EMI Troubleshooting Cookbook for Product Designers.

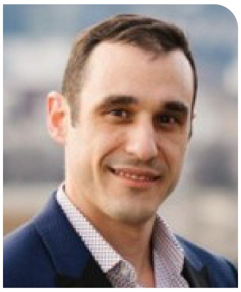
Patrick has been a senior member of the IEEE EMC Society which he joined in 1984, serving as chairman, vice chairman, secretary, and arrangements chairman of the Puget Sound Section, and has received The Legends of the IEEE Seattle Section Award in 2010. He also been on the Board of Trustees of the Seattle Gilbert and Sullivan Society where he also works as the sound engineer and. He enjoys audio and video recording musical groups, mostly in the Seattle area, and has engineered and mastered several CD's. And when he is not busy with all this, he can be found hiking somewhere with his camera.

GHERY PETTIT

PRESIDENT, PETTIT EMC CONSULTING LLC

Ghery S. Pettit received the BSEE degree from Washington State University in 1975. He has worked in the areas of TEMPEST and EMC for the past 47 years. Employers were the US Navy, Martin Marietta Denver Aerospace, Tandem Computers and Intel Corporation, prior to retiring from industry in 2015 and becoming an independent consultant.

Mr. Pettit is presently serving as Chair of CISPR SC I and is one of CISPR's representatives on the Advisory Council on EMC (ACEC) within the IEC. He has been involved in CISPR activities since 1998, both as a member of the US Technical Advisory Groups to CISPR SC G and CISPR SC I and as an active member of CISPR SC I and its maintenance teams, CISPR SC I MT7 (CISPR 32 maintenance) and CISPR SC I MT8 (CISPR 35 maintenance). He is also a member of the working groups preparing the next editions of ANSI C63.4, C63.9 and C63.16.



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.

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.

MIKE VIOLETTE

iNARTE CERTIFIED EMC ENGINEER

Mike is President 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.

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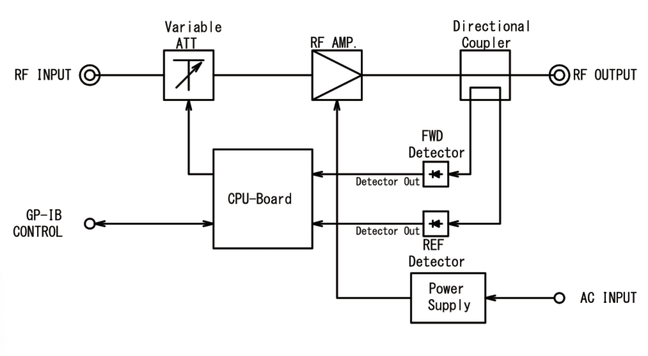

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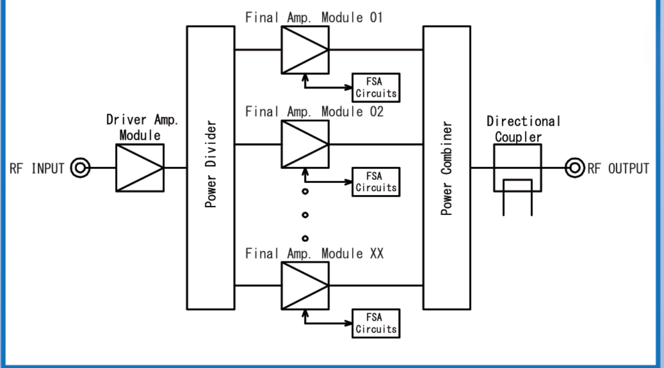

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2023 EMC SUPPLIER GUIDE

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 katherine@lectrixgroup.com for further supplier contacts.

2022 EMC SUPPLIER MATRIX SPOTLIGHT

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.H. SYSTEMS	AH SYSTEMS, INC. t: 818-998-0223 e: sales@ahsystems.com w: www.ahsystems.com	X	X	X													X	X	X			
Coilcraft	COILCRAFT t: 800-322-2645 e: sales@coilcraft.com w: www.coilcraft.com						X			X												
Fair-Rite Products Corp. Your Signal Solution®	FAIR-RITE PRODUCTS CORP. t: 1-888-FAIRRITE e: ferrites@fair-rite.com w: www.fair-rite.com						X							X								
POLYMER SCIENCE, INC.	POLYMER SCIENCE, INC. t: 888-533-7004 e: sales@polymerscience.com w: www.polymerscience.com												X	X								
SPIRA	SPIRA Manufacturing Corporation t: 818-764-8222 e: info@spira-emi.com w: www.spira-emi.com													X								

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

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

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


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2023 EMC TEST LAB DIRECTORY

WHEREVER YOU ARE IN THE COUNTRY 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 katherine@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 www.gdc4s.com	(480) 441-3033												•	•						•	•
Tempe	Lab-Tech, Inc. www.advancedtechnologieslab.com	(480) 317-0700					•															
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 https://www.nts.com/locations/danapoint	(949) 429-8602		•	•	•	•	•	•		•	•		•				•		•		
El Dorado Hills	Sanesi Associates	(916) 496-1760		•	•		•	•	•		•										•	

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	CKC Laboratories, Inc. www.ckc.com	(510) 249-1170		•	•	•	•	•	•		•	•		•	•	•		•		•	•	
Fremont	Underwriters Laboratories, Inc. www.ul.com	(510) 319-4000	•	•	•		•	•	•	•	•				•	•						
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		•	•		•	•	•		•				•	•	•					
Poway	APW Electronic Solutions www2.eem.com	(858) 679-4550						•		•			•									
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			•	•	•				•		•	•			•	•		•	•	•

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
Riverside	DNB Engineering, Inc. www.dnbenginc.com	(951) 637-2630	•		•		•	•	•	•	•					•						
Sacramento	Northrop-Grumman EM Systems Lab www.northropgrumman.com	(916) 570-4340			•		•		•		•			•						•	•	•
San Diego	Intertek (San Diego) www.intertek.com	(800) 967-5352		•	•		•	•	•		•											
San Diego	TDK-Lambda Electronics www.lambda.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		•	•		•	•	•		•			•	•					•	•	

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
CONNECTICUT																						
Newtown	TÜV Rheinland of North America, Inc. www.tuv.com	(203) 426-0888		•	•		•	•	•		•				•	•	•					
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			•						•			•	•							•

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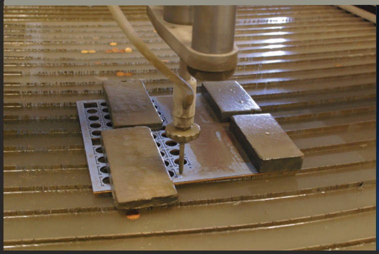

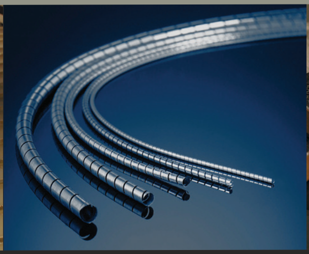

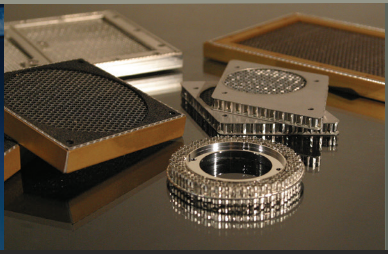

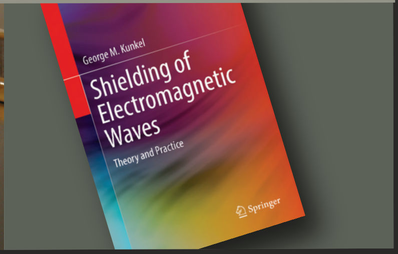

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USA continued

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
Indianapolis	F2 Labs, Inc. http://f2labs.com	(877) 405-1580			•	•	•	•	•	•	•	•			•	•				•		
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												•						•		•
Columbia	PCTest Engineering Lab www.pctestlab.com	(410) 290-6652		•	•	•	•	•	•	•	•				•		•					•
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	•		•		•	•	•		•				•	•					•	

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
Milford	Test Site Services, Inc. www.testsiteservices.com	(508) 634-3444	•	•	•		•	•	•	•	•	•		•	•	•		•		•	•	
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 www.trialon.com	(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			•		•	•	•		•			•	•	•				•		

TEST LAB DIRECTORY

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
NEW HAMPSHIRE																						
Goffstown	Retlif Testing Laboratories www.retlif.com	(603) 497-4600		•	•	•	•	•	•	•	•	•		•	•	•	•	•		•	•	
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			•	•						•		•	•			•		•		

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
Liverpool	Source1 Solutions www.source1compliance.com	(315) 730-5667			•		•	•	•		•			•		•					•	
Medford	American Environments Co. www.aeco.com	(631) 736-5883	•		•	•	•	•	•		•	•		•		•				•	•	
Melville	Underwriters Laboratories, LLC. www.ul.com	(631) 271-6200	•	•	•		•	•	•	•	•				•	•					•	
Palmyra	Source1 Solutions www.source1compliance.com	(315) 730-5667			•			•			•			•		•					•	
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.csa-international.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			•		•				•			•				•		•		
Mentor	EU Compliance Services, Inc. www.eucs.com	(440) 918-1425			•		•	•			•					•					•	
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	•												•					•		

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
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		•	•	•	•	•	•		•					•						
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.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		•	•		•		•		•				•							

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
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	•		•		•	•	•	•	•					•						
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			•		•		•		•				•							

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2023 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
UK EMCIA	Electromagnetic Compatibility Industry Association UK http://www.emcia.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

Category	Publisher	Number	Title
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
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	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

Category	Publisher	Number	Title
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
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	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
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

Category	Publisher	Number	Title
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
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	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)

Category	Publisher	Number	Title
Auto/Vehicle	Toyota	TSC7026G-3.4	Narrow Band Emissions
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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)
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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

Category	Publisher	Number	Title
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
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
www.ansi.org

ANSI Accredited C63
www.c63.org

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

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

Canadian Standards Association (CSA)
www.csa.ca

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

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

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

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

Federal Communications Commission (FCC)
www.fcc.gov

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

IEC
http://www.iec.ch

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

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

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

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

RTCA
https://www.rtca.org

SAE EMC Standards Committee
www.sae.org

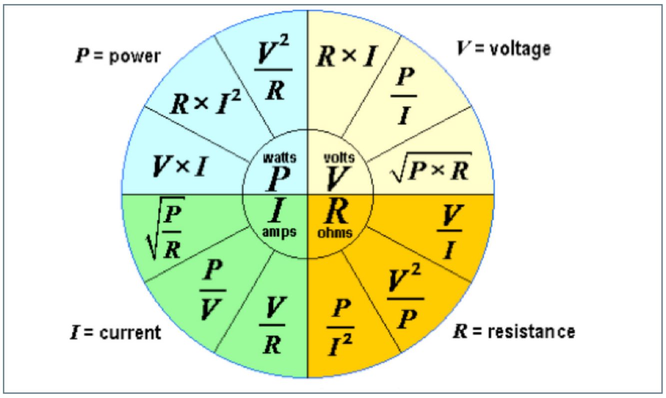
SAE EMC Standards
http://www.sae.org/servlets/works/committeeHome.do?comtID=TEVEES17

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

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: 12 inches/nsec

In most PC board dielectrics: 6 inches/nsec

VSWR AND RETURN LOSS

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

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

Reflection coefficient (ρ), given 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

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

REFERENCES & TOOLS

RETURN LOSS, GIVEN VSWR

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

Return Loss, given reflection coefficient (ρ)

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

E-FIELD FROM DIFFERENTIAL-MODE CURRENT

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

ID = differential-mode current in loop (A)

f = frequency (Hz)

L = length of loop (m)

s = spacing of loop (m)

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

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

E-FIELD FROM COMMON-MODE CURRENT

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

IC = common-mode current in wire (A)

f = frequency (Hz)

L = length of wire (m)

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

TEMPERATURE CONVERSIONS

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

ANTENNA (FAR FIELD) RELATIONSHIPS

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

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

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

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

Field Strength given watts, numeric gain, distance in meters

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

Field Strength given watts, dBi gain, distance in meters

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

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

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

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

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

PC BOARD EQUATIONS

1 oz. copper = 1.4 mils = 0.036 mm

0.5 oz. copper = 0.7 mils = 0.018 mm

Convert mils to mm: multiply by 0.0254 mm/mil

Convert mm to mils: multiply by 39.4 mil/mm

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

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

REFERENCES & TOOLS

WORKING WITH DB

The decibel is always a ratio

Power Gain = Pout/Pin

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

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

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

We commonly work with:

dBm (referenced to 1 mW)

dBμV (referenced to 1 μV)

dBμA (referenced to 1 μA)

Power Ratios

3 dB = double (or half) the power

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

Voltage/Current Ratios

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

DBM, 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):

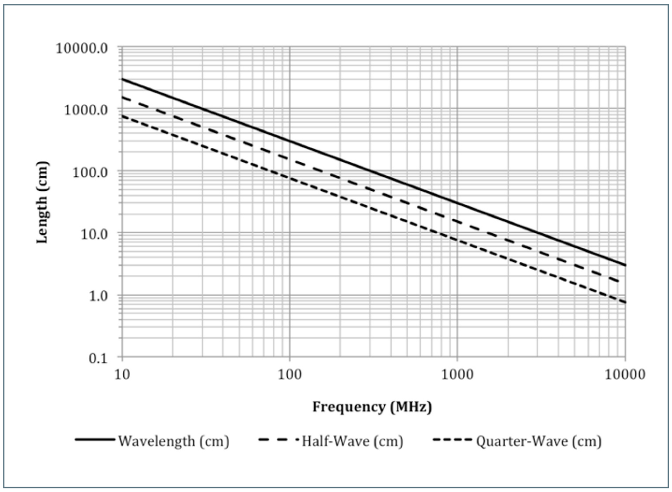
dBm to dBμV, use: dBμV = dBm + 107

REFERENCES & TOOLS

WAVELENGTH EQUATIONS (FREE SPACE)

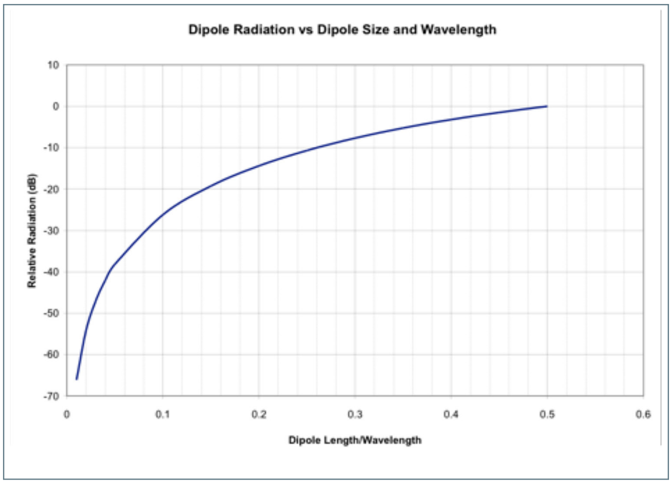
Wavelength(m) = 300/f(MHz)
Half-wavelength(ft.) = 468/f(MHz)

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

ACRONYMS

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

RECOMMENDED EMC BOOKS, MAGAZINES AND JOURNALS

2022 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/2022-emc-testing-guide/

2022 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/2022-emc-fundamentals-guide/

2022 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/2022-iot-wireless-5g-emc-guide/

2022 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/2022-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.

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

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

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

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

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

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

RECOMMENDED EMC BOOKS, MAGAZINES AND JOURNALS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

LINKEDIN GROUPS

Electromagnetic Compatibility Forum

Electromagnetics and Spectrum Engineering Group

EMC - Electromagnetic Compatibility

EMC Experts

EMC Troubleshooters

ESD Experts

Signal & Power Integrity Community

EMI/EMC Testing

IEEE EMC Society

iNARTE

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

A SHORT HISTORY OF A FEW *ITEM* ISSUES

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1977

My first issue of ITEM (Interference Technology Engineers Master) is from 1977. Was this the first issue of ITEM? No, it was not. However, it was my first issue. Why? I got my start in EMC in 1976 while working for the US Navy and was too late to get the 1976 issue. I graduated from college in 1975 and moved from Code 2330 (Nuclear Controls Engineering Division) at Mare Island Naval Shipyard (MINSY) to Code 310 (TEMPEST Engineering) at NAVELEX VJO (Naval Electronics Systems Engineering Center, Vallejo), a tenant activity at MINSY in June 1976. I've been involved in EMC and related areas ever since.

The 1977 issue of ITEM provides a great window into the world of EMC "back in the day."

Have you ever wondered where the FCC Rules dealing with unintentional radiators came from? Starting on page 163 of the 1977 issue there is a multi-page article about Docket 20870. This docket was the NPRM (Notice of Proposed Rulemaking) that started it all. The NPRM provides the justification for the proposal. This NPRM ultimately resulted in Part 15, Subpart J of the FCC Rules. Subpart J? Back then every time the FCC identified a new way to use RF energy without requiring a station or user license they created a new subpart to Part 15 to deal with that. Ultimately this was republished as 3 subparts. Subpart A dealt with general rules, subpart B dealt with unintentional radiators (devices which generate RF energy, but do not need to radiate it in order to function and part C dealt with intentional radiators (devices which generate RF energy and must radiate it in order to function). All was well. For a while. How many subparts are there to Part 15 today? Take a look.

There are articles dealing with CISPR (as it existed back then),MIL-STD 461, and the VDE (Verband Deutcher Electrotekniker)

Many of the areas covered by ITEM back in 1977 are still valid today. However, many of the companies that advertised are gone, or have been acquired by others. Remember Singer (EMC test equipment, not sewing machines)? They had a 6 page ad in the 1977 issue. They had, at some time prior, bought the Stoddard line of test equipment. I remember using the Stoddard 533 line of receivers while employed by the Navy. Other than the 533X-11 variable repetition rate impulse generator, they were not listed in this advertisement.

AEL had a 1 page ad for their LFR-100A receiver which they claimed was the only full approved TEMPEST test receiver. Long gone today. Remember the Watkins-Johnson 8940B? They also had a 1 page ad for their automated receiver. There is also a one page ad for Ailtech receivers and other test equipment. Rohde & Schwarz even appears in this issue.

A one page ad for the 1977 IEEE International Symposium on EMC gave the dates, location (Seattle) and chair (Len Carlson, remember him? His wife and he were among the guests at our daughter's wedding in 2003, time flies!). Yeah, I'm old too.

This article could be a lot longer, but there are other issues of ITEM that need to be discussed.

Back in 1977, ITEM was published annually by R&B Enterprises. Robert Goldblum was the publisher and editor. 17 individuals were listed as Contributing Editors. R&B Enterprises had, as a division, Scientific Employment Services, that many practitioners of the EMC specialty used to learn of job opportunities.

1987

The next issue of ITEM that we'll look at is 1987. 10 years later. I had changed employers twice (left the US Navy in October 1979, went to work for Martin Marietta Denver Aerospace for 4 years and then moved back to California to go to work for Tandem Computers (a commercial company). ITEM had changed hands a bit, it was now published by ROBAR Industries, INC., a division of R&B Enterprises.

The IEEE International Symposium on EMC was held in Atlanta, Georgia. Hugh Denny was the committee chair.

A number of receiver manufacturers were similar to those in 1977, but some had changes. Watkins-Johnson was still there, but was advertising their WJ-8999 portable EMC/TEMPEST receiver. A picture in an advertisement by Eaton looks like they had taken over the Singer line of test equipment at some time during the preceding 10 years. Electro-Metrics showed their automated test receiver system and in a separate advertisement they talked about their non-tunable test receiver. Hewlett Packard (yes, that was the outfit that originally sold their EMC receivers) had a 2 page advertisement showing their receiver solution. AEL had a 1 page advertisement talking about their TEMPEST receiver. And Dynamic Sciences, Inc had a 1 page advertisement for their DSI 9000 TEMPEST receiver.

A large number of test equipment manufactures were represented in the 1987 issue. Many are still in business today. The same goes for companies selling shielded rooms, although a number of them have merged in the years since. LectroMagnetics, RayProof and Lindgren are all now under ETS-Lindgren in Texas. Speaking of ETS-Lindgren, then called EMCO, they advertise in this issue of ITEM, but only for test equipment.

Test houses were prominent in the 1987 issue of ITEM. Retlif had an advertisement saying "The first word in military testing … and the last." BTW, do you remember where they got their name? Reverse the letters and see what it spells. Other test labs included DLS Electronic Systems (still in business today), Amador Corporation and CK Consultants, Inc. (also still in business). This is just a small sampling of the test houses advertising in the 1987 issue of ITEM.

There are also a large number of manufacturers listed who sell various pieces of test equipment and supplies. 3M shows their copper and aluminum tape, and supplies I cannot imagine an EMC lab functioning without today.

1995

The next issue of ITEM that we'll take a look at is 1995. The cover says "ITEM 1995 The International Journal of EMC" This is the 25th anniversary edition of ITEM, the first edition being published in 1971. I started a 20 year career at Intel Corporation in March of that year.

EMC and TEMPEST receivers in the 1995 issue changed a bit. Dynamic Sciences International, Inc now advertised two receivers, the DSI-200 system for EMC and the DSI-110 for TEMPEST. Electro-Metrics shows their latest receiver systems. Hewlett Packard showed their portable pre-compliance spectrum analyzer.

There are a number of manufacturers of parts for EMC control and test equipment. Fischer Custom Communications grew their presence in ITEM significantly between 1987 and 1995. A huge change in the commercial world occurred in Europe by their introduction of what I call the EMC Professionals Employment Act of 1992 (actually called the EMC Directive). In addition to mandating emissions testing they now mandated immunity testing. More tests equals more testing time and more testing equipment. Many people in this corner of the EMC world can thank the EU for their work. And, of course, ITEM grew again. Many more and larger advertisements for immunity test equipment and systems. EMCO (now ETS-Lindgren) starts off with an advertisement for their GTEM cell. FerriShield talks about their RFI suppressors. There is an article on IEC 801. Three parts of this standard existed at the time. IEC 801-2 dealt with ESD testing, IEC 801-4 covered EFT testing and IEC 801-5 covered surge testing. Not covered in the article because it was dealing with transient testing was IEC 801-3 which covered radiated immunity testing. Roger Southwick contributed an article on site attenuation testing.

Test equipment manufacturers advertising in the 1995 issue of ITEM included Solar Electronics Company (a long time presence in ITEM), IFI (Instruments for Industry), Schaffnet EMC, Inc., Chase, Amplifier Research, A.H. Systems, Electro-Metrics, and EMCO.

A wide variety of manufacturers of EMC suppression components were in this issue, as well.

The IEEE International Symposium on EMC was held again in Atlanta in 1995.

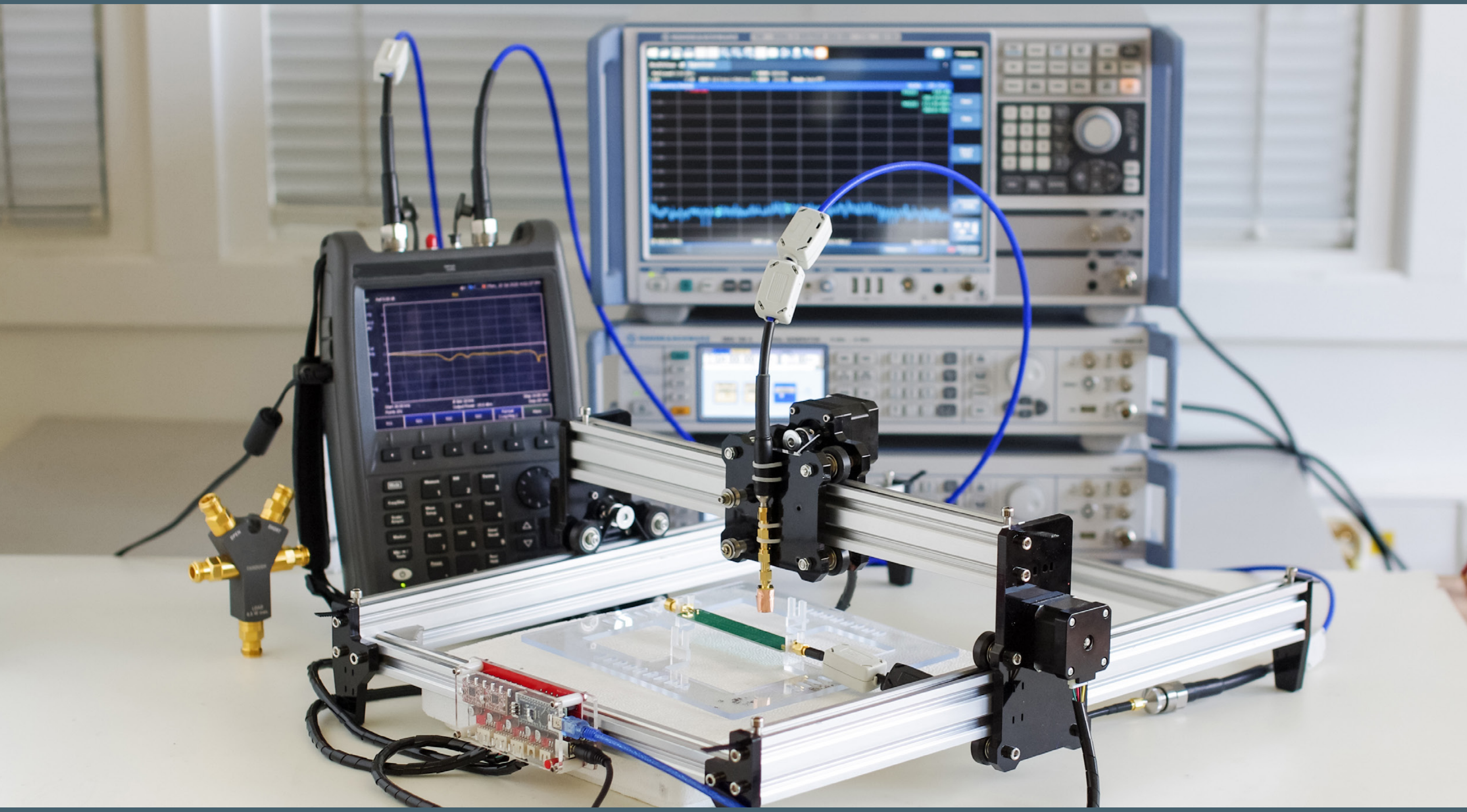
2005

By this time the name of ITEM had changed. Published by ITEM Publications it was titled Interference Technology.

EMCO had changed their name. They were now (sometime in the last 10 years) ETS-Lindgren. Dynamic Sciences was now advertising a single solution for EMC and TEMPEST, the DSI-600. Nothing from Hewlett Packard or their successors. Rohde & Schwarz had an advertisement for their EMI receivers. The number of companies advertising receivers continued to shrink. Test equipment suppliers were coalescing into the names we recognize today.

A significant change (or addition) to ITEM started in 2005. As a result of feedback received in 2004 at the IEEE International Symposium on EMC an on-line version of ITEM was created. And it wasn't limited to a single issue, different areas were covered in separate publications. This approach has continued to this day. Go to www.interferencetechnology.com to see all the options. At the time it was written, the current version of ITEM available for download is the 2022 issue.

EMC FUNDAMENTALS



EMC EQUIPMENT MANUFACTURERS

INTRODUCTION

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

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

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

COMMERCIAL STANDARDS

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

FCC

https://www.ecfr.gov

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

ANSI

http://webstore.ansi.org

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

IEC

https://webstore.iec.ch

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

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

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

CISPR

https://webstore.iec.ch

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

CISPR 16-2-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-2: Methods of measurement of disturbances and immunity - Measurement of disturbance power
CISPR 16-2-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-3: Methods of measurement of disturbances and immunity - Radiated disturbance measurements
CISPR 16-2-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-4: Methods of measurement of disturbances and immunity - Immunity measurements
CISPR TR 16-2-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 2-5: In situ measurements for disturbing emissions produced by physically large equipment
CISPR TR 16-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports
CISPR TR 16-4-1	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-1: Uncertainties, statistics and limit modelling - Uncertainties in standardized EMC tests
CISPR 16-4-2	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-2: Uncertainties, statistics and limit modelling - Measurement instrumentation uncertainty
CISPR TR 16-4-3	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-3: Uncertainties, statistics and limit modelling - Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR TR 16-4-4	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-4: Uncertainties, statistics and limit modelling - Statistics of complaints and a model for the calculation of limits for the protection of radio services
CISPR TR 16-4-5	Specification for radio disturbance and immunity measuring apparatus and methods - Part 4-5: Uncertainties, statistics and limit modelling - Conditions for the use of alternative test methods
CISPR 17	Methods of measurement of the suppression characteristics of passive EMC filtering devices
CISPR TR 18-1	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 1: Description of phenomena
CISPR TR 18-2	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 2: Methods of measurement and procedure for determining limits
CISPR TR 18-3	Radio interference characteristics of overhead power lines and high-voltage equipment - Part 3: Code of practice for minimizing the generation of radio noise
CISPR 20	Sound and television broadcast receivers and associated equipment - Immunity characteristics - Limits and methods of measurement (to be withdrawn July 2021)
CISPR 24	Information technology equipment - Immunity characteristics - Limits and methods of measurement (to be withdrawn July 2021)
CISPR 25	Vehicles, boats and internal combustion engines - Radio disturbance characteristics - Limits and methods of measurement for the protection of on-board receivers
CISPR 32	Electromagnetic compatibility of multimedia equipment – Emission requirements
CISPR 35	Electromagnetic compatibility of multimedia equipment - Immunity requirements

AUTOMOTIVE ELECTROMAGNETIC COMPATIBILITY STANDARDS

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

CISPR (AUTOMOTIVE EMISSIONS REQUIREMENTS)

https://webstore.iec.ch

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

ISO (AUTOMOTIVE IMMUNITY REQUIREMENTS)

https://www.iso.org

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

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

SAE (AUTOMOTIVE EMISSIONS AND IMMUNITY)

http://standards.sae.org

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

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

GM
https://global.ihs.com

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

FORD
https://www.fordemc.com

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

DaimlerChrysler

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

Automotive Electromagnetic Compatibility Standards From
https://cecas.clemson.edu/cvel/emc/

MEDICAL STANDARDS

COLLATERAL STANDARDS

https://www.webstore.iec.ch

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

OTHER RELEVANT STANDARDS

https://www.webstore.iec.ch

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

For more extensive listings of medical standards, download the 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

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LINKS TO LONGER ARTICLES

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https://interferencetechnology.com/electromagnetic-interference-sources-and-their-most-significant-effects/

Duff, Designing Electronic Systems for EMC: Grounding for the Control of EMI, 2011
https://interferencetechnology.com/designing-electronic-systems-for-emc-grounding-for-the-control-of-emi-3/

Armstrong, Fundamentals of EMC Design: Our Products Are Trying to Help Us, 2012
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https://interferencetechnology.com/clocking-strategies-for-emi-reduction/

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Armstrong, Cost-Effective EMC Design by Working With the Laws of Physics (Webinar), 2013
https://interferencetechnology.com/watch-our-webinar-on-cost-effective-emc-design-by-working-with-the-laws-of-physics/

EMC STANDARDS ORGANIZATIONS

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

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

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

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

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

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

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

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

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

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

IEC
http://www.iec.ch

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/

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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.

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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.

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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.

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

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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.

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RECOMMENDED MINI GUIDES FROM *INTERFERENCE TECHNOLOGY*

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

2022 EMC Fundamentals Guide
https://learn.interferencetechnology.com/2022-emc-fundamentals-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/

2022 EMC SI & PI Guide
https://learn.interferencetechnology.com/2022-signal-and-power-integrity-guide/

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

2020 Medical EMC Guide
https://learn.interferencetechnology.com/2020-medical-emc-guide/

2020 Europe EMC Guide
https://learn.interferencetechnology.com/2020-europe-emc-guide/

2020 EMC Testing Guide
https://learn.interferencetechnology.com/2020-emc-testing-guide/

2020 EMC Fundamentals Guide
https://learn.interferencetechnology.com/2020-emc-fundamentals-guide/

2020 Military & Aerospace EMC Guide
https://learn.interferencetechnology.com/2020-military-and-aerospace-emc-guide/

2020 IoT, Wireless, 5G EMC Guide
https://learn.interferencetechnology.com/2020-iot-wireless-5g-emc-guide/

RECOMMENDED WEBSITES

Doug Smith
http://emcesd.com

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

Henry Ott
http://www.hottconsultants.com

Interference Technology
https://interferencetechnology.com

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

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

Patrick André
http://andreconsulting.com

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

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

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

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

LIST OF LINKEDIN GROUPS

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

PLACING A METAL PLATE IN FRONT OF A EUT MAY NOT BE ENOUGH TO SOLVE RADIATED EMISSIONS EXCEEDANCES OR RADIATED SUSCEPTIBILITY FAILURES

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EXAMPLE OF AN EUT WHICH HAS FAILED RADIATED SUSCEPTIBILITY

As described in reference 1. the EUT was exposed to a radiated immunity test at a level of 20V/m.

The side which contained a vertical metal plate, with an approximately 0.3m x 0.3m dimension and which was electrically isolated from a metal baseplate failed at 12V/m and 300MHz.

On the other sides of the EUT, without the vertical plate, the EUT passed at 20V/m with a good margin. All four sides of the EUT contained cables and connectors with no significant differences in layout.

A 4mm gap existed between the vertical plate and the baseplate.

When this gap was closed with conductive adhesive, used as caulking, the EUT passed at 35V/m when the side of the EUT with the plate was irradiated.

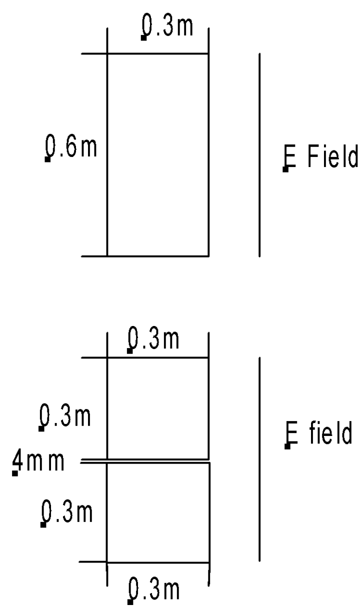


Figure 1 0.6cm x 0.3m plate with and without a 4mm gap.

TESTING A METAL PLATE WITH AND WITHOUT A GAP

As the results of the immunity test on the EUT seemed counter intuitive it was decided to test a metal plate with and without a gap in a radiated immunity test set up. The coupling between a log/periodic biconical transmitting antenna with a frequency range of 20MHz to 1100GHz and a small electric field probe was measured. The tests were of the coupling without a metal plate, a metal plate having a 4mm gap in the center and a solid metal plate.

The metal plates, the orientation of the incident E field and the gap is shown in figure 1.

MEASUREMENT TEST SET UP.

The tests were performed on a free space range with ferrite tiles and foam absorber on the poorly conducting ground between the two antennas, see reference 1. The distance between the log periodic biconical antenna and the metal plate was 1m.

The receiving antenna was a 4.2cm PCB antenna with two bow tie structures to make the antenna close to an isotropic antenna. A similar antenna was used as one of the antennas in a isotropic probe from 10kHz to 18GHz described in reference 2. The antenna in reference 2 had an isotropic deviation of maximum 0.9dB.

The antenna in the set up described here was connected to a differential high impedance, wide dynamic range RF/IF detector with a frequency range of 10MHz to 1GHz. The dynamic range is 83dB+/- 1dB with a sensitivity of -76dB or better. The detector was connected to a preamplifier the output of which is connected to an A/D converter. The output of the A/D is connected to a fiber optic driver. The power supplies for the preamplifier, A/D and fiber driver was derived from a 9V battery.

As the only connection to the electronics was the non conductive fiber cable the potential for error introduced by a conductive cable was avoided.

TEST RESULTS

More detailed test results are provided in reference 1. A summary of the test results is that, though counter intuitive, the metal plate with a gap provides gain, as was seen in the immunity test on the EUT. This means that the coupling between the two antennas when a metal plate with a 4mm gap is introduced between the two antennas is higher than with the metal plate removed. For the 0.6m x 0.3m plate the gain is 12dB at 1cm distance, Figure 2, and for the 0.5m x 0.5m plate it is 8dB at 1cm, Figure 4.

N.B. a negative attenuation is gain.

The other very interesting result is that the plate with gap provides 0dB coupling at 10cm and 300MHz , figure 2 and 2dB attenuation at 20cm and 500MHz, figure 4.

At 1cm the attenuation of the solid metal plate is not very high, only 14dB for the 0.6m x 0.3m at 300MHz.

For the 0.5m x 0.5m solid metal plate the attenuation at 1cm is 19dB at 300MHz and 17dB at 500MHz. The 0.5m x 0.5m attenuation at 25cm is 4dB at 300MHz and 5dB at 500MHz.

The 0.6m x 0.3m solid metal plate achieves very little attenuation at further distances from the plate, as low as 8dB at 20cm behind the plate and at 300MHz , figure 3.

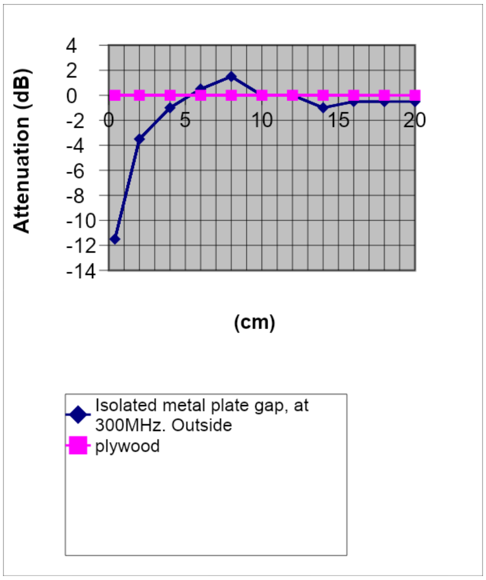


Figure 2 Attenuation of gap at 300MHz Gain © IEEE 2017

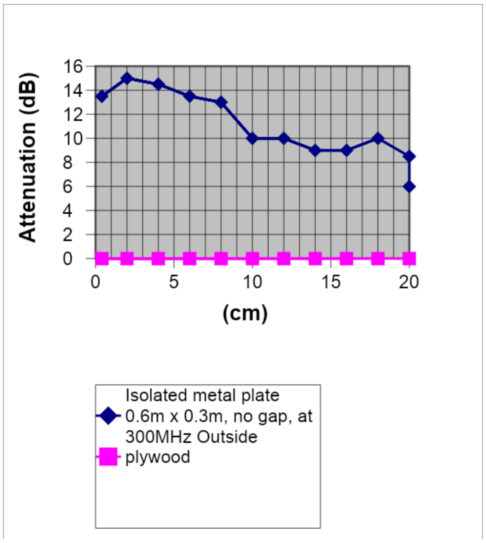


Figure 3 Attenuation of solid metal plate at 300MHz © IEEE 2017

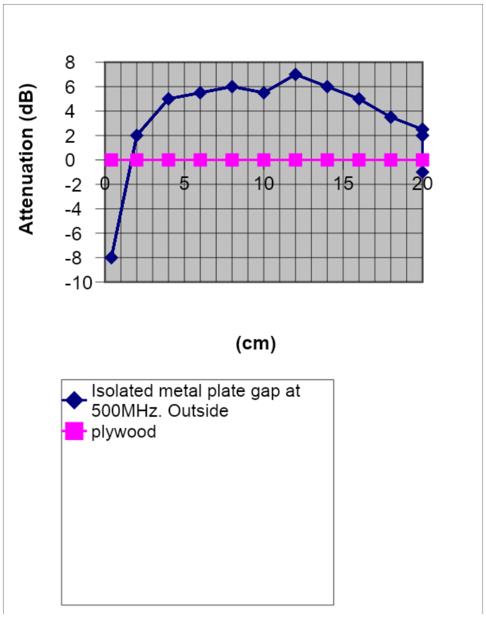


Figure 4 Attenuation of metal plate with 4mm gap at 500MHz. © IEEE 2017

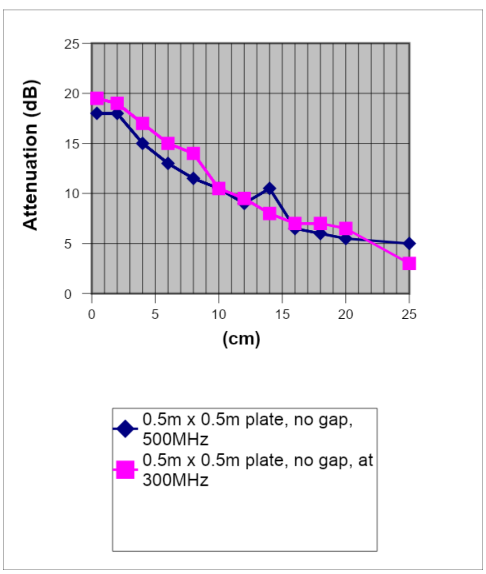


Figure 5 Attenuation of solid metal plate when the dimension is changed to 0.5m x 0.5m

USE OF AN ELECTROMAGNETIC ANALYSIS COMPUTER PROGRAM (COMPUTER ELECTROMAGNETICS, CEM ,PROGRAM) TO FURTHER VALIDATE THE TEST RESULTS

The most common form of analysis uses the Method of Moment (MOM) formulation in which the structure is modelled as wires or patches. The wires are broken down into small wire segments which are typically no larger than /10 lambda. Metal plates are broken up into surface patches which again should be small compared to a wavelength.

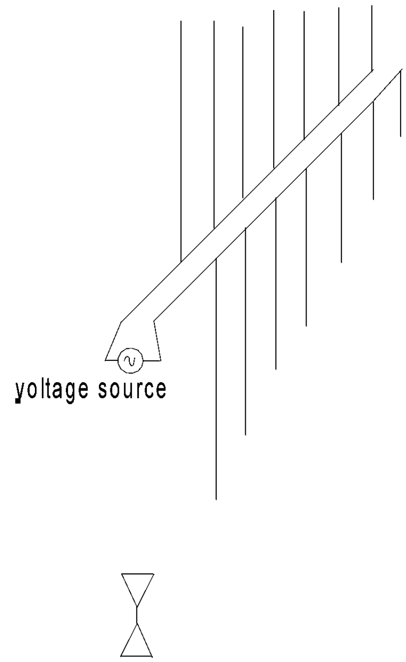


Figure 6 Log periodic antenna used in the modelling.

Figure 6 shows the thin wires used to model the transmitting antenna and the bow tie receiving antenna.

When current flows on these wires, due to an applied voltage, an E field is generated. Likewise with an E field incident on the wires a current flows. The computer program is used to analyses the radiated E field or the induced current. The Geometric Theory of Diffraction (GTD) formulation is a high frequency ray optics approach that has been extended to include diffraction effects from edges and corners. The MOM/GTD program is very useful and accurate at computing the creeping wave around a cylinder and this computation has been compared to measurements in reference 3.

The computed attenuation of the metal plate with no gap, from reference 4, to the measured From reference 1 is:

Measured attenuation of solid metal plate at 300MHz	CEM computed attenauation at 300MHz
12.9dB	13.5dB

A comparison of the CEM computed and measure coupling using a MOM/GTD program is shown in figure 7. The blue trace is the program and the red is the bow tie measurement, with only a 1dB variation between the two.

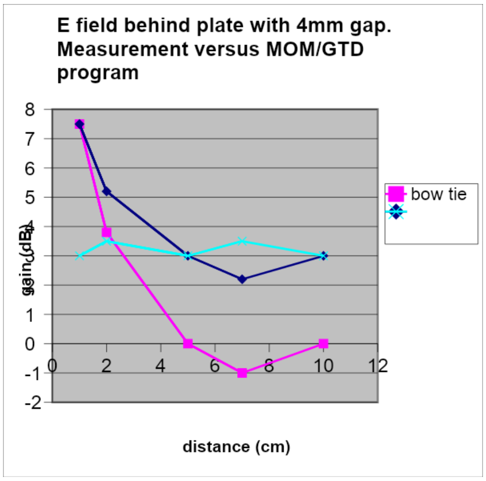


Figure 7 Gain comparison between the CEM prediction for the metal plate with 4mm gap at 300MHz and the measurement.

CONCLUSIONS

The study has shown that placing a solid metal plate in front of a EUT to shield it in a radiated immunity/susceptibility test or to reduce the radiated emissions from a EUT, achieves minimal shielding and zero attenuation at a short distance behind the plate.

It has also been shown that a plate with a horizontal gap can show a gain in the vertically oriented field transmitted through the gap, even though the gap is only 4x10-3 lambda in width.

We also see that the width of the gap and the dimensions of the plate are relatively frequency independent. We see gain at 230MHz, 250MHz, 300MHz and 500MHz. For example the gain at 500MHz is 7dB ,at 230MHz it is 6dB and at 250MHz 9dB.

It was thought that the gain may be highest when the vertical dimension of the plate equals 0.5 lambda and this was not the case.

The vertical dimension of the plate at 0.6m is 0.6 lambda at 300MHz, 0.5 lambda at 250MHz and 1 lambda at 500MHz and the gain is virtually independent of this relationship.

The width of the gap was changed from 2mm to 3mm with very little change in gain.

The attenuation of the solid metal plate is very slightly affected by its dimension. For example a 0.6m x 0.3m plate has an attenuation of 8dB at 300MHz and a distance of 20cm whereas the 0.5m x 0.5m plate attenuation is 5db at 300MHz and a distance of 20cm.

The magnetic field with both the direct coupling and the coupling through the plate with aperture was also measured, with again a gain measured with the plate with aperture, although not as high as seen with the electric field coupling.

The measurements have been validated by a Computer Electromagnetics (CUT) program, described in reference 4, with a good correlation between measurements and computed results.

REFERENCES

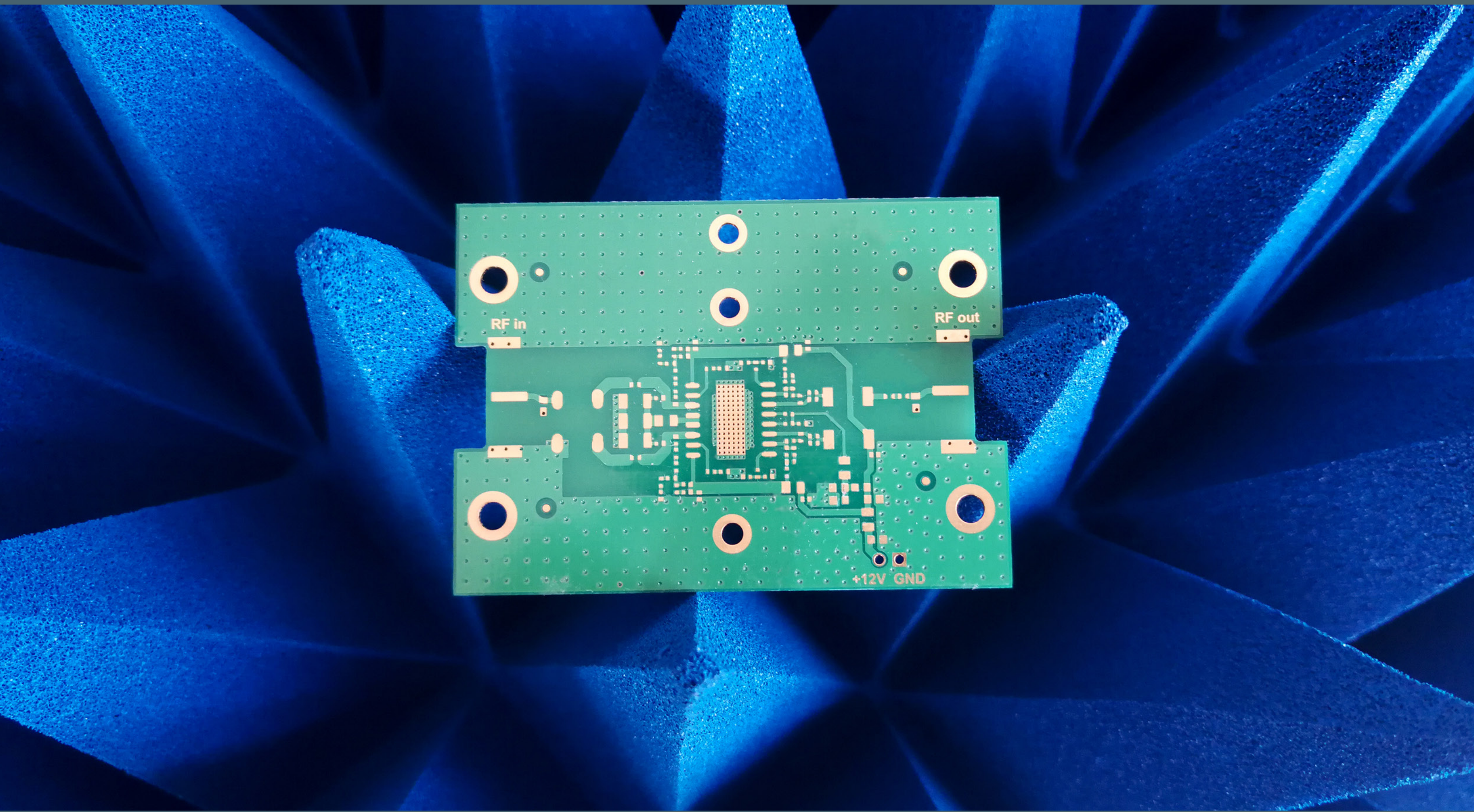
Reference 1 : A study of Electric Field Behind Isolated Metal Plate in a Radiated Immunity Test Set Up. David Weston. EMC Consulting Inc. Merrickville, Ontario, Canada. IEEE Electromagnetic Compatibility magazine Volume 6, Number 2, 2nd Quarter 2017

Reference 2: An isotropic probe for radiated susceptibility measurements from 10kHz to 18GHz and 5V/m to 220V/m. David A. Weston May 2022

Reference 3: Comparison of Techniques for Prediction and Measurement of Antenna to Antenna Coupling on an Aircraft. 10th International Symposium on Electromagnetic Compatibility 2011. David A. Weston.

Reference 4: Use of an electromagnetic analysis computer program to further validate the study of the electric field behind an isolated metal plate in a radiated immunity Test Set up and the result of a literature search. David A. Weston ResearchGate January 2022.

EMC TESTING



EMC EQUIPMENT MANUFACTURERS SUPPLIER MATRIX

INTRODUCTION

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

EMC Equipment Manufacturers Supplier Matrix		Type of Product/Service												
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
A.H. Systems	www.ahsystems.com	X	X		X						X			
Aaronia AG	www.aaronia.com	X	X			X					X			
Advanced Test Equipment Rentals	www.atecorp.com/category/emc-compliance-esd-rfi-emi.aspx	X	X			X	X	X	X	X	X		X	X
AR RF/Microwave Instrumentation	www.arworld.us	X	X			X		X	X	X	X			X
Anritsu	www.anritsu.com					X					X			X
BHD Test and Measurement	www.bhdtm.com		X			X	X	X	X	X	X		X	X
Compliance Worldwide	www.complianceworldwide.com								X	X	X			
CPI	www.cpii.com	X	X			X								
Electro Rent	www.electrorent.com		X			X	X	X	X	X	X		X	X
EM Test	www.emtest.com/home.php									X	X	X		
EMC Partner	www.emc-partner.com						X			X				
Empower RF Systems	www.empowerrf.com		X						X					
Exodus Advanced Communications	www.exoduscomm.com		X											
F2 Laboratories	www.f2labs.com								X	X	X			
Gauss Instruments	www.gauss-instruments.com/en/					X								
Instruments For Industry (IFI)	www.ifi.com		X						X	X				
ITG Technologies, Inc.	www.itg-electronics.com		X											

EMC Equipment Manufacturers Supplier Matrix		Type of Product/Service												
Manufacturer	Contact Information - URL	Antennas	Amplifiers	Near Field Probes	Current Probes	Spectrum Analyzers/EMI Receivers	ESD Simulators	LISNs	Radiated Immunity	Conducted Immunity	Pre-Compliance Test	TEM Cells	Rental Companies	RF Signal Generators
Kent Electronics	www.wa5vjb.com	X												
Keysight Technologies	www.keysight.com/us/en/home.html			X		X		X			X			X
Microlease	www.microlease.com/us/home		X			X	X	X	X	X	X		X	X
Milmega	www.milmega.co.uk		X						X	X				
Narda/PMM	www.narda-sts.it/	X	X			X		X	X	X	X			
Noiseken	www.noiseken.com						X			X	X			
Ophir RF	www.ophirrf.com		X							X				
Pearson Electronics	www.pearsonelectronics.com				X									
PPM Test	www.ppmtest.com	X			X						X			
Rigol Technologies	www.rigolna.com			X	X	X					X			X
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X	X	X	X		X	X	X	X			X
Siglent Technologies	www.siglentamerica.com			X		X					X			X
Signal Hound	www.signalhound.com			X		X					X			X
Solar Electronics	www.solar-emc.com	X			X		X	X		X				
TekBox Technologies	www.tekbox.com		X	X				X			X	X		
Tektronix	www.tek.com			X		X					X			
Teseq	www.teseq.com/en/index.php		X		X		X		X	X	X	X		
Test Equity	www.testequity.com/leasing/		X			X	X	X	X	X	X		X	X
Thermo Keytek	www.thermofisher.com/us/en/home.html						X			X				
Thurlby Thandar (AIM-TTi)	www.aimtti.us					X					X			X
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X			X		X	X		X			
TPI	www.rf-consultant.com													X
Transient Specialists	www.transientspecialists.com								X	X		X		
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X			X		X	X	X	X		X	X
Vectawave Technology	www.vectawave.com		X											
Windfreak Technologies	www.windfreaktech.com													X

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 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
(DIRECTORY, BOOKS, ORGANIZATIONS, LINKEDIN GROUPS)

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.

SUMMARY OF COMMERCIAL EMC TESTS

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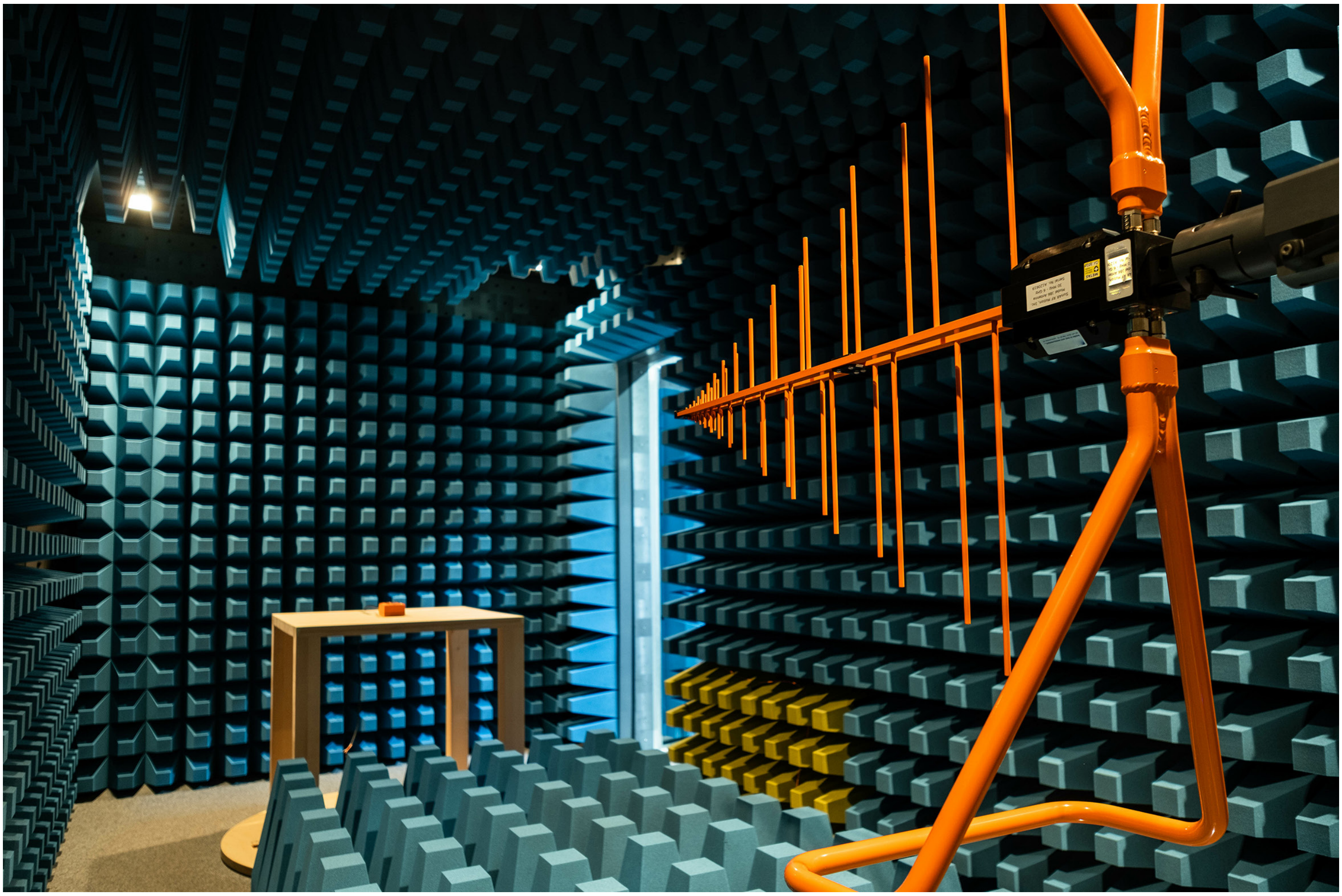
Introduction

Commercial EMC tests cover a wide range of products. These include the obvious ones like computers and their peripherals, but also cover household appliances, electric tools and a wide variety of other products. While the standards, including limits and test methods may differ, all EMC test standards have a few things in common. The most basic are the limits for emissions and the types and levels of immunity testing.



SUMMARY OF COMMERCIAL EMC TESTS

Emissions tests (and their associated limits) are put in place for commercial equipment primarily to protect radio and television broadcasting services. Other radio communications services are also protected. While a very few commercial emissions standards existed prior to the introduction of the personal computer to the marketplace, the proliferation of these devices spurred the development of standards and regulations around the world due to the large number of interference complaints directly traceable to these new devices. Early personal computing devices were designed and built with no regard to controlling radio frequency emissions and, as a result, they generated large amounts of RF emissions. Indeed, it could be argued that the early personal computing devices were broadband radio transmitters masquerading as computers. Mainframe computers had similar weaknesses, but as they typically weren't installed in residential areas the impact was smaller.

Emissions testing typically comprises of two parts. Conducted emissions on power and telecommunications ports and radiated emissions. The breakpoint between the two (conducted and radiated) in commercial standards is 30 MHz. This frequency was chosen as at the typical test distances involved (3 meters and 10 meters today) frequencies above 30 MHz tend to provide plane wave (far field) emissions, allowing for fairly repeatable measurements from laboratory to laboratory. Below 30 MHz this may not be the case. Thus, conducted emissions are measured. Limits for powerline conducted emissions were set based on the source and victim devices being connected to the same circuit. Limits for conducted emissions on telecommunication ports are set assuming a certain conversion of the differential mode (desired) signals on the cable being converted to common mode (due to characteristics of the cable) which then radiates.

CONDUCTED EMISSIONS

Conducted emissions on the incoming power lines are measured (typically) using a Line Impedance Stabilization Network (LISN) or Artificial Mains Network (AMN). These are two different names for the same box. The LISN or AMN is placed between the Equipment Under Test (EUT) and the incoming power line (mains) to provide a defined power line impedance and a coupling point to the receiver (Figure 1). The LISN or AMN is placed on the horizontal ground plane, or directly beneath it with the EUT connected directly to the EUT port. The block diagram below shows this test setup.

The EUT is placed either on the horizontal ground plane on the floor (with an insulating spacer) or on an 80 cm high non-conducting table, depending on the intended installation of the EUT (table top or ground mounted). The frequency range of interest is scanned with the appropriate detectors and bandwidth and the results are noted. Measurement are made on each conductor of the incoming line separately. Most commercial EMC standards have measurements made over the frequency range of 150 kHz to 30 MHz.

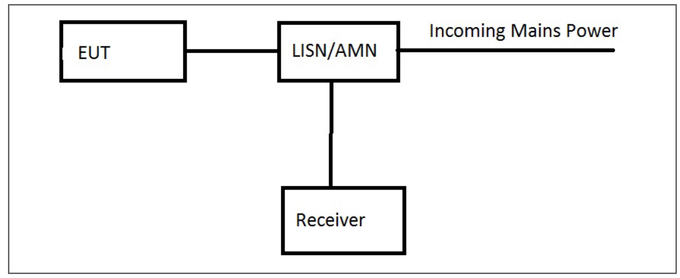


Figure 1 – Generalized test setup for conducted emissions using a line impedance stabilization network (LISN).

RADIATED EMISSIONS

Radiated emissions may be measured in either an Open Area Test Site (OATS) or an RF Semi-Anechoic Chamber (SAC). The OATS is the "gold standard" test facility. It consists of a large open area free of objects which might reflect RF energy. It typically is equipped with a reflecting ground plane. The size of the clear area is defined in various standards as an elliptical area whose major axis is twice the measurement distance and whose minor axis is the square root of 3 times the measurement distance. Experience has shown over the decades that these dimensions are too small. Doubling them has been tried and even that has been shown to have its weaknesses, especially when the OATS is surrounded by a chain link fence for security. The picture below shows a 30 meter OATS built in 1989 for Tandem Computers Incorporated near Hollister, California. The clear area is at least twice the required dimensions for a 30 meter site and takes a considerable amount of land. This site is no longer in operation, but it illustrates the point. The building on the ground plane was constructed of RF transparent material and covered the turntable. All utilities were run underground, including the air conditioning ducts with the air conditioning units being installed outside the clear area. The site was never utilized at a measurement distance of 30 meters, so it was a superb 10 meter site.

Figure 2 – A typical open area test site (OATS).

A significant weakness of the OATS facility is that in addition to measuring the emissions from the EUT it is a great facility to measure all the local RF ambient signals from broadcast and communications services, as well. If these signals are strong enough they will totally mask the emissions from the EUT that you were trying to measure. As a result, for best operation an OATS must be located in a very remote area. And this is no guarantee that the ambient level will remain low. Apple Computer had a great OATS near Pescadero, California that had a very low ambient when it was built in the 1980s. Apple ultimately stopped using the facility when the local ambient signals grew to the point where operation was no longer possible and moved totally to 10 meter SACs near their development facilities.

Regardless of whether measurement are taken at an OATS or in a SAC, the block diagram of the test set-up remains the same. Emissions from the EUT are measured using an antenna for the appropriate frequency range, a pre-amplifier (if necessary) and a measuring receiver. Measurements are taken with the antenna in both the vertical and horizontal polarities. See the block diagram in *Figure 3*.

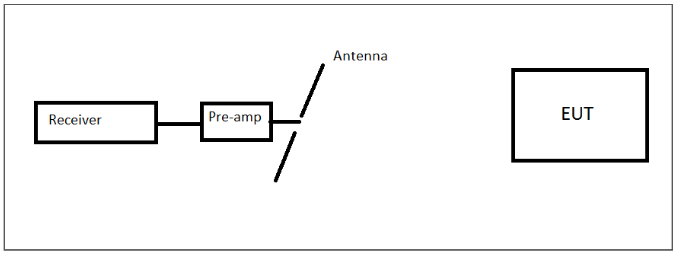


Figure 3 – General test setup for radiated emissions testing.

The need for height scans is shown by the diagram in *Figure 4*. The objective is to adjust the antenna height until the direct and reflected signals are maximized. An example of an antenna mast for this purpose is shown in the photograph above of the Tandem 30 meter OATS (*Figure 2*).

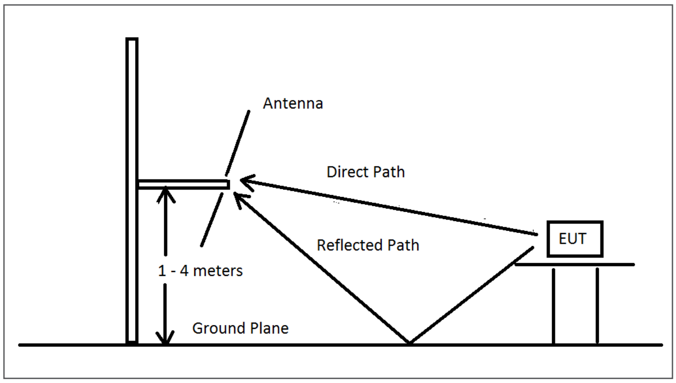


Figure 4 – Diagram showing the direct and reflected waves. The antenna height is adjusted to maximize the measurement.

Emissions tests are required in many countries around the world. Immunity testing of commercial products is required in a smaller number of countries, but these are some major countries, so a manufacturer must be aware of them.

COMMERCIAL IMMUNITY TESTS

Commercial immunity testing typically covers the following types of tests:

1. ELECTROSTATIC DISCHARGE (ESD)

There are two types of ESD tests – contact discharge and air discharge. In the contact discharge test the tip of the ESD simulator is placed on the test point of the EUT and the discharge is initiated. The discharge occurs inside the simulator and these tests are fairly repeatable. In the air discharge test the simulator is charged to the specified voltage and brought into contact with the EUT. The discharge, if it occurs, happens before contact is made jumping the air gap between the tip of the simulator and the EUT. How large this gap is depends of the atmospheric pressure, temperature, angle of approach, and relative humidity. It can also depend on how fast the operator approaches the EUT with the ESD gun Air discharge testing is not as repeatable, but it simulates a different ESD event. Both types of tests are typically required. For computer equipment CISPR 24 requires a contact discharge test at 4 kV and air discharge tests up to 8 kV. Tests are typically performed using the equipment and procedures called out in IEC 61000-4-2. The EUT is allowed to react to the test, but it must self-recover after the test. A classic example is a computer playing music over a speaker. You hear a POP! in the speaker when the ESD event occurs, but the music keeps playing afterwards. This is considered a pass. If the music stopped and required operator intervention to re-start, that would be considered a failure.

2. RADIATED ELECTRIC FIELD IMMUNITY

This tests the immunity of the EUT to nearby radio transmitters. The frequency range of 80 MHz to 1 GHz is typically tested, although newer standards have tests required as high as 6 GHz. This test is performed in a fully anechoic chamber or a SAC with removable absorbers placed on the floor. Signal levels are used that would annoy the neighbors and cause the local regulators to issue fines, so a shielded environment is a necessity. The current requirements in IEC 61000-4-3 (a commonly used basic standard) call for the E-field to be uniform to within certain requirements before the EUT is brought into the test volume. Four sides of the EUT are typically evaluated. The EUT typically must continue to operate through the test as though nothing was happening to it or must self-recover with no loss of data to be considered a pass.

3. ELECTRICAL FAST TRANSIENTS

This test introduces a series of rapid pulses into the EUT through the power and any signal lines that could exceed 3 meters in length. Like ESD testing, the EUT must operate after the test without operator intervention, but may react to the test as it occurs, so long as the system self-recovers with no loss of data. IEC 61000-4-4 calls out the test equipment and procedures for this test.

4. ELECTRIC SURGE

This test simulates what happens on the power input to the EUT when there is a nearby lightning strike. High energy surges are applied to the EUT line input. IEC 61000-4-5 details the test equipment and procedures for performing surge testing.

5. CONDUCTED RF

In commercial standards the breakpoint between conducted RF and radiated RF immunity testing is typically 80 MHz. Generating uniform fields much below 80 MHz is difficult. As a result, below that frequency RF energy is typically injected onto cables connected to the EUT. An example of a block diagram for such a test is shown in *Figure 5*. The 6 dB attenuator is placed as close to the Coupling Decoupling Network (CDN) as possible. While this isn't clearly shown in IEC 61000-4-6, the reason for placing it as close to the CDN as possible is that it provides a matching impedance to the transmission line, maximizing power transfer to the CDN, whose input impedance is not precisely known. Otherwise, you may be throwing away half the power you paid to generate.

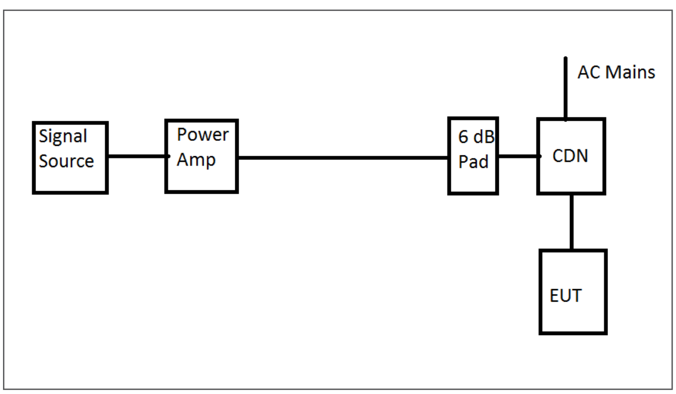


Figure 5 – Typical test setup for the conducted immunity test.

The typical frequency range for conducted RF immunity testing of commercial equipment is 150 kHz to 80 MHz.

6. POWER FREQUENCY MAGNETIC FIELDS

This test is run for products which might reasonably be expected to have immunity problems with power frequency magnetic fields. Such products, as called out in CISPR 24 for example, might include Cathode Ray Tube (CRT) displays, magnetic field sensors and Hall devices. The EUT is placed in the middle of a large coil of wire through which a power frequency current flows. The current level to generate the specified field level (for example, 1 Amp/meter in CISPR 24) is run through the coil and the EUT is checked for proper operation. All three axes are tested. Most products do not require this test, but it is included in the product family standards. IEC 62000-4-8 details how to perform this test.

7. DIPS AND DROPOUTS

This test is designed to simulate real world examples of momentary input power voltage fluctuations. In the case of CISPR 24 (and CISPR 35) there are three tests that are performed, typically by a computerized power source. The first is a >95% voltage reduction for one half cycle of the incoming power. The voltage change occurs at the zero crossover point on the power waveform. This simply means that one half cycle of the incoming power to the EUT is chopped off. The EUT is allowed to react, but must self-recover without operator intervention. The second test is a 30% reduction (70% residual voltage) for one half second (25 cycles at 50 Hz or 30 cycles at 60 Hz) - a short brown-out. Again, the EUT may react, but must self-recover. The third commonly used test is a >95% reduction in input voltage for 5 seconds. It's like the power cord was pulled out of the wall socket for 5 seconds and then plugged back in. Obviously, unless the EUT has a built in battery or UPS, it will crash. As long as function can be restored by the operator in accordance with the instructions and no data protected by battery back-up is lost or damaged, the EUT passes this test. IEC 61000-4-11 provides the details on how these tests are to be run.

The test levels utilized in commercial immunity tests are designed to provide a reasonable level of certainty that the product will operate in its intended environment. They do not represent the worst case that a product might experience in the field, but they have been shown over the years to be adequate. Indeed, most products exhibit higher levels of immunity that required when tested to their breaking point and the design features used to meet the emissions requirements typically are adequate for providing this level of immunity.

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-464C Electromagnetic Environmental Effects Requirements for Systems, 01 Dec 2010. (MIL-STD-464D to be released in 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

MIL-STD-1541A Electromagnetic Compatibility Requirements for Space Systems,Cancelled 27 April 2017.

WIRELESS / 5G / IOT

WIRELESS & IoT EMC SUPPLIERS MATRIX

INTRODUCTION

There are two main categories of equipment in this handy supplier guide: EMI troubleshooting & measurement equipment and direction finding equipment.

EMI troubleshooting and measurement equipment includes spectrum analyzers, near field probes, current probes, antennas, and other pre-compliance equipment.

Direction finding (or DFing) equipment usually includes specialized portable, mobile, or base station spectrum analyzers with custom antennas and mapping software especially designed for locating interfering sources.

Wireless & IoT EMC Supplier Matrix		Type of Equipment								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Mobile DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Spectrum Analyzers / Receivers
360Compliance	www.360compliance.co/								X	
Aaronia AG	www.aaronia.com	X	X		X	X		X	X	X
Alaris Antennas	www.alarisantennas.com		X							
Anritsu Company	www.anritsu.com		X							X
Avalon Test Equipment Corp	www.avalontest.com	X	X	X		X	X		X	X
CommsAudit	www.commsaudit.com/products/direction-finding		X		X	X				X
Doppler Systems	www.dopsys.com		X		X	X		X		
The EMC Shop	www.theemcshop.com	X	X	X			X		X	X
Gauss Instruments	www.gauss-instruments.com/en/									X
Intertek	www.intertek.com								X	
Kent Electronics	www.wa5vjb.com		X							

Wireless & IoT EMC Supplier Matrix		Type of Equipment								
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Current Probes	Fixed DF Systems	Mobile DF Systems	Near Field Probes	Portable DF Systems	Pre-Compliance Test	Spectrum Analyzers / Receivers
Keysight Technologies	www.keysight.com/us/en/home.html						X		X	X
Morcom International	www.morcom.com/direction_finding_systems.html							X		X
MPB srl	www.gruppompb.uk.com		X	X					X	X
MVG, Inc	www.mvg-world.com/en		X				X		X	
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X						X	X
Pearson Electronics	www.pearsonelectronics.com			X						
RDF Antennas	www.rdfantennas.com/bc-121-5.php							X		
RDF Products	www.rdfproducts.com				X	X				X
Rhotheta America	www.rhotheta.com/				X	X		X		
Rigol Technologies	www.rigolna.com			X			X		X	X
R&K Company Limited	www.rk-microwave.com	X								
Rohde & Schwarz USA, Inc.	www.rohde-schwarz.com/us/	X	X	X	X	X	X	X	X	X
Siglent Technologies	wwwsignlentamerica.com						X			X
Signal Hound	www.signalhound.com			X						X
SPX/TCI	www.spx.com/en/our-businesses/detection-and-measurement/TCI/		X		X	X		X		X
SteppIR Communication Systems	www.steppir.com		X							
TechComm	www.techcommdf.com		X		X	X		X		X
Tektronix	www.tek.com					X	X	X	X	X
Teseq	www.teseq.com/en/index.php	X		X					X	
Thurlby Thandar (AIM-TTi)	www.aimtti.us								X	X
TMD Technologies	www.tmd.co.uk	X								
UST	www.unmannedsystemstechnology.com/company/marshall-radio-telemetry/							X		X

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

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.

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.

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.

ETSI - EUROPEAN TELECOMMUNICATIONS STANDARDS INSTITUTE

http://www.etsi.org

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

NAB - NATIONAL ASSOCIATION OF BROADCASTERS

http://nab.org

The National Association of Broadcasters 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.

SATELLITE INDUSTRY ASSOCIATION

http://www.sia.org

The Satellite Industry Association (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

http://www.tiaonline.org

The Telecommunications Industry Association (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.

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 GROUPS & ORGANIZATIONS

WIMAX FORUM

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 our membership and certifying products.

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
(GROUPS, WEBSITES, BOOKS, FORMULAS & TABLES)

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 WIRELESS REFERENCES
(GROUPS, WEBSITES, BOOKS, FORMULAS & TABLES)

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

USEFUL WIRELESS REFERENCES
(LINKS & WHITEPAPERS)

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

VIDEO / Handheld Interference Hunting for Network Operators (Rohde & Schwarz):
https://www.rohde-schwarz.com/us/solutions/wireless-communications/gsm_gprs_edge_evo_vamos/webinars-videos/video-handheld-interference-hunting_229255.html

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

THE VITAL ROLE OF SIMULATION FOR VIRTUAL EMI AND EMC TEST ENVIRONMENTS

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THE VIRTUAL ROLE OF SIMULATION FOR VIRTUAL EMI AND EMC TEST ENVIRONMENTS

Before deploying microwave and millimeter-wave devices and systems within 5G, the Internet of Things (IoT), and high-speed wireless communication, it is essential to predict their performance. This need has increased the demand for virtual test platforms through simulation software.

High carrier and system bus frequencies are necessary for high-data-rate communication between multiple devices present in such systems. However, increased operational frequencies may induce undesirable and troublesome electromagnetic compatibility (EMC) and electromagnetic interference (EMI) issues, especially when communication is congested. Moreover, the impact from other physics is no longer negligible in mmWave devices. Multiphysics phenomena, such as structural deformation caused by heat expansion, need to be a part of the design consideration as well. Fortunately, a wide range of EMC and EMI scenarios can be virtually emulated and tested without having to elaborately adapt test configurations to real-world environments.

Using electromagnetics simulation software for evaluating device functionality reduces time and costs during the development and production cycle. Virtual evaluations can be performed prior to fabrication, test, and manufacture, and are an important component in reliable quality control processes.

The goal of simulation is to describe the real world as closely as possible on the computer by using proven physics equations. Ideally, the numerical model is used to mimic multiple physical phenomena representing a great variety of operational conditions, which is hard to realize in a lab environment. Accurately analyzing real-world designs and conditions comes at a cost. The more complex the analysis, the more computational resources are needed. Therefore, engineering judgment is used for excluding unnecessary parts from the analysis and for configuring the simulation settings to ensure efficient computations.

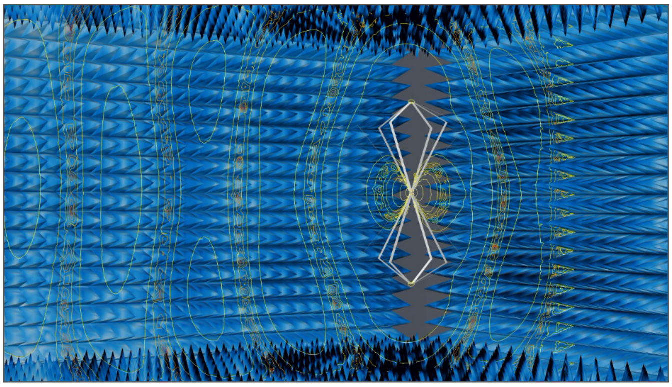


Figure 1: Contour plot of the logarithmic field distribution of a biconical antenna in a fully anechoic chamber.

When evaluating EMI and EMC performance of radiating devices, test engineers often perform measurements in a fully anechoic chamber. Simulation tools are used to set up a numerical environment that can reproduce such tests virtually (*Figure 1*) by using, for example, the finite element method (FEM). For instance, the pyramidal absorbers that are attached to the anechoic chamber walls contain lossy conductive carbon particles. The absorbers attenuate the incident electromagnetic waves gradually with only small amounts of unwanted reflections. For efficiency, instead of modeling the full-sized wall of absorbers, the simulation uses only a single pyramidal unit cell with periodic boundary conditions (*Figure 2*). This is an efficient way of estimating the performance of the complete set of absorbers to make sure the reflectivity is at a minimum. Even if the model consists of just a single unit cell, the periodic boundary conditions make it equivalent to an infinite array of pyramidal absorbers. The effective homogeneous material properties obtained from the unit cell simulation are then used for the entire anechoic chamber wall.

To validate the virtual version of the anechoic chamber, a wideband biconical antenna is placed inside the anechoic chamber. The performance of the antenna (for example, far-field radiation patterns and S-parameters) is computed to validate that there is no degradation of performance due to the incomplete absorber characterization.

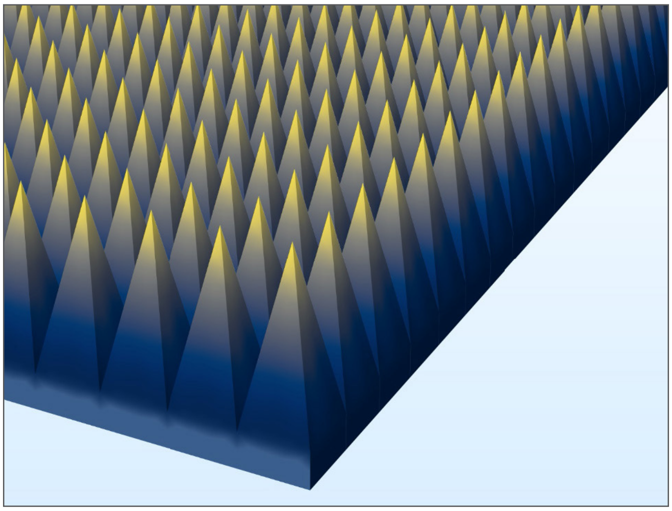


Figure 2: Microwave absorber simulation using Floquet periodic boundary conditions.

Although the real-world representation of the antenna inside the fully anechoic chamber in the simulation is visually quite appealing, as shown in *Figure 1*, its computational cost is unnecessarily high. The simulation can be made much faster and more efficient in terms of memory usage by using a numerical technique that is equivalent to the anechoic chamber walls. Such techniques involve using perfectly matched layer (PML) and absorbing boundary condition features. To efficiently study the near and far fields and other antenna parameters, it is sufficient to place the same biconical antenna in a much smaller surrounding air domain enclosed by a perfectly matched layer (*Figure 3*).

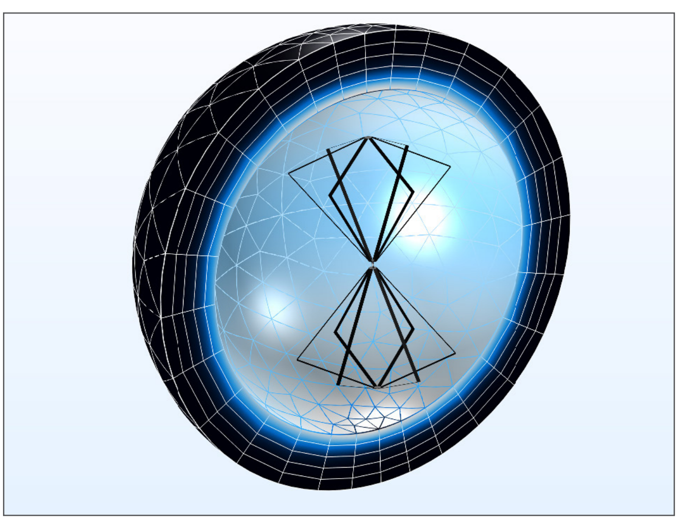


Figure 3: Biconical antenna enclosed by a PML. The PML at the front is removed from view to show the interior.

In order to simulate a large system efficiently, it is crucial to choose proper numerical boundary conditions. In addition, eliminating design details that are deemed to have negligible impact on the results, and just keeping the relevant components, can make further efficiency gains. By using PMLs, a large system can be simulated and not limited to just device-level modeling.

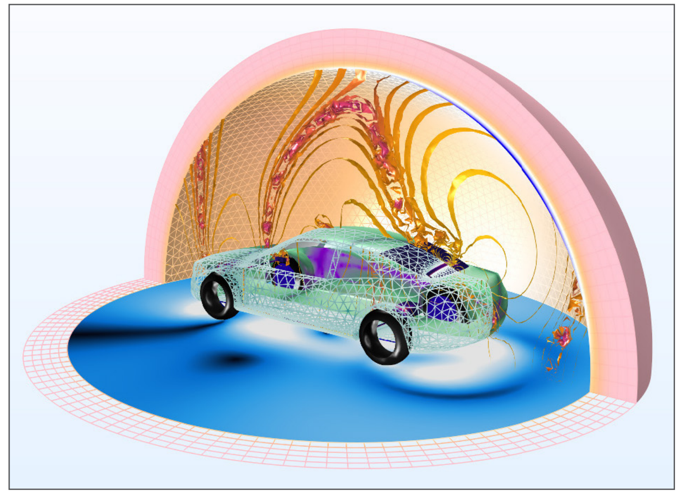


Figure 4: Impact on cable harness by the radiation from the rear windshield in the FM radio frequency band.

In *Figure 4*, the electric field transmitted from a fictitious radiating device on the rear windshield of a car is studied to see the radiated emission effect over the cable harness inside. The PML covers the upper half-space, absorbs all outgoing waves, and ensures that reflected waves do not bounce back onto the car. Meanwhile, the bottom ground and the car body generate reflection and multipath fading effects on the cable harness. The electromagnetic waves coupled to the cable are a source for unwanted conducted emission as well. In a real car system, it would be hard to access and relocate the source and victims for the EMI/EMC test. However, by using simulation, it is possible to analyze arbitrary configurations. In this way, by not being limited by physical testing, engineers can produce more robust system designs.

By using simulation, one can estimate the actual performance of devices for IoT applications when they are deployed in a real environment. IoT devices may be placed in a living room, a garage, or other spaces in a house. The electrical size of the problem in terms of the number of spanned wavelengths can easily exceed what can be addressed by so-called full-wave numerical methods. Full-wave methods include the finite element method (FEM), the finite difference time domain (FDTD) method, and the method of moments (MoM). There are alternative computational electromagnetics approaches available for approximating the performance of IoT devices without sacrificing too much accuracy. In addition, such approximate methods can produce useful results while still using limited computational resources. One such approach is the method of ray tracing. *Figure 5* shows multiscale simulation capabilities when ray tracing is employed together with FEM. The part of the simulation that uses FEM analyzes a small simulation domain surrounding the antenna of a wireless router that includes a truncated surrounding air domain. Rays are launched from the antenna location, and their initial strength is proportional to the directional intensity of the 3D far-field radiation pattern of the antenna. The antenna coverage inside a media room (*Figure 5*) can be approximated quickly without long simulation times or excessive memory usage. This multiscale electromagnetics modeling technique is a great alternative for overcoming the limitations of traditional computation methods for large EMI and EMC problems.

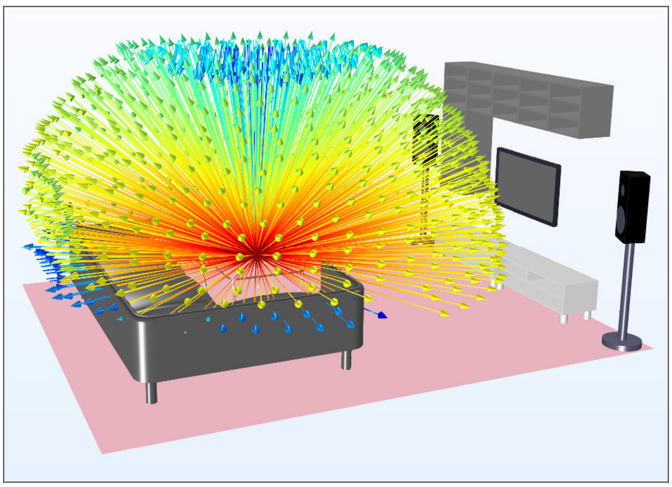


Figure 5: Multiscale electromagnetics simulation example. It combines the conventional finite element method for antenna analysis and ray tracing for describing indoor communication.

Simply combining existing computational methods can overcome the limitations of traditional numerical analysis. Two such situations are when you need to produce wideband results with high-frequency resolution, or when you need to analyze signal integrity and time-domain reflectometry (TDR) for a large device. Such simulations can be very time consuming. However, in both cases, the computational performance can be greatly boosted by conducting a fast Fourier transform (FFT), either from the time domain to the frequency domain or the other way around. For example, you can first perform a transient analysis and then run a time-to-frequency FFT to achieve a wideband S-parameter and far-field calculation in the frequency domain. Alternatively, you can first perform a frequency sweep and then run a frequency-to-time FFT for a time-domain bandpass impulse response. This is useful for time-domain reflectometry analysis, such as identifying a defective part of a transmission line, which results in impedance mismatch and signal quality degradation.

Simulation provides virtual analysis platforms for a wide range of test scenarios. However, learning how to use electromagnetics simulation software may not be the best use of time for everyone in an organization. Limited training and access to simulation software may restrict usage of electromagnetics simulation tools to a small set of expert users. Completed numerical EMI and EMC test models may frequently need new input parameters in order to adjust to a real-world test environment's variations. The need for updating boundary conditions, mesh, and postprocessing settings outside of the simulation group can cause unexpected delays in the development cycle. The good news is that simulation software has evolved to accommodate specialists who are not dedicated simulation engineers. The simulation models can be converted to easy-to-use apps (*Figure 6*). An app has a straightforward, specialized user interface (UI) and can be shared with colleagues and customers through existing web browsers or as a standalone executable file. Such standalone apps do not require purchasing extra software licenses and can run regardless of the operating system. A large number of people involved in EMI test projects can easily access the virtual test kit provided by an app and optimize the product without learning how to use the software behind the curtain.

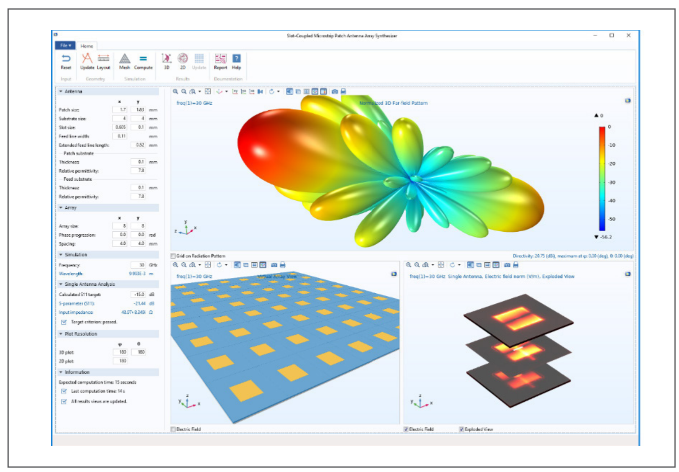
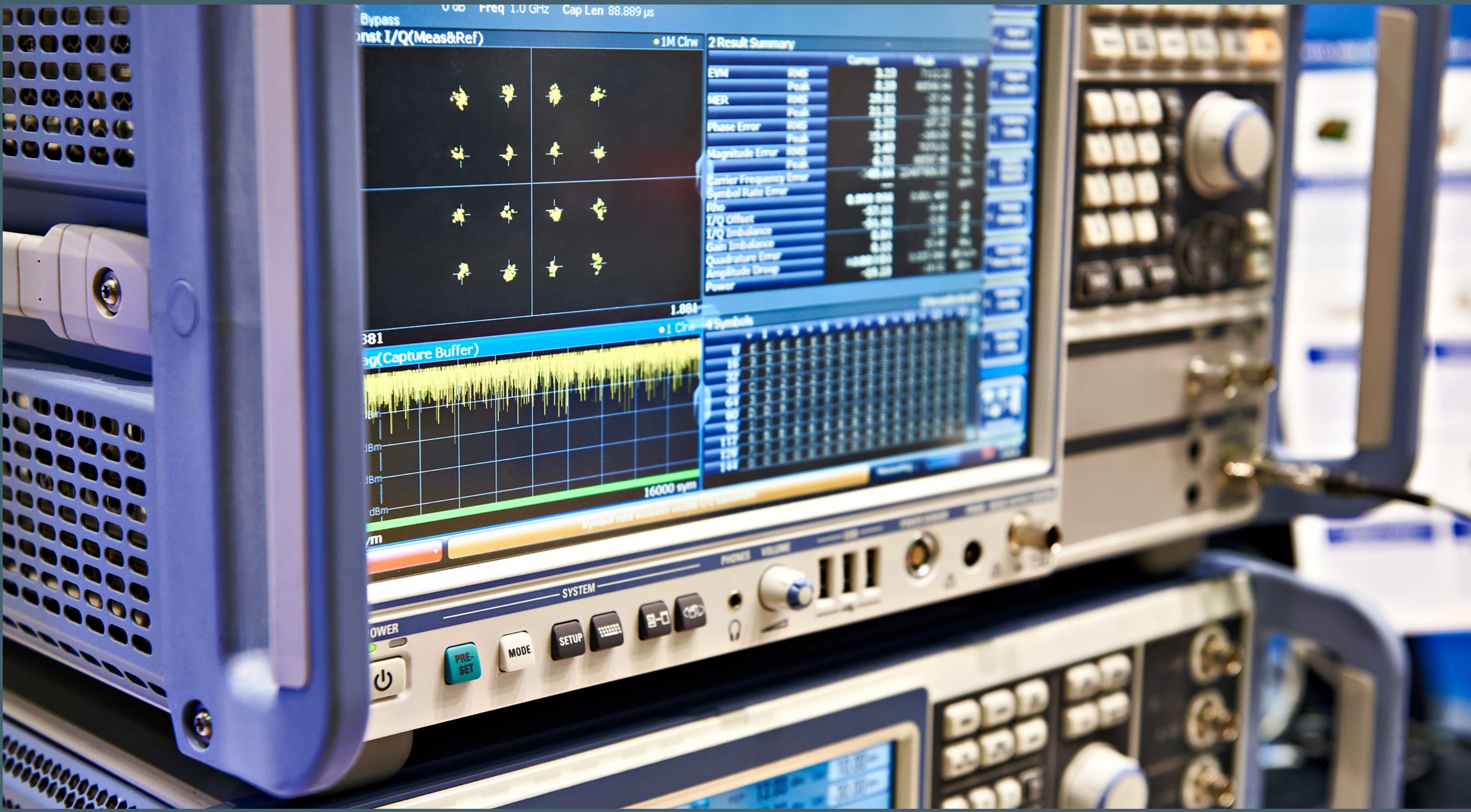


Figure 6: Simulation app for quickly estimating the far-field pattern of a phased array antenna using a full-wave single antenna simulation and array factor.

The variety of simulation tools that support multiple numerical methods within electromagnetics helps engineers and researchers not only to design conventional devices, such as filters, couplers, antennas, and waveguide structures, but also to test EMI and EMC problems in applications for 5G, IoT, and wireless communication. Conventional electromagnetics analyses can be extended to include multiple physical effects using multiphysics simulation. The simulation software industry is also evolving to meet the demands of the fast-paced market for emerging high-speed communication technologies and help more people benefit from simulation.

EMI, SI & PI


Freq 1.0 GHz
Cap Len 88.889 µs
1M Clrw
2 Result Summary
EVM
MER
Phase Error
Magnitude Error
16000 sym
SYSTEM
PRE-SET
MODE
SETUP

STOP USING THE CRITICAL LENGTH RULE IN HIGH SPEED PCB DESIGN

Zachariah Peterson
Owner, Northwest Engineering Solutions LLC

The PCB world is in flux and an inrush of new designers is appearing on the horizon. Unfortunately, marketing material from manufacturers and CAD companies continues to spread outdated design guidelines that are easily misapplied, or they are simply wrong. One of these design rules that appears to be endemic is the critical length rule for transmission lines. This rule is used by high-speed design novices and it is often taken out of context.

The critical length rule basically states the following:

- If the length of a transmission line between a source and load is 25% of the distance a signal would travel during its entire rise time, then the transmission line can have any impedance.

This rule is only correct in very specific situations, something which I will illustrate mathematically later in this article. The other problem with this rule is that the 25% limit is arbitrary. I have seen guides on the internet cite factors of 1/2, 1/3, 1/4, 1/5, 1/6, 1/8, 1/10, 1/12, and 1/20. If a signal integrity design guideline prescribes 9 different constraint values, then that guideline should be followed.

HOW TO DERIVE A CRITICAL LENGTH FOR A TRANSMISSION LINE

The critical length is used to define an upper limit on transmission line length. Most commonly, these various critical length rules are used as excuses to not calculate impedance for a bus that has an impedance specification. There is another version of this rule that I'd refer to as the 2x propagation delay rule, which is just a restatement of the critical length rule with a 1/2 factor. In either case, these factors are arbitrary; an interconnect designer that uses these rules is just guessing.

While I believe high-speed interconnect designers should never use the critical length rule for impedance controlled buses, it is possible to accurately calculate this. Determining a correct value for a critical length requires calculating the input impedance for the transmission line in question at the channel's bandwidth limit. To do this requires a few inputs for our proposed transmission line:

- Some channel bandwidth limit
- An acceptable deviation from the channel's target impedance
- The transmission line impedance as it is placed in a PCB

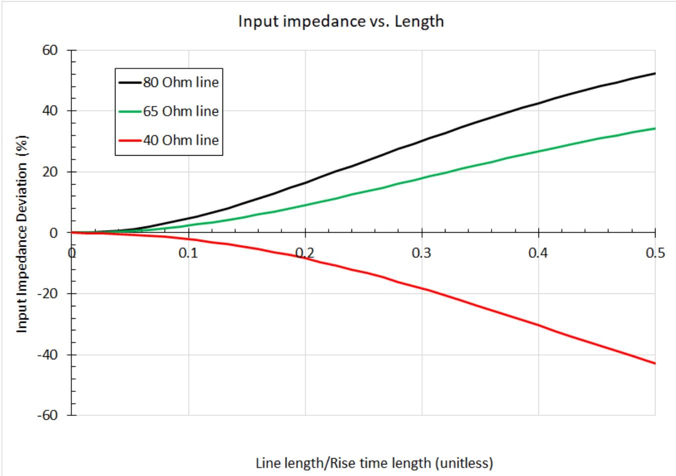
The input impedance you calculate using these inputs should be compared with the acceptable deviation from the channel's target impedance. As we will see in the next example, the deviation between the input impedance and the target impedance will be a function of line length and the transmission line's characteristic impedance. It is this comparison that is used to determine a critical length.

EXAMPLE CALCULATION

Let's look at an example. Suppose we are designing a stripline to operate in a 50 Ohm channel, and we can accept an impedance deviation of no more than ±20%. If we can assign a channel bandwidth limit, then we can calculate the line's input impedance at the bandwidth limit.

The example below shows results for a stripline embedded in a Dk = 4 medium with Df = 0.02. The characteristic impedance of the line was varied around the target impedance to determine the input impedance. For the moment we ignore copper losses and roughness (skin effect resistance).

The value on the x-axis is the line length divided by the rise time length (i.e., the length of time the signal travels during 10%-90% transition). In this example, we've assumed a signal rise time of 2.5 ns being driven into an RC terminated load.



Input impedance deviation vs. line length for an RC terminated channel being driven with a trapezoidal signal at 2.5 ns rise time.

The critical length is found by drawing an intersection with the ±20% impedance deviation point for each curve. As we can see quite clearly, larger impedance deviations between the transmission line's characteristic impedance and the target impedance allow for longer critical lengths.

Line Characteristic Impedance	Critical Length
40	31% rise time length
65	32% rise time length
80	23% rise time length

Transmission line critical length values assuming a 20% impedance tolerance, 2.5 ns signal, RC terminated load.

If we extend the bandwidth requirement but keep the rise time constant, the critical length will decrease. This would account for any other digital input with additional parasitics, such as package/lead inductance.

In the above results, I have used the 3dB bandwidth limit for resistively terminated capacitive load to calculate the bandwidth. However, it should be noted that there will be signals that have no explicit relation between bandwidth and rise time. For example, in PAM-modulated signals, the bandwidth requirement is set by the receiver's Nyquist frequency. With FM/QAM or other modulated RF signals carrying digital data, there is no rise time at all, so the input impedance must be used in all cases.

SUMMARY OF RESULTS

In conclusion, the above results illustrate 6 important conclusions about transmission line critical length rules in high-speed design:

- The critical length can be longer when the allowed impedance deviation is larger
- The critical length is shorter when the channel bandwidth is larger
- A critical length value depends on the following factors:
  - The line's characteristic impedance
  - The line's propagation constant (including losses)
  - The channel's acceptable deviation from target impedance
  - The channel's required bandwidth

Note that any critical length you calculate for an impedance-controlled interface *has no explicit dependence on the rise time of the signal*.

Finally, because the analysis above works with single-ended interfaces, it is important to note that the analysis also works with differential interfaces. This works because the single-ended impedance of the line in a differential pair is just the line's odd-mode impedance, and there will be a slightly modified propagation constant. The calculation process shown above will not change.

WHEN CAN A CRITICAL LENGTH BE USED?

There is only a single practical situation in which the critical length rule can be used: in push-pull buses with fast rise time but no impedance specification. The most common example is SPI; the GPIOs on some ASICs and processors also exhibit this behavior. The I/O buffers on these parts also do not have fixed impedance.

In this case, you are basically using a critical length value as an estimate of when the bus needs to be slowed down with a series resistor, rather than attempting to hit some impedance specification. This is because single-ended push-pull buses like SPI and typical GPIOs do not have any impedance specification. In this case, slowing down the bus provides two functions:

- Reduces radiation on from I/Os
- Reduces intensity of reflections/ringing

The reduction in speed is helpful both for EMI and SI in moderate-speed single-ended buses. Adding series resistors is a simple option for SI and EMI that can also be modified without changing the design. If it is found that the series resistors are not needed, then they can be swapped in the assembly with 0 Ohm resistors and no other changes would be needed on the design.

WHAT IS THE CHANNEL BANDWIDTH IN THESE CALCULATIONS?

It is typical for someone to start using the classic -3 dB RC circuit bandwidth approach to qualify the channel bandwidth in terms of a rise time. In reality, this is not the correct bandwidth, including in terminated channels with a specific impedance requirement.

Deriving a relationship between the bandwidth and the rise time is much more complex than simply approximating an I/O as a charging/discharging RC circuit. This is another instance where the RC discharge approach is only appropriate in the simplest cases where the input can be approximated as a load capacitance within the channel's bandwidth. In real systems, determining the bandwidth for use in a critical length calculation requires solving a complex transcendental equation, and that will be a topic left for a future article.

CONCLUSION

What is ironic is the fact that novice designers will use the critical length rule as an excuse to avoid calculating impedance, and yet correct use of the rule requires calculating at least 3 impedances. In addition, rise time also plays no role in determining a critical length. The fact that people can quantify the critical length in terms of a fraction of the rise time is a mere coincidence. The example above proves this.

In conclusion, I've taken to telling new designers and the purported experts in marketing departments to stop quoting this rule as gospel. The rule as described is only practically valid in very limited cases of fast push-pull interfaces with no impedance specification. A much easier approach is to just calculate and design to your interface's target impedance, even in the case where your digital links would be considered "electrically short."

KNEE FREQUENCY IS A MISLEADING BANDWIDTH METRIC

Zachariah Peterson
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INTRODUCTION

There is a transmission line critical length rule that is often used in high-speed PCB design by novice engineers. This rule should not be used and is not appropriate for high-speed PCBs.

The bandwidth limit of a digital signal or a high-speed digital channel is often used in certain calculations to get estimates of channel behavior. For example, the knee frequency is often used to understand how small impedance discontinuities might affect signal propagation, or it may be used to understand maximum expected dielectric or conductor losses. It is important to understand the bandwidth your channel needs in relation to signal bandwidth.

Unfortunately, the knee frequency is a misleading metric that is often misinterpreted. It is most often incorrectly cited as the limit of a digital signal's bandwidth. This is not exactly correct, and it only becomes correct in an ideal situation that is not observed in reality.

WHAT IS THE KNEE FREQUENCY?

In high-speed digital design, the knee frequency is sometimes used to calculate signal integrity metrics. The -3 dB for a high-speed channel is often cited as the following formula:

$$f = \frac{0.35}{t_{rise}}$$

where the t(rise) term in the denominator is a 10%-90% rise time for the signal.

Many guidelines will cite the knee frequency with a coefficient of 0.5 instead of 0.35. Regardless of the coefficient or name, the knee frequency/-3 dB frequency will then be cited as the upper limit of a digital signal's bandwidth as a function of the input signal's 10%-90% rise time. This is incorrect. In fact, the knee frequency tells you a channel's response to a perfect square wave. The input square wave has a rise time of 0; the rise time cited above is the edge rate of the signal ***as one would measure at the receiver***. Furthermore, it ignores loss in the channel and pin/package inductance.

The above formula can be derived in the Laplace domain by looking at the response of an RC circuit to a perfect square wave input. Real high-speed channels and component packages do not behave like this. The RC model listed above is only an approximation of real behavior. For practical purposes, the only instance where the RC model applies is in infinitely short single-ended push-pull buses where pin/package inductance is negligible because this approximates to a simple RC circuit.

Instead, we first have to notice three points about digital signals and high-speed channels:

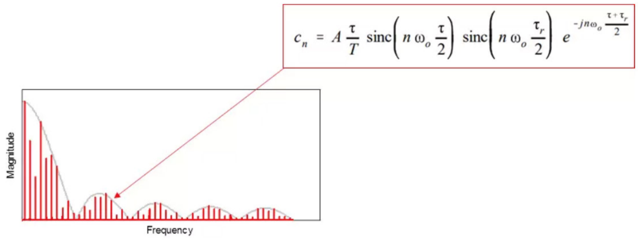
1. Most high-speed channels are modeled as being terminated at some target impedance
2. There is a load capacitance, and package parasitics, that affect the rise time seen at the receiver
3. The losses in the channel limit the bandwidth, regardless of how the channel is terminated

The result of these three points is that the edge rate seen at the receiver is not the same as the edge rate of the signal injected into the transmission line by the driver. So which one defines the bandwidth of a digital signal? The answer is: neither of these!

FACT #1: DIGITAL SIGNALS HAVE INFINITE BANDWIDTH

Probably the most often quoted point about digital signals is that they have finite bandwidth, and the bandwidth limit is the knee frequency. This is incorrect. All digital signals have infinite bandwidth, and this can be derived by calculating the Fourier series of a trapezoidal signal, Gaussian/error function edge rate signal, or Lorentzian edge rate signal. No matter how you approximate the signal's edge rate, you will find that the bandwidth is infinite.

While I won't belabor the derivation of a digital signal's bandwidth in this article, I'll instead show the important result with which digital designers and EMC experts should be familiar. If you approximate a digital signal as a trapezoidal wave, you will find that the amplitude envelope on the wave's harmonics is a sinc function. This is how we get the well-known graph such as that shown below.



The amplitude envelope for the harmonics of a digital signal follow a sinc function.

If a real digital signal with an imperfect edge has infinite bandwidth, does the channel also need to have infinite bandwidth? The answer is a definite "no" as I'll outline below.

FACT #2: HIGH-SPEED CHANNELS DO NOT NEED INFINITE BANDWIDTH

Although digital signals do not have a bandwidth limit, real interconnects do have bandwidth limits. The bandwidth of a channel is limited by the following factors:

- Frequency-dependent Insertion loss in the channel (dielectric, conductor)
- Return loss from vias, land pads, connectors, cable interfaces, etc.
- The termination at the receiver, which may be an LC circuit model
- Noise in the channel

As long as you design a channel to provide the minimum amount of bandwidth, then the channel should work properly for a given noise limit. The trick is determining that exact limit, which requires knowing the requirements for your receiver to determine a logic state from a received signal.

Finally, in systems where channel bandwidth calculations are very important, the required channel bandwidth generally may have no explicit relation to rise time. Today, this comprises the majority of computing and networking interfaces. For example, in bitstreams that use pulse-amplitude modulation (PAM), the required channel bandwidth is based on the receiver's sample rate and is calculated using the Nyquist theorem. For a modulated signal transmitting a data rate D with N signal levels per signal would require a minimum channel bandwidth of:

$$B = \frac{D}{2 \log_2 N}$$

While it is true that data rate generally correlates with signal rise time, there is no explicit relationship or requirement; different transmitters could source signals with different edge rates and the channel will still work. For example, if we look at a 112G PAM-4 bitstream with a 25% UI rise time, we would find that the minimum channel bandwidth is 40 GHz. The receiver only requires a channel bandwidth of 28 GHz, so we find that using the signal rise time to determine a design constraint sets an unrealistic design target for our high-speed channel.

CONCLUSION

In conclusion, the knee frequency formula has very limited applicability and is no longer a valid metric for describing bandwidth requirements in real high-speed channels. At best, it is an approximation for single-ended channels with a known rise time requirement at the receiver.

This is because losses and the termination create a very complex bandwidth vs. rise time relation. When we look at differential channels, which comprise most high-speed interconnects, the model leading from a component landing pad to the on-die termination circuit can be an LC circuit, depending on the package design.

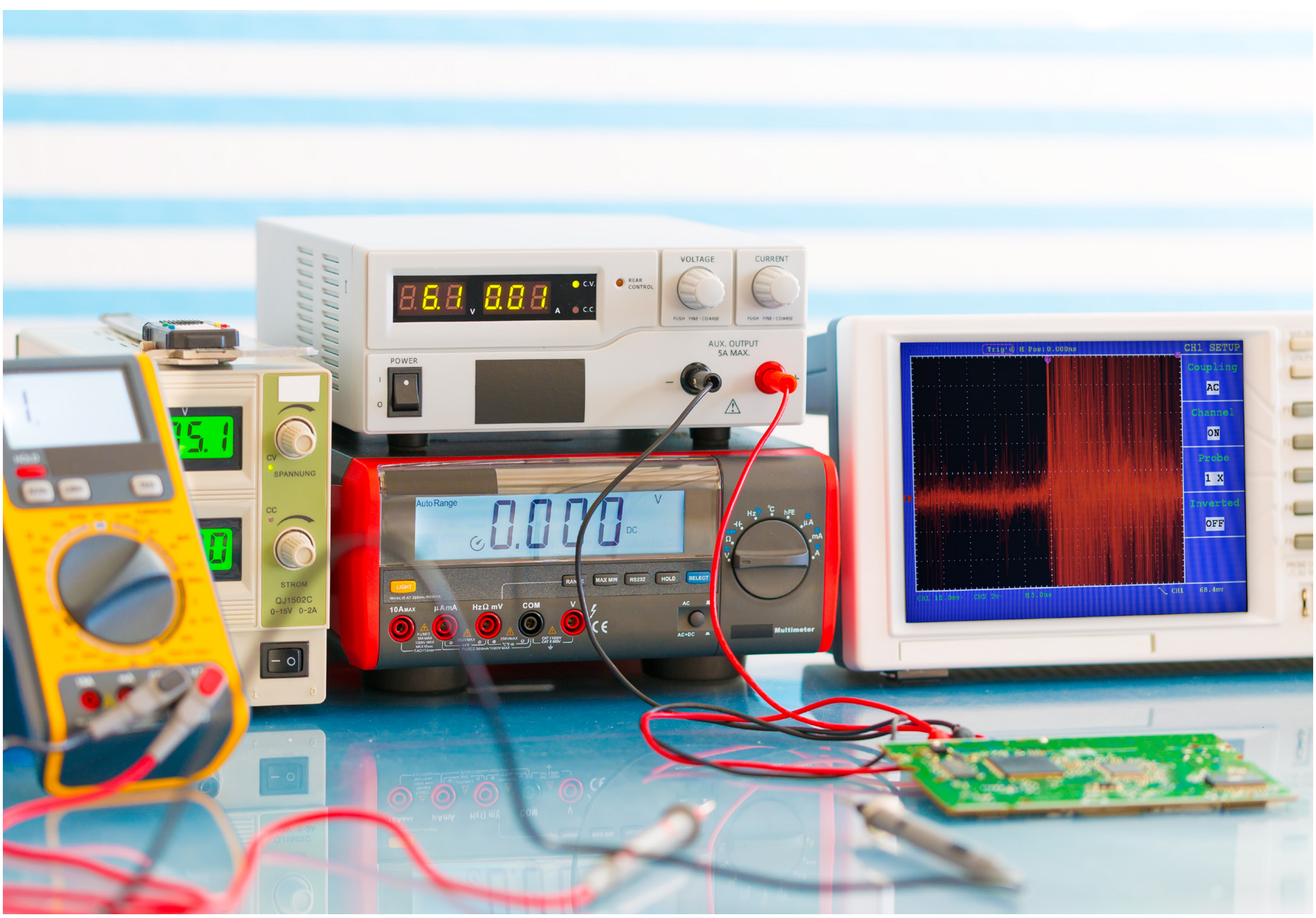
If you wanted to calculate the response of a real transmission line to an arbitrary input signal, you would need to determine a transfer function for the channel and use the channel's impulse response function. If you determine the signal at the receive end of an interconnect must operate faster than some rise time limit, you could then relate this to the channel's bandwidth limit. Unfortunately, signal integrity is much more complex and requires taking a broadband approach, not just looking at the channel's bandwidth limit.

MILITARY & AEROSPACE EMC

EMC EQUIPMENT MANUFACTURERS

Introduction

The following chart is a quick reference guide of test equipment and includes everything you'll need from the bare minimum required for key evaluation testing, probing, and troubleshooting, to setting up a full in-house precompliance or full compliance test lab for military and aerospace testing. The list includes amplifiers, antennas, current probes, ESD simulators, LISNs, near field probes, RF signal generators, spectrum analyzers, EMI receivers, and TEM cells. Equipment rental companies are also listed. The products listed can help you evaluate radiated and conducted emissions, radiated and conducted immunity and a host of other immunity tests, such as the new ESD test for MIL-STD-461G.



EMC Equipment Manufacturers		Type of Product/Service															
Manufacturer	Contact Information - URL	Amplifiers	Antennas	Conducted Immunity	Current Probes	EMC Filters	EMC Testing	ESD Simulators	LISNs	Near Field Probes	Pre-Compliance Test	Radiated Immunity	Rental Companies	RF Signal Generators	Software	Spectrum Analyzers/EMI Receivers	TEM Cells
A.H. Systems	www.ahsystems.com	X	X		X						X						
Aaronia AG	www.aaronia.com	X	X								X					X	
Advanced Test Equipment Rentals	www.atecorp.com	X	X	X	X			X	X	X	X	X	X	X		X	X
ALTAIR	www.altair.com														X		
Amplifier Research (AR)	www.amplifiers.com	X	X	X					X		X	X		X		X	
Anritsu	www.anritsu.com										X			X		X	
Electro Rent	www.electrorent.com	X		X				X	X		X	X	X	X		X	
EM Test	www.emtest.com/home.php			X							X						X
EMC Partner	www.emc-partner.com			X				X									
Empower RF Systems	www.empowerrf.com	X										X					
Fischer Custom Communications	www.fischercc.com				X				X	X	X						
Gauss Instruments	www.gauss-instruments.com/en/															X	
Haefley-Hippotronics	www.haefely-hipotronics.com			X				X									
HV Technologies, Inc.	www.hvtechnologies.com	X		X								X		X		X	
Instrument Rental Labs	www.testequip.com	X		X				X	X		X	X	X	X		X	
Instruments For Industry (IFI)	www.ifi.com	X		X								X					
ITG Electronics	www.itg-electronics.com					X											
Keysight Technologies	www.keysight.com/us/en/home.html								X	X	X			X	X	X	
Microlease	www.microlease.com/us/home	X		X				X	X		X	X	X	X		X	
Milmega	www.milmega.co.uk	X		X								X					
Narda/PMM	www.narda-sts.it/narda/default_en.asp	X	X	X					X		X	X				X	
Noiseken	www.noiseken.com			X				X			X						
Ophir RF	www.ophirrf.com	X		X													
Pearson Electronics	www.pearsonelectronics.com				X												
PPM Test	www.ppmtest.com		X								X	X			X	X	
R&B Laboratory	www.rblaboratory.com						X										
Rigol Technologies	www.rigolna.com				X					X	X			X	X	X	
Rohde & Schwarz	www.rohde-schwarz.com/us/home_48230.html	X	X	X	X				X	X	X	X		X	X	X	
Siglent Technologies	www.siglentamerica.com									X	X			X	X	X	
Signal Hound	www.signalhound.com									X	X			X	X	X	
Solar Electronics	www.solar-emc.com	X			X		X	X		X							
TekBox Technologies	www.tekbox.net	X							X	X	X				X		X
Tektronix	www.tek.com									X	X				X	X	
Teseq	www.teseq.com/en/index.php	X		X	X			X			X	X					X
Test Equity	www.testequity.com/leasing/	X		X				X	X		X	X	X	X		X	
Thermo Keytek	www.thermofisher.com/us/en/home.html			X				X									
Thurlby Thandar (AIM-TTi)	www.aimtti.us										X			X		X	
Toyotech (Toyo)	www.toyotechus.com/emc-electromagnetic-compatibility/	X	X						X		X	X				X	
TPI	www.rf-consultant.com										X			X			
Transient Specialists	www.transientspecialists.com			X								X					X
TRSRenTelCo	www.trs-rentelco.com/SubCategory/EMC_Test_Equipment.aspx	X	X	X					X		X	X	X	X		X	
Vectawave Technology	www.vectawave.com	X															
Windfreak Technologies	www.windfreaktech.com										X			X			

REFERENCES
(ARTICLE LINKS, DIRECTORIES, CONFERENCES, & LINKEDIN GROUPS)

LINKS TO LONGER ARTICLES

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SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

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INTRODUCTION

Military and aerospace EMC tests cover a wide range of products. While the standards, including limits and test methods may differ, all EMC test standards have a few things in common. The most basic are the limits for emissions and the types and levels of susceptibility testing.

Emissions tests (and their associated limits) are put in place for military and aerospace equipment primarily to protect other systems from interference. These other systems may or may not include radio equipment. Examples abound showing the effect of inadequate EMC design.

SUMMARY OF MILITARY AND AEROSPACE EMC TESTS

While many military and aerospace EMC issues may be addressed by operational changes, testing is still required to find weaknesses.

Military and aerospace EMC testing is performed at the system and subsystem levels. MIL-STD-464C provides requirements at the system or platform level. The latest version, MIL-STD-461G, provides requirements at the equipment or subsystem level. *Reference 1* provides details on both of the standards, but this article will highlight some key tests, particularly as they relate to MIL-STD-461G.

Ratio	Description
CE101	Conducted Emissions, Audio Frequency Currents, Power Leads
CE102	Conducted Emissions, Radio Frequency Potentials, Power Leads
CE106	Conducted Emissions, Antenna Port
CS101	Conducted Susceptibility, Power Leads
CS103	Conducted Susceptibility, Antenna Port, Intermodulation
CS104	Conducted Susceptibility, Antenna Port, Rejection of Undesired Signals
CS105	Conducted Susceptibility, Antenna Port, Cross-Modulation
CS109	Conducted Susceptibility, Structure Current
CS114	Conducted Susceptibility, Bulk Cable Injection
CS115	Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation
CS116	Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads
CS117	Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads
CS118	Conducted Susceptibility, Personnel Borne Electrostatic Discharge
RE101	Radiated Emissions, Magnetic Field
RE102	Radiated Emissions, Electric Field
RE103	Radiated Emissions, Antenna Spurious and Harmonic Outputs
RS101	Radiated Susceptibility, Magnetic Field
RS103	Radiated Susceptibility, Electric Field
RS105	Radiated Susceptibility, Transient Electromagnetic Field

Table 1: MIL-STD-461G Emission and susceptibility requirements

MIL-STD-461G divides test requirements into 4 basic types. Conducted Emissions (CE), Conducted Susceptibility (CS), Radiated Emissions (RE) and Radiated Susceptibility (RS). There are a number of tests in each category and the following table, taken from MIL-STD-461G Table IV, shows these test methods.

A brief description of each these tests will be provided below. These are summarized from a more detailed introduction to MIL-STD-461G, which is found in the *References 1, 2, and 3*. Keep in mind that a complete copy of MIL-STD-461G is 280 pages, so any information here is brief and the standard must be read and understood. A copy of MIL-STD-461G may be obtained free. See *Reference 4*.

CE101 Conducted Emissions, Audio Frequency Currents, Power Leads. CE101 is applicable from 30 Hz to 10 kHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. Emission levels are determined by measuring the current present on each power lead. There is different intent behind this test based on the usage of equipment and the military service involved. The specific limits are based on application, input voltage, frequency, power and current.

CE102 Conducted Emissions, Radio Frequency Potentials, Power Leads. CE102 is applicable from 10 kHz to 10 MHz for leads that obtain power from sources that are not part of the EUT. There is no requirement on output leads from power sources. The lower frequency portion is to ensure EUT does not corrupt the power quality (allowable voltage distortion) on platform power buses. Voltage distortion is the basis for power quality so CE102 limit is in terms of voltage. The emission levels are determined by measuring voltage present at the output port of the LISN. Unlike CE101, CE102 limits are based on voltage. The basic limit is relaxed for increasing source voltages, but independent of current. Failure to meet the CE102 limits can often be traced to switching regulators and their harmonics.

CE106 Conducted Emissions, Antenna Port. CE106 is applicable from as low as 10 kHz to as high as 40 GHz (depending on the operating frequency) for antenna terminals of transmitters, receivers, and amplifiers and is designed to protect receivers on and off the platform from being degraded by antenna radiation from the EUT. CE106 is not applicable for permanently mounted antennas.

CS101 Conducted Susceptibility, Power Leads. CS101 is applicable from 30 Hz to 150 kHz for equipment and subsystem AC and DC power input leads. For DC powered equipment, CS101 is required over the entire 30 Hz to 150 kHz range. For AC powered equipment, CS101 is only required from the second harmonic of the equipment power frequency (120 Hz for 60 Hz equipment) to 150 kHz. In general, CS101 is not required for AC powered equipment when the current draw is greater than 30 amps per phase. The exception is when the equipment operates at 150 kHz or less and has an operating sensitivity of 1 μV or better. The intent is to ensure that performance is not degraded from ripple voltages on power source waveforms.

CS103, CS104 and CS105 Conducted Susceptibility, Antenna Port, Intermodulation, Rejection of Undesired Signals and Cross-Modulation. This series of receiver front-end tests include test methods for Intermodulation (CS103), Rejection of Undesired Signals (CS104) and Cross Modulation (CS105). They were designed for traditional tunable super-heterodyne type radio receivers. Due to the wide diversity of radio frequency subsystem designs being developed, the applicability of this type of requirement and appropriate limits need to be determined for each procurement. Also, requirements need to be specified that are consistent with the signal processing characteristics of the subsystem and the particular test procedures to be used to verify the requirement.

CS109 Conducted Susceptibility, Structure Current. CS109 is a highly specialized test applicable from 60 Hz to 100 kHz for very sensitive Navy shipboard equipment (1 μV or better) such as tuned receivers operating over the frequency range of the test. Handheld equipment is exempt from CS109. The intent is to ensure that equipment does not respond to magnetic fields caused by currents flowing in platform structure. The limit is derived from operational problems due to current conducted on equipment cabinets and laboratory measurements of response characteristics of selected receivers.

CS114 Conducted Susceptibility, Bulk Cable Injection. CS114 is applicable from 10 kHz to 200 MHz for all electrical cables interfacing with the EUT enclosures.

CS115 Conducted Susceptibility, Bulk Cable Injection, Impulse Excitation. CS115 is applicable to all electrical cables interfacing with EUT enclosures. The primary concern is to protect equipment from fast rise and fall time transients that may be present due to platform switching operations and external transient environments such as lightning and electromagnetic pulse.

CS116 Conducted Susceptibility, Damped Sinusoidal Transients, Cables and Power Leads. CS116 is applicable to electrical cables interfacing with each EUT enclosure and also on each power lead. The concept is to simulate electrical current and voltage waveforms occurring in platforms from excitation of natural resonances with a control damped sine waveform.

CS117 Conducted Susceptibility, Lightning Induced Transients, Cables and Power Leads. CS117 is one of two new test methods added to MIL-STD-461G. CS117 is applicable to safety-critical equipment interfacing cables and also on each power lead. Applicability for surface ship equipment is limited to equipment located above deck or which includes interconnecting cables, which are routed above deck. The concept is to address the equipment-level indirect effects of lightning as outlined in MIL-STD-464 and it is not intended to address direct effects or nearby lightning strikes.

CS118 Conducted Susceptibility, Personnel Borne Electrostatic Discharge. CS118 is applicable to electrical, electronic, and electromechanical subsystems and equipment that have a man-machine interface. It should be noted that CS118 is not applicable to ordnance items. The concept is to simulate ESD caused by human contact and test points are chosen based on most likely human contact locations. Multiple test locations are based on points and surfaces which are easily accessible to operators during normal operations. Typical test points would be keyboard areas, switches, knobs, indicators, and connector shells as well as on each surface of the EUT.

RE101 Radiated Emissions, Magnetic Field. RE101 is applicable from 30 Hz to 100 kHz and is used to identify radiated emissions from equipment and subsystem enclosures, including electrical cable interfaces. RE101 is a specialized requirement, intended to control magnetic fields for applications where equipment is present in the installation, which is potentially sensitive to magnetic induction at lower frequencies.

RE102 Radiated Emissions, Electric Field. RE102 is applicable from 10 kHz to 18 GHz and is used to identify radiated emissions from the EUT and associated cables. It is intended to protect sensitive receivers from interference coupled through the antennas associated with the receiver.

RE103 Radiated Emissions, Antenna Spurious and Harmonic Outputs. RE103 may be used as an alternative for CE106 when testing transmitters with their intended antennas. CE106 should be used whenever possible. However, for systems using active antenna or when the antenna is not removable or the transmit power is too high, RE103 should be invoked. RE103 is applicable and essentially identical to CE106 for transmitters in the transmit mode in terms of frequency ranges and amplitude limits. The frequency range of test is based on the EUT operating frequency.

RS101 Radiated Susceptibility, Magnetic Field RS101 is a specialized test applicable from 30 Hz to 100 kHz for Army and Navy ground equipment having a minesweeping or mine detection capability, for Navy ships and submarines, that have an operating frequency of 100 kHz or less and an operating sensitivity of 1 μV or better (such as 0.5 μV), for Navy aircraft equipment installed on ASW capable aircraft, and external equipment on aircraft that are capable of being launched by electromagnetic launch systems. The requirement is not applicable for electromagnetic coupling via antennas. RS101 is intended to ensure that performance of equipment susceptible to low frequency magnetic fields is not degraded.

RS103 Radiated Susceptibility, Electric Field. RS103 is applicable from 2 MHz to 18 GHz in general, but the upper frequency can be as high as 40 GHz if specified by the procuring agency. It is applicable to both the EUT enclosures and EUT associated cabling. The primary concern is to ensure that equipment will operate without degradation in the presence of electromagnetic fields generated by antenna transmissions both onboard and external to the platform. The limits are platform dependent and are based on levels expected to be encountered during the service life of the equipment. It should be noted that RS103 may not necessarily be the worst case environment to which the equipment may be exposed.

RS105 Radiated Susceptibility, Transient Electromagnetic Field. RS105 is intended to demonstrate the ability of the EUT to withstand the fast rise time, free-field transient environment of EMP. RS105 applies for equipment enclosures which are directly exposed to the incident field outside of the platform structure or for equipment inside poorly shielded or unshielded platforms and the electrical interface cabling should be protected in shielded conduit.

Not all tests are required for each type of device or intended use environment. MIL-STD-461G provides a matrix in Table V showing how these tests are used based on the intended use of the device.

Equipment and Subsystems Installed In, On, or Launched From the Following Platforms or Installations	Type of Product/Service																		
	CE101	CE102	CE106	CS101	CS103	CS104	CS105	CS109	CS114	CS115	CS116	CS117	CS118	RE101	RE102	RE103	RS101	RS103	RS105
Surface Ships	A	A	L	A	S	L	S	L	A	S	A	L	S	A	A	L	L	A	L
Submarines	A	A	L	A	S	L	S	L	A	S	L	S	S	A	A	L	L	A	L
Aircraft, Army, Including Flight Line	A	A	L	A	S	S	S		A	A	A	L	A	A	A	L	A	A	L
Aircraft, Navy	L	A	L	A	S	S	S		A	A	A	L	A	L	A	L	L	A	L
Aircraft, Air Force		A	L	A	S	S	S		A	A	A	L	A		A	L		A	
Space Systems, Including Launch Vehicles		A	L	A	S	S	S		A	A	A	L	A		A	L		A	
Ground Army		A	L	A	S	S	S		A	A	A	S	A		A	L	L	A	
Ground Navy		A	L	A	S	S	S		A	A	A	S	A		A	L	L	A	L
Ground, Air Force		A	L	A	S	S	S		A	A	A		A		A	L		A	

A: Applicable (in green)
L: Limited as specified in the individual sections of this standard. (in yellow)
S: Procuring activity must specify in procurement documentation. (in red)
Table 2: MIL-STD-461G Requirement matrix

Again, the reader is referred to *References 1* through *3* for more details, or to MIL-STD-461G for the details of the standard (*Reference 4*). This guide also provides a list of standards that apply to various military equipment.

A popular and common aerospace EMC requirement required by the FAA for commercial aircraft is RTCA/DO-160, Environmental Conditions and Test Procedures for Airborne Equipment. The latest version is RTCA/DO-160 G, published on December 8, 2010, with Change 1 published on December 16, 2015. DO-160 covers far more than just EMC issues, but the EMC subjects covered include input power conducted emissions and susceptibility, transients, drop-outs and hold-up; voltage spikes to determine whether equipment can withstand the effects of voltage spikes arriving at the equipment on its power leads, either AC or DC; audio frequency conducted susceptibility to determine whether the equipment will accept frequency components of a magnitude normally expected when the equipment is installed in the A/C; induced signal susceptibility to determine whether the equipment interconnect circuit configuration will accept a level of induced voltages caused by the installation environment; RF emissions and susceptibility; lightning susceptibility; and electrostatic discharge susceptibility.

This document can be purchased from RTCA on their website (*Reference 5*). A manufacturer producing products subject to the requirements in RTCA/DO-160 should obtain a copy and ensure they have a complete understanding of the content of the document and that any laboratory testing to it is properly accredited.

Examples of differences in test equipment between commercial and military standards.

There are differences in test equipment used compared with commercial EMC tests. Some examples are provided below.

Where 50 µH LISNs are universally required for commercial EMC tests, there are specific cases for CE01 and CE02 tests where a 5 µH LISN is called out. Limits for CE101 tests are provided in dBµA. LISNs are only used for line impedance stabilization. The measurements are taken with current probes. Limits for CE102, on the other hand, are given in dBµV and measurements are taken in much the same way as for commercial standards with the receiver connected to the RF output port of one of the LISNs and the other RF output port(s) terminated in 50 Ohms. It should be noted that MIL-STD-461G calls out a 20 dB pad on the output of the LISN to protect the receiver from transients. This is not a requirement in the commercial standards, but is worth considering when setting up a laboratory for commercial testing, as well.

Military EMC standards, such as MIL-STD-461G will require the use of different antennas for radiated emissions testing. Commercial equipment standards, such as CISPR 32 and ANSI C63.4, require the use of linearly polarized antennas and do not contain requirements for magnetic field testing.

MIL-STD-461G, RE101, requires the use of a 13.3 cm loop sensor, not required in the commercial standards. A receiver capable of tuning from 30 Hz to 100 kHz is needed.

MIL-STD-461G, RE102, requires testing of radiated emissions to as low as 10 kHz. From 10 kHz to 30 MHz a 104 cm (41 inch) rod antenna is used. This frequency range is not covered in CISPR 32 or the FCC Rules for radiated emissions. Thus, the antenna and receiver requirements are different. From 30 MHz to 200 MHz a biconical antenna is used, also commonly used in commercial testing. From 200 MHz to 1 GHz a double ridge horn antenna is called out in 461G. This is different than the tuned dipole or log periodic dipole array antennas used for commercial testing.

The test procedures are also different for radiated emissions testing, requiring different laboratory set-ups and test facility types. No turntable is needed for MIL-STD-461G, nor is an antenna mast capable of moving the antenna over a range of heights.

MIL-STD-461G, RS103, can require significantly higher field intensities for radiated susceptibility testing. Where CISPR 35 requires 3 V/m from 80 MHz to 1 GHz and at a few discrete frequencies up to 5 GHz (with the option of testing a few discrete frequencies at up to 30 V/m), MIL-STD-461G requires testing from 20 V/m to as high as 200 V/m over the range of 2 MHz to 40 GHz for certain equipment. Additional test equipment (signal generators, amplifiers, antennas, etc.) is required over that needed for commercial testing.

Each test in MIL-STD-461G requires its own unique test equipment. Some may be usable for commercial testing, others may not. If testing to MIL-STD-461G, ensure that the equipment is proper for the tests being performed. A detailed understanding of the requirements in MIL-STD-461G is required to ensure that the proper equipment is being used and the laboratory is following the appropriate processes.

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