INTERFERENCE TECHNOLOGY®

2018 EUROPEAN EMC GUIDE

| ITALY EDITION |

AUTOMOTIVE
RESILIENCE IS KEY TO THE CONNECTED AND AUTONOMOUS REVOLUTION

MEASUREMENT
EMC RADIATED EMISSION MEASUREMENTS AT 1/3/5/10/30 METERS

DETERMINING SEMI-ANECHOIC CHAMBER RESONANCE AS A SOURCE OF RADIATED EMISSION MEASUREMENT VARIATION BETWEEN CHAMBERS AND COMPARING TO OATS MEASUREMENTS

DESIGN
EMC OF CONNECTORS

SIMULATION IN EMC

BASICS OF PASSIVE FILTERS FOR EMC COMPLIANCE

STANDARDS
WHAT IS THE DIFFERENCE BETWEEN CISPR 13/22 AND CISPR 32?

TEST
ESD AND DIGITAL ISOLATORS

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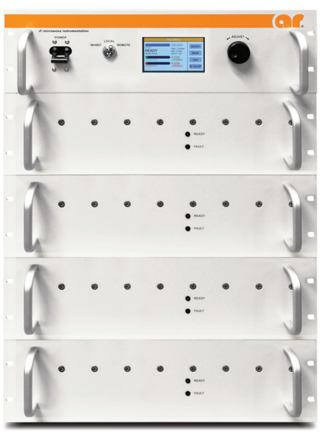

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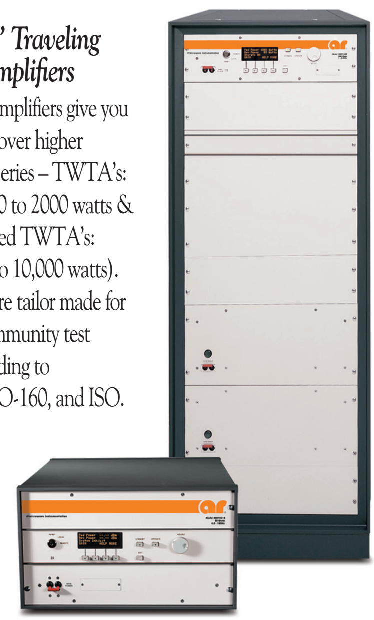

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EDITORIAL

Hi, I hope you enjoy this issue of the 2018 European EMC Guide! This year, we're distributing these as free digital downloads, reflecting Interference Technology's continuing direction to provide our readers with timely articles faster using modern digital platforms. This year's issue is the largest ever with eight technical articles. This time, we'll be keeping the content in English, but customizing some of the reference material into ten local countries or regions.

Inside, you'll find several articles discussing EMC measurement, test and design topics. Our lead article is by Anthony Martin, Chief EMC Engineer at Horiba MIRA, entitled "Resilience is Key to the Connected and Autonomous Revolution. Martin cautions all who are working in the EV and autonomous vehicle space that we need to look carefully at all aspects of safety, security, and risk analysis during the development of these new technologies. There will certainly be some ethical issues arise as fully autonomous vehicles become more widely used.

This issue also includes articles on a comparison of antenna measurement distances by Dan Hoolihan, measurement variation between EMI chambers by the author of the book, "Electromagnetic Compatibility" (reviewed in our blog section), Dan Weston, EMI aspects of cable connectors by Carsten Stange, EMC simulation by Peter Futter, designing products for ESD immunity by new author, Don MacArthur, reviewing the differences between CISPR 13/32 and CISPR 32 by Ghery Pettit, and wrapping up with using injection probes for troubleshooting radiated immunity, by new author, Aziz Yuldashev.

We've also included a recap of important standards news, a Products & Services directory for each major country or region, as well as a reference section listing seminars, trade shows, standards working groups, and major EMC standards.

Having just attended the annual Battery & Electric Vehicle Expo in Novi, Michigan this last September, I can tell you that there are "all hands on deck" when it comes to development of new battery and electric vehicle (EV) technologies. Every auto manufacturer and their venders are participating at a furious pace. China turns out to be leading the world in this technology and an estimated one third of the exhibiters were Chinese companies offering everything from materials, components, batteries, motors, and transmissions, to fully developed EVs. The Chinese are also at the forefront of EV standards development. The Chinese government recently joined Norway, France and England to announce mandates requiring a certain percentage of EVs and ultimately a conversion to 100% EVs, which should further boost development worldwide. Major EV development is also occurring in India, Europe, and North America.

The two biggest changes in the European standards landscape during 2017 was the new Radio Equipment Directive (RED) became mandatory for any product containing wireless connectivity. Following close on it's heels, the new 4th edition of IEC 60601-1-2 for medical products will become mandatory in 2018 and the U.S. FDA is already urging manufacturers to step up their game by following it early.

Radio Equipment Directive - The Radio Equipment Directive, 2014/53/EU, became mandatory for new and existing products June 12, 2017. You can refer to Charlie Blackham's article on the updates and what it means to manufacturers earlier this year. Because the RED now includes the requirements to meet the Low Voltage and EMC Directives, as well as providing a risk assessment due to EMI potential failures, it is going to cause many changes for manufacturers who think they can continue to comply with the LVD and/or EMC Directives. At the very least, it will require a rewrite of the Declarations of Conformity.

IEC 60601-1-2 - As mentioned, the update to IEC 60601-1-2 (Edition 4) for medical products was published February 2014 and becomes mandatory for all products December 31, 2018. The U.S. FDA has embraced the new edition and is urging manufacturers to incorporate it now for new products. The new edition will be a greater challenge for manufacturers, as they will now need to perform a detailed risk analysis, as well as quite a bit of additional documentation. There are also significant changes in immunity test levels. Author, Darryl Ray has contributed an article in the 2017 issue describing all the changes and it may be downloaded from the Digital Downloads tab on our web site.

News from Interference Technology - Be sure to check out the many prerecorded presentations from EMC Live 2017 and the streamed video recordings of selected presentations from the 2017 Symposium on EMC & SIPI. These web-based presentations include a number of interesting topics by top names in the industry.

Finally, I wanted to point out all the new FREE downloadable EMC guides we've produced this past year. If you scroll down our home page a bit, you'll see the list of guides. Some of the more popular ones include Military/Aerospace, Automotive, Wireless Interference, EMC Testing, and EMC Fundamentals. Check them out here: http://www.interferencetechnology.com.

A special project this year included our new EMC Desk Reference, which is available for sale as a 45-page printed desk reference edition. Buy your printed copy here: https://learn.interferencetechnology.com/emc-desk-reference/

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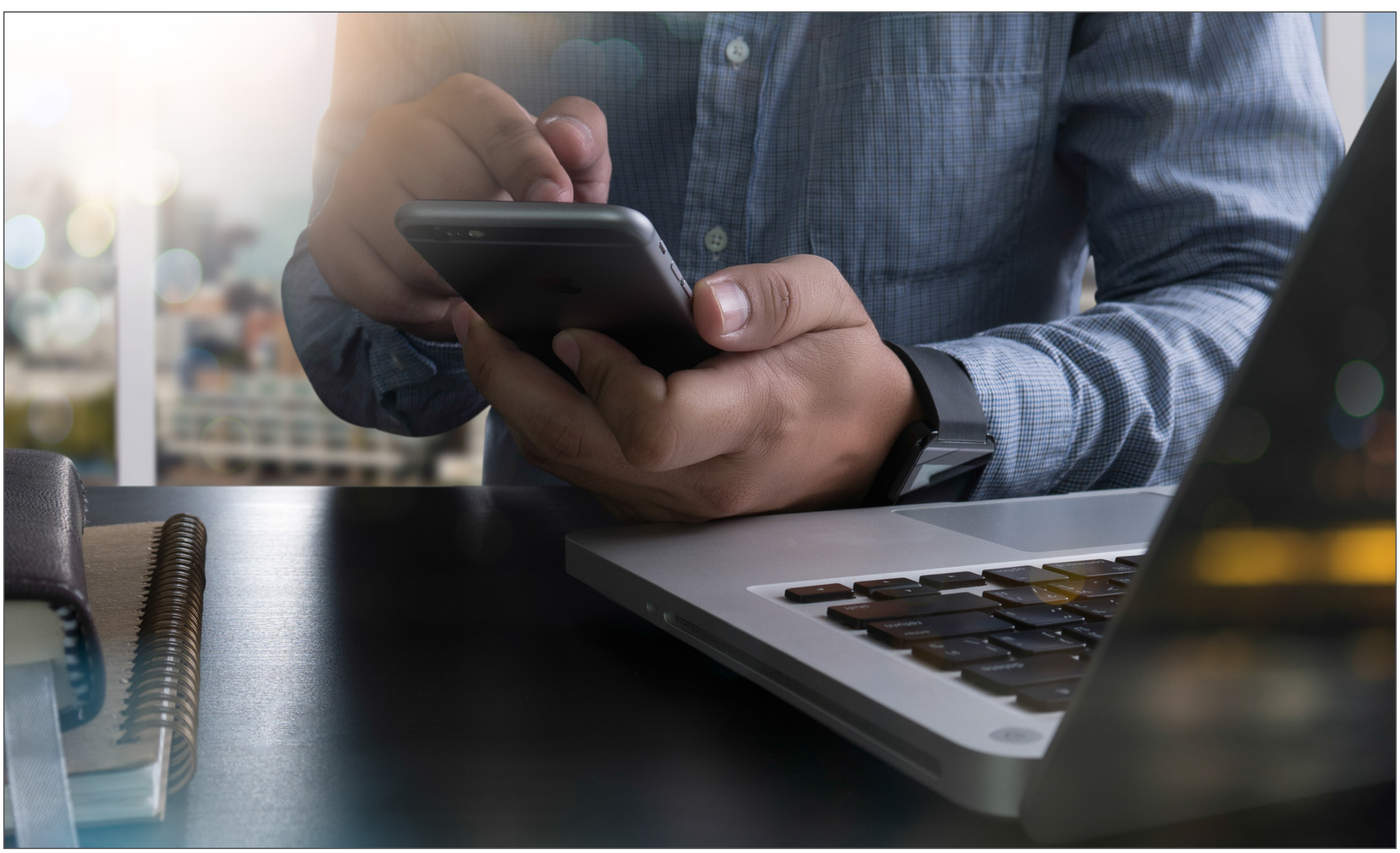

INTERNATIONAL STANDARDS UPDATE

EMC DIRECTIVE

COMPLYING WITH THE NEW EMC DIRECTIVE

Editor's Note: The following reply was received from Keith Armstrong, EMC consultant in the UK, to a news item regarding complying with the new EMC Directive.

Armstrong writes,

"I see lots of test labs publishing over-simplified guidance on complying with the new EMC Directive, including the one by [a test lab] in ITEM's latest Newsletter.

They need to read it properly, and also widen their scope to look at the changes that will occur when the RED replaces R&TTE.

However, even people who have reviewed the RED in articles in ITEM and other trade mags have also missed an important issue:

From 12 July 2017, if your product has an embedded radio function ({Bluetooth} module) it will have to declare its compliance to the essential requirements of the EMCD, LVD, and RED using only RED-listed harmonised standards!

Unless all the hundreds of current EMCD and LVD standards are quickly "dual-listed" in the OJEU under RED, this is going to cause huge problems.

Also there are new requirements for:

- *The Technical Documentation to include an adequate assessment of the risks of causing EMI or suffering from it;*
- *Every "economic operator" in the supply chain to bear / share the responsibility for EU compliance. (This could mean sharing confidential information with importers, distributors, etc.)*
- *Manufacturers name and address to be indelibly marked on the product (or that of his Authorised Rep.)*
- *The names and addresses of all importers and distributors in the supply chain to be marked on the product*
- *Perhaps the most important immediate change: the use of a specified format and wording in the DoC, and a single DoC covering all applicable Directives – effective from 20 April 2016. Products may well be being disallowed entry to the EU at this very moment simply because they don't use this specified DoC!"*

HAS THE EMC DIRECTIVE ACHIEVED WHAT IT SET OUT TO DO?

NewElectronics (UK) has written a white paper on the EMC Directive – its history, the new legislative framework and how it affected the Directive, how well it's being enforced, and market surveillance.

The EMC Directive is all about electrical interference – both emissions and immunity. As test house TUV puts it 'Do not disturb. Do not be disturbed'. When enacted in 1989, the Directive was regarded by many with horror and some degree of panic. Today, EMC is one of the constraints which designers deal with regularly and which results in better products.

The New Legislative Framework was a package of measures designed to improve market surveillance, boost the quality of conformity assessments, and clarify the use of CE Marking. As a result, the 2004 Directive will be replaced in April 2016 by Directive 2014/30/EU – and these changes are likely to have serious repercussions.

There were always concerns about how the EMC Directive would be policed and enforced. Being largely complaints driven, enforcement was expected to be self regulating, with competitors watching each other. "But this did not happen," observes Nick Wainwright, chief executive of York EMC Services. "Perhaps lack of confidence in their own efforts meant manufacturers kept their heads down."

As for market surveillance, for more than a decade, cross border EMC investigations have been undertaken by European authorities.

They have tackled a range of products known to be sources of EMC problems, including 'energy saving lamps', power tools, consumer entertainment systems, LED lighting products and solar panel inverters. In all cases, major shortfalls were found, both in terms of technical assessment (primarily emissions) and administration. Interestingly, the highest number of failures came from LED lighting.

To see more, click here.

WHAT'S NEW: IEC 61000-4-5 SECOND EDITION VS. THIRD EDITION

by Jeff Gray, Chief Technology Officer, Compliance West USA

Introduction

IEC 61000-4-5 is part of the IEC 61000 series, which describes surge immunity testing caused by over-voltages from switching and lightning transients. The second edition of IEC 61000-4-5 was released in 2005 and has been in use for many years. The third edition was released as an EN standard in 2014. The general philosophy of the third edition is unchanged from the second edition. However there have been a number of refinements to the standard: additional explanation to clear up ambiguities, new descriptions that were not included in the second edition, and new (informative) Annexes that can be used to help in the application of the standard. The purpose of this article is to outline the changes and additions that are now part of IEC 61000-4-5 3rd edition.

Critical Transition Dates

Transition from the second edition to the third edition is already taking place within the EU according to the following dates:

- 19 Mar. 2015 – Date of Publication (dop): The third edition has to be implemented by publication of an identical national standard by CENELEC member countries.
- 19 June 2017 – Date of Withdrawal (dow): National standards that conflict with the third edition must be withdrawn (i.e. the second edition can no longer be used).

To read the full article, *[*Read more...]
To learn more, click here.

EMC STANDARDS PACKAGE

This EMC Standards package includes standards that address the unintentional generation, propagation, and reception of electromagnetic energy, the associated unwanted effects, and the correct operation of different equipment involving electromagnetic phenomena in their operation.

In the package: 220+ active, draft, and archived IEEE and ANSI EMC related standards; robust search tools powered by the intuitive IEEE Xplore digital library; e-mail alerts and updates regarding new standards and draft; and IEEE Redline Versions of Standards.

RADIO EQUIPMENT DIRECTIVE (RED)

RADIO EQUIPMENT DIRECTIVE GUIDANCE

The new Radio Equipment Directive (RED), 2014/53/EU, now requires any product that includes wireless capability to switch from having to meet the EMC and Low Voltage Directives to just complying with RED, as the new RED includes both EMC and product safety requirements. Products will be required to meet RED starting June 13, 2017.

The European Commission has provided a guidance document helping manufacturers understand the new requirements. Both the new directive and guidance document may be accessed on the Commission website.

RADIO EQUIPMENT DIRECTIVE

When comparing these directives to the previous version you will find that many changes were made, particularly to the Radio Equipment Directive and its applicability to certain product families.

The RED Guide has been made available on 2017-05-19:
https://ec.europa.eu/docsroom/documents/23321/attachments/1/translations/en/renditions/native

The Commission has also developed a document containing 'Frequently Asked Questions':
https://ec.europa.eu/docsroom/documents/24921/attachments/1/translations/en/renditions/native

ARTICLES - GENERAL

HOW TO SELECT THE RIGHT EMC STANDARD FOR YOUR PRODUCT

Many companies developing products find it difficult to determine the appropriate EMC standard to comply with. The IEC (International Electrotechnical Commission) has developed a web page that explains EMC and offers a tabbed selection method for determining the right standard that applies to your product family.

You can then go to their web store and purchase downloadable standards applicable to your product.

For more information, click here.

BLUE GUIDE FOR EU PRODUCT RULES AVAILABLE

The European Union's (EU) "Blue Guide" describes general rules for placing electronic products on the market within the EU.

It describes how the EU regulates the free movement of goods, when the harmonization rules apply, the product supply chain and their obligations, product requirements, conformity assessment, and accreditation.

The document goes on to describe how market surveillance works and includes several informative annexes.

To download the guide, click here.

HOW THE IEC IS ORGANIZED FOR EMC

International EMC standards can be confusing to the newcomer. The IEC has posted a chart as to how the various standards organizations are organized.

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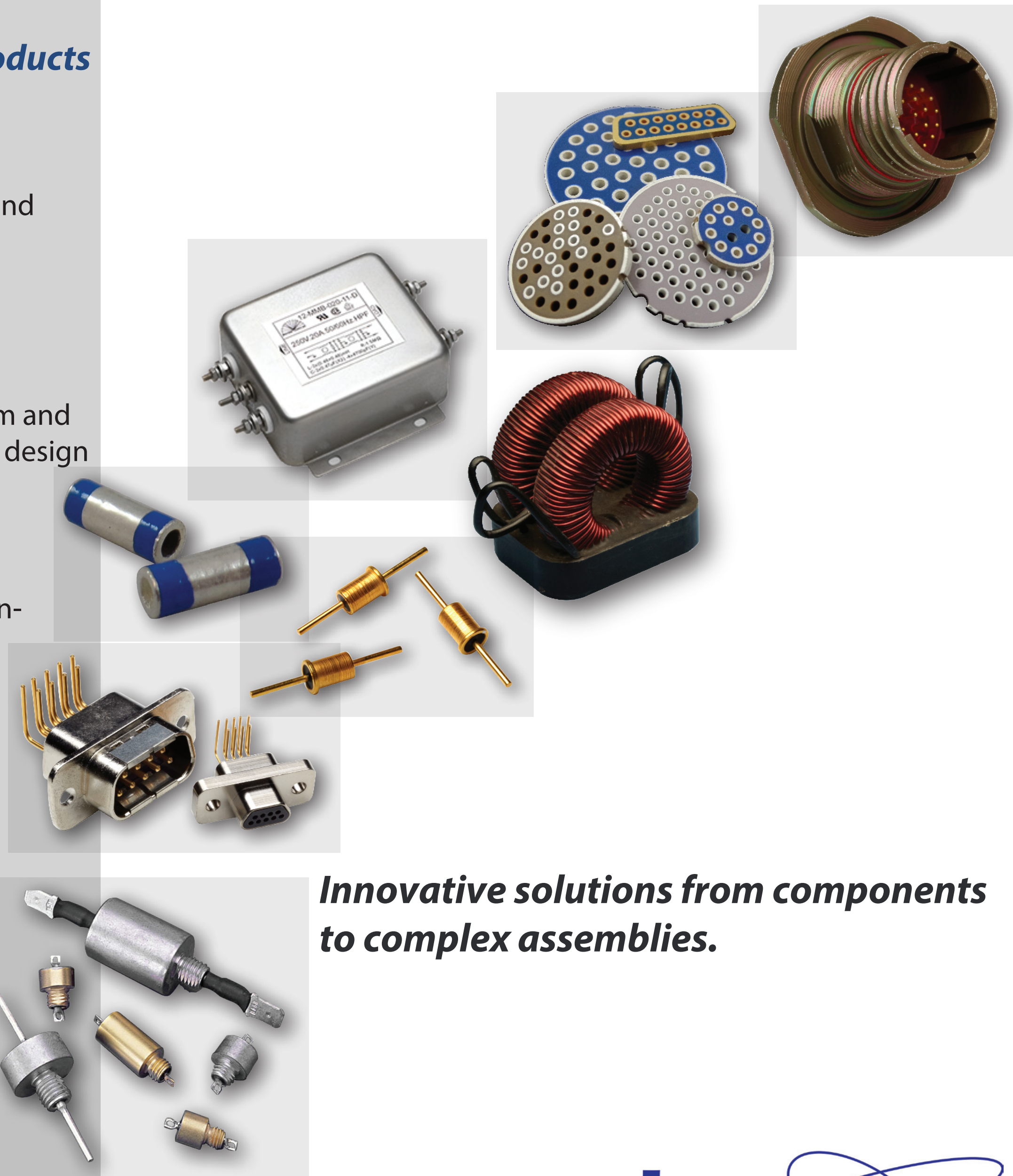
Coaxial Filters & Interconnects
Delivering a broad range of custom and off-the-shelf options to meet your design requirements

Magnetics
Broad range of custom, application-specific solutions

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

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



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The first level of organization is the committees, such as TC77, CISPR, and various product committees. These committees have liaisons with associated standards organizations, such as ISO, ITU, CENELEC, and many others. Many of these groups have working relationships with national, regional, and international organizations. In the U.S., for example, one of the primary standards organizations is ANSI.

For more information, click here.

ANSI C63.27:2017, AMERICAN NATIONAL STANDARD FOR EVALUATION OF WIRELESS COEXISTENCE

ANSI C63.27:2017, American National Standard for Evaluation of Wireless Coexistence has been released and it is a required compliance submission to the FDA. The standard has been published by the IEEE and has been approved by the American National Standards Institute on January 31, 2017. The standard provides a protocol based process and test methods to validate the ability of wireless devices to coexist with other wireless services that operate in the RF bands of a given wireless device. The standard specifies Key Performance Indicators (KPIs) that manufacturers can use to assess the coexistence ability of their radios. In addition, the standard has an outline of a required test plan and report contents, performance criteria, analysis & summary of test results, and analysis of uncertainties. Note that test laboratories may not have this standard adopted and manufacturers may need to make a special request from their test houses to test to this coexistence standard.

THE WEARABLE FUTURE

The IEC has released a blog article, The Wearable Future, that explains the trend of smart wearable devices, the potential market, and how they are monitoring the technology and applying appropriate EMC and safety standards.

Several new interesting wearable devices are described that were announced at the recent Consumer Electronics Show (CES) in Las Vegas last January.

Author of the blog post, Antoinette, reports, "The IEC will continue to monitor this rapidly expanding industry and develop International Standards for the electronics used in wearables, which cover terminology, dependability and safety. This will allow manufacturers of components to be aligned when it comes to the technology. Additionally, IEC Conformity Assessment Systems, based on IEC International Standards, provide independent testing and certification to ensure the safety, reliability and performance of products and the systems within which they work."

To read more of the blog post, click here.

AUTOMOTIVE

UPDATES FOR GM'S GMW3097 EMC TESTING

(October 11th, 2016) Elite Engineering reports that General Motors is now requiring suppliers of electronic modules and accessories to email a summary of EMC test results following each individual test as testing to GM's latest GMW 3097 (June 2015) standard progresses through various phases of testing.

CANADA

CANADIAN RSS-210 ISSUE 9 TRANSITION

Innovation, Science and Economic Development Canada (ISED) recently issued a public notice with details on the transition period from Issue 8 to Issue 9 of RSS-210 Licence-Exempt Radio Apparatus: Category I Equipment. Read here.

MEDICAL

ETSI RELEASES DRAFT STANDARD FOR LOW POWER MEDICAL IMPLANTS

(July 1, 2016) The present document together with ETSI EN 301 489-1 [1] covers the assessment of all radio transceivers associated with inductive Ultra Low Power Active Medical Implant (ULP-AMI) transmitters and receivers operating in the range from 9 kHz to 315 kHz and any associated external radio apparatus (ULP-AMI-Ps) transmitting in the frequency range of 9 kHz to 315 kHz including external programmers and patient related telecommunication devices in respect of ElectroMagnetic Compatibility (EMC). Non-radio parts of the above equipment may be covered by other directives and/or standards when applicable.

To download the draft, click here.

IEC 60601-1-9 – ENVIRONMENTALLY CONSCIENCE DESIGN FOR MEDICAL EQUIPMENT

The standard for environmentally conscious design, IEC 60601-1-9, was published in 2007 (amended in 2013) as a collateral standard to IEC 60601, the widely accepted series of international standards for the basic safety and essential performance of medical electrical equipment. Compliance with the IEC 60601 series is required by regulatory bodies responsible for electrical medical equipment in many countries.

The requirements of IEC 60601-1-9 are based on practical experience made by reputable medical manufacturers which showed that the application of the standard may result in cost savings and marketing benefits.

Clients continue to increase pressure on manufacturers to develop medical devices with an environmentally conscious design, as it is seen as an aspect of an overall good design practice.

For more, click here.

FDA FINALIZES GUIDANCE IN SUPPORTING CLAIMS OF EMC

The U.S. Food and Drug Administration (FDA) has issued final guidance in supporting claims of electromagnetic compatibility (EMC) of medical devices.

The document is recommended for use in conjunction with consensus standards, as well as other FDA guidance documents pertaining to specific devices.

Typically, the FDA reviews EMC information based on the risk of device malfunction and/or degradation if the device is exposed to electromagnetic interference by other devices near its intended electromagnetic environment. The proliferation of smartphones, wearables, home appliances, and other electronic devices poses a threat to safe performance of medical devices, and the FDA wants manufacturers to follow established standards and guidance documents to mitigate risks.

Manufacturers are recommended to follow device-specific guidance, such as one issued for Infusion Pumps Total Product Life Cycle, and cross-cutting guidances, such as Design Considerations for Devices Intended for Home Use.

In addition to following these FDA-recognized standards and guidance documents, and in order to support a claim of electromagnetic compatibility in premarket submissions, the FDA recommends in the final guidance that manufacturers include several items of information. The final guidance document applies to premarket approval (PMA) applications, humanitarian device exemption (HDE) applications, premarket notification [510(k)] submissions, investigational device exemption (IDE) applications, and de novo requests.

To learn more, click here.

MILITARY

MIL-STD-461G: THE "COMPLEAT" REVIEW

By *Ken Javor, EMC Compliance January 2016*

MIL-STD-461G was released on 11 December 2015 and will become contractually obligatory on programs initiated after that date.

This account is more than a simple laundry list arrived at by performing a side-by-side “F” vs. “G” comparison. Instead, it is an insider account into the issues with which the Tri-Service Working Group (TSWG) was grappling, and the thought processes behind the changes, as well as, of course, the changes themselves. It also lists some of the issues brought to the table that were not incorporated in MIL-STD-461G, and why.

It will greatly assist the reader if a copy of MIL-STD-461G is available as this account unfolds.

To read the full article, [Read more...]

WHY IS THERE AIR (IN MIL-STD-461G)?

By Ken Javor, EMC Compliance January 2016

As noted in Javor's MIL-STD-461G review, SAE Aerospace Information Report (AIR), AIR 6236, *In-House Verification of EMI Test Equipment* was written specifically to support MIL-STD-461G. Specifically, section 4.3.11 *Calibration of measuring equipment* has been reduced in scope to devices such as EMI receivers and spectrum analyzers, oscilloscopes and (RS103) electric field sensors. Section 4.3.11 now says, “After the initial calibration, passive devices such as measurement antennas, current probes, and LISNs, require no further formal calibration unless the device is repaired. The measurement system integrity check in the procedures is sufficient to determine acceptability of passive devices.” AIR 6236 was written to support the verification of proper operation of such devices in the EMI test facility using only test equipment commonly available in an EMI test facility. The idea behind the AIR was that if a measurement system integrity check was problematic, the AIR 6236 measurements would demonstrate whether or not there was a problem with a transducer. AIR 6236 was published in December 2015. Also, the procedures in the AIR can be used in-house to routinely self-check EMI test equipment, if desired.

This synopsis, by the AIR’s author, discusses what’s in it, and why, and includes a test procedure for one piece of equipment that was left out of the AIR.

The *Introduction* says that the AIR provides guidance on how to self-check the devices listed below, using equipment commonly found in EMI test facilities. The purpose is not to calibrate these devices, but to check that they have not varied significantly from manufacturer’s specifications.

To read the full article, [Read more...]

MIL-STD-464C REVISION PROCESS UNDERWAY

US DoD has begun the process to revise MIL-STD-464C. Industry comments are welcome, and should be funneled through the two industry reps to the DoD Tri-Service Working Group: ken.javor@emccompliance.com and briand.lessard@lmco.con.

Format for comment submission is very specific and must be adhered to rigorously. The comment should provide change from, change to, and rationale. A suitable form is available from ken.javor@emccompliance.com.

IN-HOUSE VERIFICATION OF EMI TEST EQUIPMENT

SAE International has made available the AIR6236A document. This AIR provides guidance to the EMI test facility on how to check performance of the following types of EMI test equipment: current probe, Line Impedance Stabilization Network (LISN), directional coupler, attenuator, cable loss, low noise preamplifier, rod antenna base, and passive antennas.

All performance checks can be performed without software. A computer may be required to generate an electronic or hard copy of data. This is not to say that custom software might not be helpful; just that the procedures documented herein specifically eschew the necessity of automated operation.

For more, click here.

ASSIST IS OFFICIAL ARCHIVE FOR MIL-STD DOCUMENTS

ASSIST is a web site used by standardization management to


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develop, coordinate, distribute, and manage defense and federal specifications and standards, military handbooks, commercial item descriptions, data item descriptions, and related technical documents prepared in accordance with the policies and procedures of the Defense Standardization Program (DSP).

Besides DoD-prepared documents, ASSIST also has selected international standardization agreements, such as NATO standards ratified by the United States and International Test Operating Procedures.

Since it always has the most current information, ASSIST is the official source for specifications and standards used by the Department of Defense.

Find all archived copies of MIL-STD-461, here.

UNITED KINGDOM (UK)

UK ELECTROMAGNETIC COMPATIBILITY REGULATIONS 2016

As the UK marches towards Brexit, it's important to track any recent EMC standards activity.

In this case, the UK Parliament quickly incorporated the latest EMC Directive (2014/30/EU), which became effective April 20, 2016. This Directive requires all electronic products to have a successful conformity assessment before being placed on the European market.

On December 8, 2016, it will become UK law as the Electromagnetic Compatibility Regulations 2016. These regulations transpose Directive 2014/30/EU of the European Parliament and repeals and replaces Directive 2004/108/EC relating to Electromagnetic Compatibility.

UK'S DECISION TO REGULATE INTERFERENCE FROM APPARATUS

In the UK, Ofcom has decided to issue new regulations for wireless telegraphy.

Wireless Telegraphy (Control of Interference from Apparatus) Regulations 2016 is intended to tackle undue interference from electrical and electronic apparatus.

In most cases, electrical and electronic apparatus are capable of emitting electromagnetic energy, but is minimal. However, in some cases the level of energy emitted from apparatus can cause undue interference to wireless communications.

"Ofcom has powers to take enforcement action in instances where some types of electrical or electronic apparatus causes undue interference to wireless communications (i.e. wireless telegraphy)." The regulations are intended to keep pace with technical developments and are expected to come into force on 18th April 2016.

UNITED STATES FCC

FCC EXTENDS TRANSITION PERIOD FOR LAB ACCREDITATION

(June 15, 2016) The Federal Communications Commission moved to provide testing laboratories with an additional year to meet an accreditation requirement under its equipment authorization rules. The Commission will also provide guidance on the process for recognition of accreditation bodies. The Commission took these actions through a Memorandum Opinion and Order and Order on Reconsideration in ET Docket 13-44.

To read more, click here.

FCC RELEASES UPDATED LED LIGHTING EMC GUIDANCE

(June 17, 2016) Effective June 17, 2016, all RF LED lighting devices, including those that have been considered to operate on frequencies below 1.705 MHz, are now required to have Radiated Emissions measurements performed at a minimum from 30 MHz to 1000 MHz.

Radio frequency (RF) light-emitting diode (LED) lighting products are subject to FCC rules to ensure that devices do not cause harmful interference to radio communications services. This KDB publication clarifies how the FCC rules apply to these products, and outlines manufacturers' responsibilities for controlling interference. This publication does not address older legacy lighting technologies such as incandescent, fluorescent, and high intensity discharge (HID) lighting products.

For more, click here.

STANDARDS ORGANIZATION ACTIVITIES & GUIDANCE

CISPR 35 PUBLISHED – MULTIMEDIA IMMUNITY

Blog post by Ghery Pettit. Now that CISPR 35 is finally published, the questions that you want answered are: What is the same as CISPR 24? What has changed? What is new? To read the full blog post, click here.

IEC REVISES COMMON TERMINOLOGY FOR INFORMATION SECURITY MANAGEMENT

All information held and processed by an organization is subject to the risks of attack, error and natural disaster, and other vulnerabilities inherent to its use. Information security is considered a valuable "asset" requiring appropriate protection, for example, against the loss of availability, confidentiality and integrity.

The recently revised ISO/IEC 27000:2016, Information technology – Security techniques – Information security management systems – Overview and vocabulary, gives a comprehensive view of information security management systems covered by the ISMS family of Standards, and defines related terms and definitions.

ISO/IEC 27000 gives a high-level overview of the ISMS family of Standards (ISO/IEC 27001), how they support the implementation of requirements contained in ISO/IEC 27001, Information technology – Security techniques – Information security management systems – Requirements, and how they relate to each other.

The Standard defines the key factors of a successful implementation and the numerous benefits of using the ISMS family of Standards. It provides an understanding of how the ISO/IEC 27001 family fits together through its multi-faceted approach, clarifying the Standards' scopes, roles, functions and relationship to each other. In addition, ISO/IEC 27000 gathers in one place all the essential terminology used in the ISO/IEC 27001 family.

Click here for more.

EMF DIRECTIVE – WORKPLACE HEALTH AND SAFETY IN ELECTROMAGNETIC FIELDS

As of July 1, 2016, all EU member states are required to have implemented Directive 2013/35/EU for the protection of persons from electromagnetic fields (EMF) in the workplace in national laws. As a consequence, companies throughout Europe must now ensure that their employees are not exposed to fields greater than the exposure limits, some of which have been newly defined. This requires monitoring and minimizing risk through preventive measures where necessary.

The underlying EMF Directive defines "Minimum health and safety requirements regarding the exposure of workers to the risks arising from the physical effects of electric, magnetic, and electromagnetic fields in the frequency range between 0 Hz and 300 GHz". Its limit values are primarily based on the recommendations of ICNIRP, the International Commission for Non-Ionizing Radiation Protection. They have been reworked in line with the latest scientific findings and refer exclusively to the proven direct short term effects on the human body.

The new feature of the EMF Directive is the requirement that employers must now assess the risk separately for each workplace. The responsibility of ensuring that the limit values for workers are not exceeded means that every risk has to be assessed first and then the actual exposure levels recorded in a way that complies with the Directive. The emission specifications of device manufacturers or computed values can be used for this, particularly in areas such as offices and laboratories where only low-current equipment is used. For certainty, measurement is now required everywhere else where a higher local EMF exposure level is suspected, such as in metal industry production plant, welding or smelting equipment.

This new set of rules stipulates that specialist personnel should record the field values at regular intervals and then document these in traceable form for this purpose.

For more, click here.

CISPR: INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

As its full name implies, CISPR's principal task is at the higher end of the frequency range, from 9 kHz upwards, preparing standards that offer protection of radio reception from interference sources such as electrical appliances of all types, the electricity supply system, industrial, scientific and electromedical RF, broadcasting receivers (sound and TV) and, increasingly, IT equipment (ITE)

SUBCOMMITTEES

As the scopes of the various subcommittees listed below indicate, CISPR's work involves equipment and methods for measuring interference, establishing limits and immunity requirements, and prescribing (in liaison with other IEC technical committees) methods of measuring immunity.

The committee also takes account of the impact of safety regulations on interference suppression of electrical equipment.

- CIS/A covers radio-interference measurements and statistical methods
- CIS/B handles interference relating to industrial, scientific and medical RF apparatus
- CIS/D deals with EM disturbances related to electric and electronic equipment on vehicles and devices powered by internal-combustion engines
- CIS/F covers interference relating to household appliances, tools, lighting and similar equipment
- CIS/H sets limits for the protection of radio services, and
- CIS/I, formed in 2001 from the former CIS/E and CIS/G, deals with EMC of information technology equipment (ITE), multimedia equipment and receivers.

In addition, CISPR has a steering committee known as SC S.

In some technical areas, there is the possibility of overlap in the standards adopted by CISPR and those of other IEC and ISO technical committees. Where this involves emission and immunity of devices other than receivers, CISPR considers the requirements jointly with the appropriate committee.

TECHNOLOGY CONVERGENCE

The convergence of certain newer technologies is making it difficult to decide whether some products should be designed to television or to computer EMC standards. This results in some manufacturers having to test their multimedia products to both, which is costly and time-consuming for industry.

CISPR SC I is working to produce new EMC standards, for example CISPR 35, for multimedia products. Meanwhile, the existing product standards (CISPR 13, 20, 22 and 24) will continue to be fully maintained for the foreseeable future.

A GUIDANCE FOR USERS OF THE CISPR STANDARDS

This guidance document is presented to you in order to guide you in the selection of appropriate CISPR EMC Standards applicable to your products, systems and installations. This document also gives an overview of the latest version of published CISPR Standards covering EMC aspects of products, systems and installations. This may be downloaded here.

CISPR PROVIDES STANDARDS FOR SMARTGRID

CISPR's (International Special Committee on Radio Interference) primary role is standardization in the field of control of emissions above 9 kHz from devices, and as such has published various standards that cover or can be applied to SmartGrid system emission measurements and control.

To ensure protection of the radio frequency spectrum, emissions must be addressed effectively if the SmartGrid is to achieve its potential and provide benefits when deployed without interference complaints. A significant additional requirement is that SmartGrid systems must be immune to sources of interference from a wide array of wanted RF signals and RF disturbances and other events which occur at SmartGrid component installations. Controlling emissions and ensuring an adequate level of immunity must both be taken on board.

CISPR has prepared a Guide to EMC in Smart Grid which gives further insight into issues which should be taken into consideration when designing and developing equipment for connection and inter-operation with the Smart Grid.

CISPR PROVIDES "GUIDE TO EMC IN SMART GRID"

CISPR has prepared a "Guide to EMC in Smart Grid", which gives insight into issues which should be taken into consideration when designing and developing equipment for connection and inter-operation with the Smart Grid.

SmartGrid systems must be immune to sources of interference from a wide array of wanted RF signals and RF disturbances and other events which occur at SmartGrid component installations. Among the issues that must be addressed is EMC, which is the ability to withstand the electromagnetic (EM) environment (have sufficient immunity) without causing interference (disturbances) primarily to radio reception, but also to other digital/electronic devices.

Electromagnetic disturbances of various types, from a variety of sources, have been reported and have caused performance degradation, outages, shutdowns and even large scale system failure to the power grid. EMC is thus an important factor for consideration in standards relating to the IEC SmartGrid program.

The SmartGrid needs to function properly and have full interoperability, with other electrical and electronic systems. To ensure this these systems and their components must be designed with due consideration for conducted electromagnetic emissions injected into the grid and for immunity to various electromagnetic phenomena originating from the grid. This needs to include devices that will be mounted on the outside of buildings and homes as well as in newly designed "SmartGrid enabled" appliances.

For more, and a copy of the grid, click here.

NEWLY RELEASED STANDARDS IN 2017

NEWLY RELEASED IEC STANDARDS (AS OF JULY 2017)

- **IEC 62232:2017, Ed. 2** – Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure
- **IEC 61851-21-1:2017, Ed. 1** – Electric vehicle conductive charging system – Part 21-1 Electric vehicle on-board charger EMC requirements for conductive connection to AC/DC supply
- **IEC 62153-4-6:2017, Ed. 2** – Metallic cables and other passive components test methods – Part 4-6: Electromagnetic compatibility (EMC) – Surface transfer impedance – Line injection method
- **IEC 61967-4:2002/COR1:2017, Ed. 1** – Corrigendum 1 – Integrated circuits – Measurement of electromagnetic emissions, 150 kHz to 1 GHz – Part 4: Measurement of conducted emissions, 1 Ω/150 Ω direct coupling method

See IEC for additional information.

- **IEC/IEEE 62704-2:2017, Ed. 1.0** – 6/28/2017 – Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 2: Specific requirements for finite difference time domain (FDTD) modelling of exposure from vehicle mounted antennas
- **IEC 61000-4-12:2017, Ed. 3.0** – 7/18/2017 – Electromagnetic Compatibility (EMC) – Part 4-12: Testing and measurement techniques – Ring wave immunity test See IEC for additional information.
- **IEC 62040-2:2016 PRV, Ed. 3.0** – (9/2/16) – Uninterruptible power systems (UPS) – Part 2: Electromagnetic compatibility (EMC) requirements
- **IEC 62228-2:2016 PRV, Ed. 1.0** – (9/23/16) – Integrated circuits – EMC evaluation of transceivers – Part 2: LIN transceivers
- **CISPR 16-2-1:2014/AMD1:2017, Ed. 3.0** – 6/30/2017 – Amendment 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 16-2-1:2014+AMD1:2017, Ed. 3.1** – 6/30/2017 – Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-1: Methods of measurement of disturbances and immunity – Conducted disturbance measurements
- **CISPR TR 16-4-4:2007+AMD1:2017, Ed. 2.1** – 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 calculation of limits for the protection of radio services

- **CISPR TR 16-4-4:2007/AMD1:2017, Ed. 2** – Amendment 1 – 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 calculation of limits for the protection of radio services

- **CISPR 25:2016 PRV, Ed. 4.0** – (9/2/16) – Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers

- **CISPR 16-1-5/AMD1:2016 PRV** – (9/2/16) – Amendment 1 – 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 16-2-3:2016, Ed. 2.0** – (9/15/16) – Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements

- **CISPR 16-2-3:2016 RLV, Ed. 4.0** – (9/15/16) – Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements

See IEC for additional information.

NEWLY RELEASED ETSI STANDARDS (AS OF JULY 2017)

- **ETSI EN 300 422-4 V2.1.1** – Wireless Microphones; Audio PMSE up to 3 GHz; Part 4: Assistive Listening Devices including personal sound amplifiers and inductive systems up to 3 GHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU

- **ETSI EN 301 357 V2.1.1** – Cordless audio devices in the range 25 MHz to 2 000 MHz; Harmonised Standard covering the essential requirements of article 3.2 of Directive 2014/53/EU

- **ETSI TR 103 403 V1.1.1** – Intelligent Transport Systems (ITS); Mitigation techniques to avoid harmful interference between equipment compliant with ES 200 674-1 and ITS operating in the 5 GHz frequency range; Evaluation of mitigation methods and techniques See ETSI website for additional information.

See ETSI website for additional information.

NEWLY RELEASED CENELEC STANDARDS (AS OF JULY 2017)

- **EN 55016-1-4:2010/A2:2017** – 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

- **EN 55016-1-5:2015/A1:2017** – 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

- **EN 55016-1-6:2015/A1:2017** – Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-6: Radio disturbance and immunity measuring apparatus – EMC antenna calibration

- **EN 50647:2017** – Basic standard for the evaluation of workers' exposure to electric and magnetic fields from equipment and installations for the production, transmission and distribution of electricity

- **EN 62433-3:2017** – EMC IC modelling – Part 3: Models of Integrated Circuits for EMI behavioural simulation – Radiated emissions modelling (ICEM-RE)

See IEC for additional information.

- **EN 55035:2017 – 7/28/2017** – Electromagnetic compatibility of multimedia equipment – Immunity requirements

- **EN 61326-3-1:2017 – 7/28/2017** – 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 See CENELEC for additional information.

See IEC for additional information.

REFERENCES

List of Common EMC Standards
You shouldn't be surprised that Wikipedia has a comprehensive list of EMC standards. The list includes CISPR, IEC, ISO, European EN, FCC, and MIL-STD. There is also a link to the GR-1089-CORE EMC and product safety standards for network telecommunications equipment. A good link to bookmark. For more, Click here.

Directory of World Power Plugs for Travelers
There are 14 commonly-used power line plugs used in over 200 countries. The IEC has made available a useful directory of power line plug styles used across the world. This handy guide for travelers is tabulated by country or by clicking on a world map.

COMMON EMC STANDARDS

Commercial Electromagnetic Compatibility (EMC) Standards

List of Common EMC Standards

You shouldn't be surprised that Wikipedia has a comprehensive list of EMC standards. The list includes CISPR, IEC, ISO, European EN, FCC, and MIL-STD. There is also a link to the GR-1089-CORE EMC and product safety standards for network telecommunications equipment. A good link to bookmark. For more, Click here.

Reference:
http://www.cvel.clemson.edu/emc/tutorials/commercial_emc_standards.html
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ANSI

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

IEC

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

IEC (continued)

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

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

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

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

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

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

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

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

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

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

ISO	
Document Number	Title
ISO 13766:2006	Earth-moving machinery -- Electromagnetic compatibility

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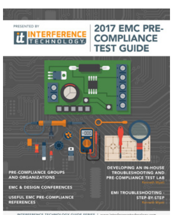

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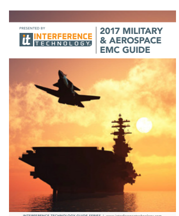

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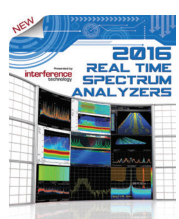

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EMV INTERNATIONAL EXHIBITION
February 20-22, 2018
Dusseldorf, Germany
www.mesago.de/en/EMV/For_visitors/Welcome/index.htm

APPLIED POWER ELECTRONICS (APEC)
March 4-8, 2018
San Antonio, Texas
www.apec-conf.org

APEC focuses on the practical and applied aspects of the power electronics business. This is not just a designer's conference; APEC has something of interest for anyone involved in power electronics.

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RESILIENCE IS KEY TO THE CONNECTED AND AUTONOMOUS REVOLUTION

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Introduction

Connected and autonomous vehicles have long been hailed as the answer to safe transport. Around 1.25 million people die in road traffic accidents worldwide each year according to E&T– and driver error accounts for over 90 per cent of those deaths[1]. In theory, the removal of the driver as the lead decision maker for vehicle control should reduce this number, with the SMMT estimating that 2,500 lives will be saved between 2014 and 20302 through the introduction of autonomous vehicles. It is imperative however, that the industry ensures that the control technology underpinning the revolution remains safe, secure and functional as autonomous vehicle development progresses.

Artificial Intelligence (AI) technologies, which utilise machine learning, are at the heart of vehicle automation. There have been significant strides in the development of the basic algorithms used in machine learning in addition to an increase in the amount of quality data available. Infra-red sensors, Light Detection And Ranging (LiDAR) systems, 360° vision systems, wireless connectivity and many more data sources all combine to provide machine learning algorithms with a wealth of rich information from which to learn, optimise and grow. It is now widely acknowledged that autonomous vehicles offer the application that AI has been waiting for, and that the introduction of autonomous vehicles will be sooner than we think.

Wireless technologies and the associated benefits that they bring are an ever-increasing and indispensable part of modern society. Services such as Digital Radio and TV (DAB and DVB-T), GSM, 3G, 4G, Wi-Fi and Bluetooth are now commonplace in most executive and prestige vehicles. With demand increasing and implementation costs reducing, these technologies are becoming available across the majority of vehicles offered by manufacturers. For example, Bluetooth is common in all but the most basic entry level vehicles, and DAB and DVB-T are optional on most mid-range vehicles. Integrated GSM, 3G, 4G, 5G and Wi-Fi technologies will be available in the next wave of models from the major high-end vehicle manufacturers, and along with Intelligent Transport Systems (ITS), are set to deliver the much awaited 'connected car' and the connectivity backbone for autonomous vehicles.

For engineers though, who must look through the glossy benefits and get to the nuts and bolts of what is required to realise the change, a thorough understanding of the safety, security and functionality risks of each vehicle feature will be essential in ensuring that connected and autonomous technologies are resilient. These elements of the engineering process are inextricably linked, creating a web of intertwined and hidden risks. Security and safety systems must remain functional, whilst safety systems and functional systems must remain secure from cyber threats.

Standards form a key role in the engineering process, with ISO 26262 for functional safety and SAE J3061 for cyber security representing the state of the art for achieving high levels of system confidence. Whilst changes are being implemented to tackle the issues surrounding connectivity and autonomy and significant work is undertaken to align the standards, even ISO 26262 Edition[2] scheduled for release in 2018 is unlikely to fully cover the requirements for autonomous vehicles. This is a reflection of the complexity of verifying the safe and secure operation of connected and autonomous vehicles rather than any inadequacy in the standards generation process.

It is the engineering processes within these standards, defining rigorous recommendations and regulations (throughout the product lifecycle from concept to decommissioning), that must be built upon to fully realise resilience for autonomous systems. For example, at the core of HORIBA MIRA's resilience services is a risk-driven approach for determining the requirements needed to achieve acceptable levels of safety, security and functionality and the fundamental processes required to verify that those levels have been achieved.

FUNCTIONAL PERFORMANCE

In order for connected and autonomous vehicles to function properly, we must ensure acceptable levels of performance for critical functions, such as braking, steering and acceleration. Key to this is the connected technology backbone; the broadcast systems and wireless links that enable connected vehicles to 'talk' to each other and to surrounding infrastructure. Data transmitted and received by vehicles will rise significantly, with vehicles using GSM, 3G, 4G, Wi-Fi, Bluetooth, vehicle to vehicle / infrastructure communication, and other data links and broadcast technologies.

Vehicle connectivity is improving, but not quickly enough for customers. According to J.D. Power's 2016 Vehicle Dependability Study, the number of problems with infotainment, navigation and in-vehicle communication systems—collectively known as audio, communication, entertainment and navigation or ACEN—has increased and now accounts for 20% of all customer-reported problems.[3]

For vehicle manufacturers, this poses a big issue as many customers will rate the quality of the entire electrical system in their vehicles based on the reception and connectivity experience that the vehicle delivers. Currently for mainstream vehicles, radio reception is the key tell-tale, but for high-end vehicles, this will extend to TV reception and interference. However, in the future customers will be armed with an increased number of diagnostic tools including data link corruption or dropouts which will exhibit themselves as dropped phone calls, poor Wi-Fi reception or slow data rates. These will all form the tell-tale signs of electromagnetic interference issues or poor system / antenna performance. The irony is that the number of noise sources fitted to vehicles, and their proximity to sensitive antenna systems due to space constraints, are both causing an increased risk of electromagnetic issues and at the same time the means by which customers can perceive issues.

The risk of poor performance can lead to impact on the customer, such as the inability to make a phone call via the infotainment system, as well as warranty issues which lead to lengthy debates between customer, OEM and dealership. However issues will also reduce the effectiveness of vehicle features reliant on connectivity, some of which will be part of the vehicle control strategy. OEMs are acutely aware of these issues but are reliant on costly and time consuming subjective surveys to progress design development and gather data on connectivity performance issues meaning that signing off performance confidently is a challenge.

OEMs therefore require quantitative targets and meaningful performance measures for vehicle development. To meet these requirements for robust and accurate reception and connectivity assessment methods, a number of factors must be considered including; antenna performance, the level of wanted signal received by the vehicle when moving and the unwanted interference levels from the vehicle. All of these factors must be combined such that they reflect 'real world performance', accurately simulating the vehicle occupant's experience to ensure that reception issues are identified and rated.

Connectivity is a key enabler in the future of mobility, and performance is crucial to feature functionality. Bottlenecks in connectivity must be avoided and data throughput must be maximised.

There are also many challenges ahead for electromagnetic testing of autonomous features, most of which surround the issue of system complexity. As functions are combined for co-pilot or auto-pilot features, system complexity grows rapidly. This in turn means that each system function is linked to multiple inputs from other vehicle systems. With this web of interconnectivity comes fragility, meaning fault modes are more likely. As such, test complexity increases due to the increase in stimuli for operational test modes. Efficient electromagnetic testing of autonomous features involves immersive situational testing, delivering services that use more diagnostic information, real-time vehicle data analysis, moving targets and a number of other actuator and simulator systems.

SAFETY

Traditionally, safety has been considered to include active safety, such as anti-lock braking systems, blind spot information systems and lane departure warning systems, as well as passive safety, including seat belts and airbags. However, with connectivity, electrification and automation, safety has to be considered in a completely new light. First and foremost, new technologies mean engineers are having to get to grips with new systems and tools which come with their own safety considerations. Secondly, new hazards are being created as a result of these new technologies. This includes exposure to electromagnetic energy and hazardous levels of electrical energy, potentially causing health-related issues, as well as thermal runaway, leading to thermal events such as the release of chemicals.

System failures are another potential cause of hazards and can be caused by random hardware faults or systematic faults such as software defects. Widespread application of electronic systems in vehicles means it is especially important that safety risks are managed throughout product development. The ever increasing complexity of vehicle technology requires a co-ordinated approach to safety and functionality, and that the safety of security systems and the security of safety systems must be considered together. Only by undertaking co-ordinated, pragmatic and 'goal based' programmes can robust engineering solutions be delivered while avoiding unnecessary development rework, verification and validation activities.

SECURITY

Increasing autonomy and connectivity has exposed us to the potential of greater levels of malicious activity in the form of cyber-attacks. There are many potential threats that we face, including traditional vehicle theft, owners enhancing the performance of their own car, identity theft or unauthorised remote access to vehicle functions. Each of these threats can have a variety of different consequences, including the financial, privacy and operational impacts typically associated with the information security domain, as well as potential impacts upon safety and functionality.

In order to address these threats, we must use a risk-driven security engineering approach, through which appropriate security measures can be specified, designed and implemented. Effective verification and validation is required to evaluate whether the actual level of security is as designed, and whether it is effective at preventing the relevant attacks. This involves various review, analysis and testing activities which take several forms, including verification of correct functional behaviour, proper implementation of security mechanisms, vulnerability analysis and penetration testing to confirm the effectiveness of those mechanisms.

Due to the diverse nature of the automotive supply chain, it is essential to perform this verification for individual hardware and software components, complete embedded systems and at vehicle level, to ensure that all elements are properly integrated.

It is clear that there are still challenges on the horizon yet to be fully addressed, but with a coordinated approach to safety, security and functionality, we will be able to better map, manage and mitigate the risks for connected and autonomous vehicles.

AUTHOR BIO

Anthony Martin, EMC Chief Engineer, HORIBA MIRA, received his first degree in Electrical and Electronic Engineering in 1997 followed by a PhD in Quantitative Data Validation from De Montfort University in 2000. He is a Chartered Engineer, the UK Principle Expert for the International Standards Organization (ISO), Road Vehicles, Electrical and Electronic Equipment committee and visiting senior research fellow at De Montfort University.

Since graduation he has worked at HORIBA MIRA specialising in the Coordination of large/complex programmes with emphasis on managing requirements, assessing risks, reviewing supplier designs and test results with the aim of detecting and resolving EMC issues in a cost efficient and timely manner. This work has spanned all automotive and military sectors.

This work has involved the development of bespoke EMC programme management and resolution tools including Risk Driven Systems Engineering and design/requirement matrices for major automotive, sports car and military vehicle OEMs.

As the race for superior connectivity and services between vehicle manufacturers ensues, he will continue to address the EMC test and development issues facing vehicle manufacturers including the development of advanced test methods for vehicle communication link performance assessments and coordination of associated problem resolution.

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EMC RADIATED EMISSION MEASUREMENTS AT 1/3/5/10/30 METERS

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Introduction

There are two principal types of emission measurements in the world of electromagnetic compatibility, conducted emission and radiated emission. The conducted emission measurements are either a voltage-capacitive tap type of measurement (typically on a power line) or they are a current-clamp type of measurement (typically on a signal line).

Radiated emission measurements are unique in that they must always state "the horizontal distance from the Equipment-Under-Test (EUT) to the receiving antenna" in order to compare the measured values to the appropriate regulatory limit. This horizontal distance, which is typically one, three, five, ten, or 30 meters, and the limits (both regulatory and standard-based) associated with those horizontal distances are the subject of this article.

ONE-METER MEASUREMENTS

There are two well-known EMC-measurement standards that reference a one-meter measurement distance from the EUT to the receiving antenna for radiated emissions. They are MIL-STD 461 and RTCA DO-160. There are other EMC standards that also use the one-meter horizontal-distance; one primary example is CISPR 25 – Electromagnetic Disturbances Related to Electric/Electronic Equipment on vehicles and Internal Combustion Engine Powered Devices.

First released in 1968, MIL-STD 461 has always specified a one-meter EUT-to-antenna distance; originally inside of a shielded room with bare walls and, then, in later revisions, inside of a shielded room with anechoic material on the walls. MIL-STD 461 (the latest version is MIL-STD-461G – December, 2015) is the standard used to test and qualify products sold to United States Military organizations and it has been widely duplicated in other countries' specifications for EMC of military electronic products.

RTCA DO-160 was first published in 1975 and is the EMC standard for commercial aircraft electronics in the United States and it is maintained by RTCA (an organization incorporated in Washington, DC). The latest version is RTCA-DO-160G, which was released in December of 2010. It's Section 21 addresses "Emission of Radio Frequency (RF) Energy" and it specifies a one-meter antenna distance inside of a shielded room with anechoic material (electromagnetic field absorbers) on the ceiling and about one-half of the wall surfaces. The European version of RTCA-DO-160 is EUROCAE ED-14 (EUROCAE is the European Organization for Civil Aviation Equipment; RTCA and EUROCAE work closely together and their standards are harmonized). CISPR 25 specifies a one-meter antenna distance to be used for radiated emissions from Components/Modules in an Absorber Lined Shielded Enclosure (ALSE).

The one-meter antenna distance has worked well for both Military Standard approved products and for Commercial Aviation approved products. A one-meter separation distance is a reasonable distance between an RF source and receptor of RF energy inside of a plane, a tank, or a ship. With the exception of CISPR 25 (where, again, a one-meter antenna distance is logical for closely located electronics in a vehicle), major measurement standards for terrestrial-based commercial products have conspicuously avoided a one-meter antenna measurement distance.

THREE-METER MEASUREMENTS

Three-meter measurements are growing increasingly prevalent in the measurement world. They have been used by the United States Federal Communications Commission (FCC) for a number of years. Specifically, measurements of Class B digital devices (computers and similar devices) have been permitted at 3-meters since 1979 (FCC Docket 20780). The rationale for a three-meter measurement distance for Class B equipment was that small business computers (as a source of RF energy) would be closer to the potential receptor of energy (TV, radios, etc.) than a large Class A Computer. The simulated model of the source-receptor duality for Class B Computers was a business having a small computer and an apartment (3-meters away) having the TV or radio receiver.

Par. 15.109 (Radiated emission limits) of the FCC Rules says:

> (a) **Except for Class A digital devices**, the field strength of radiated emissions from unintentional radiators at a distance of **3 meters** shall not exceed the following values:

Frequency of Emission (MHz)	Field Strength (microvolts/meter or dBuV/m)
30-88	100 uV/m or 40 dBuV/m
88-216	150 uV/m or 43.5 dBuV/m
216-960	200 uV/m or 46 dBuV/m
Above 960	500 uV/m or 54 dBuV/m

Three-meter measurements from 30-1000 MHz can be made in an Open Area Test Site or, more likely these days, in a three-meter semi-anechoic chamber due to the increasingly higher-ambient electromagnetic levels found in the environment. Fully anechoic rooms are also becoming more prevalent for 3-meter measurements.

It should be noted that three-meter measurements are also specified for radiated emission measurements for both Class A and Class B products above 1 GHz for both FCC Rules and International Standards for electromagnetic emissions.

Also, CISPR 32 – Edition 2.0 was published in 2015 and it allows Class A and Class B computers to be tested at a 3-meter horizontal distance from 30-1000 MHz.

FIVE-METER MEASUREMENTS

Radiated emission measurements made at a 5-meter horizontal antenna distance are being made in the commercial world. This is a "compromise" distance between 3-meters and 10-meters. The advantages to measurements made at 5-meters are that you can have a larger turntable in a 5-meter chamber and it is "easier" to meet the Volumetric Normalized Site Attenuation criteria for 3-meter distances in a larger 5-meter room.

However, at the present time, no standards specifically call out a 5-meter "standard" measurement distance. Limits specified at 3-meters or 10-meters are interpolated to a 5-meter distance using the inverse-distance fall-off guidance for a number of standards.

TEN-METER MEASUREMENTS

Many EMC technical experts consider the ten-meter measurement distance to be the "Gold Standard" in today's electromagnetic emission measurement world for Class A equipment. Ten-meter measurements are made at both Open Area Test Sites and in Semi-Anechoic Chambers. The semi-anechoic chambers are increasingly popular due to the steadily rising ambient levels in the real world because of digital TV and other new electronic developments.

Other advantages of the 10-meter antenna distance is that it allows a larger turntable to be used, and, therefore larger products can be tested with the receiving antenna in the "far-field" of the product's emanations. For example, at 10-meters, the EUT is one wavelength away from the antenna at 30 MHz, two wavelengths away at 60 MHz and three wavelengths away at 90 MHz. In contrast, equipment tested at 3-meters is not one wavelength away from the antenna until frequencies are at 100 MHz, two wavelengths away at 200 MHz, and three wavelengths away at 300 MHz.

Again, the FCC Rules are strongly stated in Par. 15.109 (Radiated emission limits) where it says:

(b) The field strength of radiated emissions from a Class A digital device, as determined at 10 meters, shall not exceed the following:

Frequency of Emission (MHz)	Field Strength (microvolts/meter or dBuV/m)
30-88	90 uV/m or 39 dBuV/m
88-216	150 uV/m or 42 dBuV/m
216-960	210 uV/m or 46.5 dBuV/m
Above 960	300 uV/m or 49.5 dBuV/m

NOTE - Several Asian countries require strict acceptance of 10-meter radiated emission measurements for Class A equipment when specified in their regulatory requirements based on international standards.

30-METER MEASUREMENTS

Thirty-meter measurements were the preferred measurement distance for Class A Digital Devices when the FCC rules were first released for 'computers' back in 1979.

The main reason for this was the CBEMA Report[1] released in 1977 in response to FCC Docket 20780[2]. The 1977 CBEMA report states "89 percent of receiving antennas found within 100 meters of commercial Electronic Data Processing/Office Equipment installations can be expected to be 30 meters or more from the installations." **Therefore, the CBEMA report chose "30 meters" as a reasonable control distance for radiated emission limits from Class A computers.**

Also, the FCC imposed rules at 30 meters (approximately 100 feet). In a historical article[3] by Herman Garlan, Chief of the Radio Frequency (RF) Devices Branch in 1973, he states, "The rules then in effect (for operation with a duty cycle) permitted a field-strength level of 50 uV/m at 100 feet (30 meters) on frequencies between 88-108 MHz."

Also, in the 1970s, the German VDE testing authorities used a 30-meter test distance for much of their testing[4].

Problems with relatively high-ambient levels from 30 MHz to 1000 MHz at 30 meters made it very difficult to make measurements. In addition, the antenna mast had to be 6 meters high at 30 meters, which was a challenge for EMC test labs. Normalized Site Attenuation (NSA) was also a technical challenge for 30-meter test sites; it was achievable but time-consuming and more complex than NSA at 10 meters or 3 meters.

Because of the above difficulties, in the early 1980s the FCC released Docket 80-284, which eventually changed the preferred test distance for Class A digital devices to 10 meters. **So, in the United States, the 10-meter distance for Class A devices has been the dominant distance for the last 35 years.**

NOTE - There are strong technical arguments for using a 30-meter test distance for frequencies BELOW 30 MHz due to the longer wavelengths of the electromagnetic energy at lower frequencies.

INTERNATIONAL STANDARDS

Despite a number of changes to FCC Rules since the first publication of this article in 2010, Part 15 of the FCC rules still states in 15.109 (g):

"As an alternative to the radiated emission limits shown in paragraphs (a) and (b) of this section, digital devices may be shown to comply with the standards contained in the **Third Edition** of the International Special Committee on Radio Interference (CISPR), Pub. 22, "Information Technology Equipment (ITE) – Radio Disturbance Characteristics – Limits and Methods of Measurement."

The **Third Edition of CISPR 22 (1997**) has the following limits:

Table 5 – Limits for Radiated Disturbance of Class A ITE at a measuring distance of 10 meters

Frequency Range – MHz	Quasi-Peak Limits – dBuV/m
30-230	40 (=100 uV/m)
230-1000	47 (=224 uV/m)

NOTE – The CISPR 32 – 2015 limits for Class A and Class B are same as CISPR 22 – 1997 at 10 meters.

Table 6 – Limits for Radiated Disturbance of Class B ITE at a measuring distance of 10 meters

Frequency Range – MHz	Quasi-Peak Limits – dBuV/m
30-230	30 (=32 uV/m)
230-1000	37 (=71 uV/m)

If we compare the FCC and CISPR 22 (1997)/CISPR 32 (2015) limits at <u>10 meters</u> for Class A equipment, we have the following table:

Frequency of Emission (MHz)	FCC – CLASS A (microvolts/meter)/(dBuV/m)	CISPR 22 – CLASS A CISPR 32 – CLASS A (microvolts per meter)/(dBuV/m)
30-88	90/39	100/40
88-216	150/43.5	100/40
216-230	210/46.5	100/40
230-960	210-46.5	224/47
Above 960	300/49.5	224/47

If we compare the FCC and CISPR 32 (2015) limits at 3 meters for Class B equipment, we have the following table:

Frequency of Emission	FCC – CLASS B (microvolts/meter)/(dBuV/m)	CISPR 32 – CLASS B (microvolts per meter)/(dBuV/m)
30-88	100/40	100/40
88-216	150/43.5	100/40
216-230	200/46	100/40
230-960	200/46	224/47
Above 960	500/54	224/47

The two sets of limits (FCC and CISPR 22/CISPR 32) are reasonably close for Class A equipment at 10 meters and further apart for Class B equipment at 3-meters.

INVERSE DISTANCE FALL-OFF

The inverse distance fall-off theory, also called the 1/r (1/d) theory, assumes a small source in a free-space (free-field) environment. **In general, these two conditions (small source and free-space) are not met in a typical EMC measurement.**

Most products have lengths and widths so they are not necessarily a "small source", for example, a table-top product is placed on a non-conductive table 0.8 meter above the ground plane and the power cord from EUT starts at the ground plane and reaches up to the EUT. The non-conductive table has a nominal size of 1.0 meter wide and 1.5 meters long. The product under test is usually smaller than the table but it is possible for it to be bigger than the standard table.

The ground plane is typically a solid metal floor or a metallic screen with small openings. In both cases, a reflected wave from the ground plane complicates the measurement of the radiated fields from the EUT. There have been a number of technical studies on the fall-off of electromagnetic fields from measurements close to a product versus a regulatory limit at a further distance from the product. We will look at a number of those studies in this paper.

TECHNICAL STUDIES JUSTIFYING INVERSE DISTANCE FALL FOR REAL PRODUCTS

Note: The author was unable to find any technical paper that justifies an inverse-distance fall-off for real products in an Open Area Test Site or a Semi-Anechoic Chamber especially for distances below 10 meters and frequencies between 30 and 1000 MHz.

TECHNICAL STUDIES QUESTIONING INVERSE DISTANCE FALL FOR REAL PRODUCTS

One of the first papers on "Falloffs" was written by William E. Cory and Frank C. Milstead in 1969[6]. It stated: "Propagation predictions in the near field, while less accurate, can be made to within about 10 db."

Albert A. Smith, Jr. wrote a paper in 1969[7], which modeled surface waves and space waves and found a complex relationship **below 100 MHz**. However, the paper goes on to say "Above approximately 100 MHz the space wave predominates for 'source and receiving heights of 1 meter' and the induction fields are negligible for 'antenna to EUT distances' greater than one meter."

Herman Garlan's paper[8] says in the "History of Part 15" section "The original low-power rule, the $\lambda/2\pi$ rule, was adopted in 1938. This rule provided a reasonable operating standard on frequencies up through the AM broadcast band – up to 1600 kHz. This standard was still usable up to about 10 MHz where the $\lambda/2\pi$ rule permits a field of 15 uV/m at about 5 meters or 16 feet. **While this standard served the needs of 1938, by the end of World War II, in 1945, it was hopelessly inadequate."**

The CBEMA paper was published in 1977; it was a comprehensive review of the interference potential of large computers. It says, "A practical site that allows measurements at the minimum test distance of 3 meters is shown in Figure 10-3. **Results of measurements in such practical test sites at varying distances between the equipment being tested and the measurement antenna, have been found to be within +/- 6 dB of those predicted using a 20 dB/decade fall-off relationship between the equipment and the antenna."**

Yet another paper was published in 1980 by Robert F. German and Ralph Calcavecchio[8]. This paper says "It is generally accepted that EMI radiated from large equipment should be measured at a distance of 30 meters. Measurements in the 30-1000 MHz frequency range at this distance usually are in the far-field of the source. However, 'due to ambient conditions' it is desirable to allow measurements to be made at distances of 3, 10, or 30 meters. It will be seen that, when appropriate assumptions are made, a measurement technique can be identified that relates measurements made at different distances by the 1/r attenuation factor of free space propagation." **The paper goes on to say "An EMI source is simulated by an electrically short dipole antenna. Actual EMI sources may be more complex and the topic of future work." Thus, the paper concludes 1/r works for "electrically short dipoles."**

Another paper from two engineers who worked at IBM[9], concluded **"The radiation from more than 25 different products showed a great variation from the 20 dB attenuation often assumed between three and 30 meter field strength levels."** It stated further "These products varied in maximum linear dimension from one to 10 meters." Also, the paper had three E-field falloff figures; "In all three falloff figures, it is noted that the radiated field at few frequencies attenuate at a rate of 20 dB per decade distance). This does not contradict the theoretical 20 dB falloff in free space between two points in the far-field located at a distance ratio of 10 to 1 away from a point source or from a dipole antenna small relative to the wavelength radiated. **In fact, a very large source (see Figure 8b) could in the extreme show a falloff approaching 0-dB because it contains a large number of geometrically distributed sources, both horizontally and vertically.** The fields from such multiple sources superimpose and may generate an almost plane wavefront (a plane wavefront exhibiting 0-dB falloff)."

Another paper[10], by Arlon T. Adams, Yehuda Leviatan, and Knut S. Nordby, covered a study concerned with the near fields of computer products. The study states that "The measurement distances of 3 to 30 meters may lie in the near or the far field, depending on the dimensions of the product and the frequencies emitted." Furthermore, the study says, **"In other words, the average slope in the oscillatory region is less than 20 dB per decade (it is about 10 dB per decade.) In other words, a product just meeting FCC rules at 3-m distance may exceed the rule when measured at 30 m. Thus, measurements made at short distances and then normalized to larger distances will yield far-fields smaller that they should be."** An additional paper by Adams and Nordby[11] reemphasized the above points.

In 1987, there was an article published in the 1987 IEEE International Symposium on EMC record[12] by J. D. Gavenda concerning vertical dipole sources in EUTs. **His paper stressed the point that vertical electrical fields are also produced off the end of a horizontal electric dipole, and broadside to a horizontal magnetic dipole.** The paper states "In free space at distances large compared with the wave-length and with the maximum dimensions of the EUT, the field strength falls off inversely with distance. However, the presence of a conducting ground plane causes reflected signals, which interfere constructively or destructively, depending on height above the ground plane and frequency, with the direct signal. **This invalidates any simple inverse-distance falloff rule, so correction factors must be used in the extrapolations."** In the paper, he has a falloff figure for a vertical dipole FROM 3 TO 10 meters that is a shallow-v-shaped with a only a 7 dB falloff from 30 to 100 MHz, a mere 4 dB falloff from 100 to 300 MHz, and, then, back to about a 7 dB falloff from 300 – 1000 MHz.

A very well known and respected paper was written in 1987 by Joseph DeMarinis of Digital Equipment Corporation[13]. One of the goals of this paper was the "Prediction and Measurement of correlation errors between 3-meter and 10-meter site distances and development of bands of confidence around such correlation." In its Introduction, the paper says **"It is well known that signal falloff versus site distance does not follow the 1/distance rule which is proscribed by the regulatory standards and that very large correlation errors can exist between test results taken at different distances. It was of particular interest to the project at hand, to try to understand the relationship between 3-meter and 10-meter sites."** The resulting data of the study showed a falloff of only 4 to 9 db from 30-200 MHz for vertical signals and a falloff between 9 and 14 dB for horizontal signals. From 200- 1000 MHz, the falloff for vertical signals ranged from 3 to 11 db and for horizontal signals it ranged from 8 to 13 db. All of this data, predicted and actual, was for Open Area Test Sites.

In 1993, three engineers from Austria wrote a paper on radiated emission testing at 3 meters[14]. This paper investigated a difference in extrapolation factors (0 db/decade in CISPR 11 and 20 dB/decade in CISPR 22) that existed at that time. Measurements were made at an Open Area Test Site and showed a range of falloff from 1 to 18 dB from a setup representing a typical personal computer. The paper presented worst-case extrapolation factors, for 3 and 10-meter test results, for both horizontal and vertical polarizations.

Another paper in 1996 by Christopher l. Holloway and Edward F. Kuester[15] looked at the comparison of OATS and semi-anechoic chambers. It stated that by looking at site attenuations of the two venues an equivalent comparison could be made. It concluded that **"This comparison is generally quite good at frequencies higher than 300 MHz, but at lower frequencies (30 -300 MHz), large discrepancies are often observed due to reflections from the chamber walls."**

Finally, a paper given in 2009 by Blankenship, Arnett, and Chen described another perspective on looking at the falloffs from 3 to 10 meters[16]. This paper also predicted a complicated falloff curve for signals between 3 and 10 meters and it was based on testing in semi-anechoic chambers.

CONCLUSIONS AND RECOMMENDATIONS

It can be seen that over the past forty years that the measurement of radiated emissions from electronic equipment has been an active topic.

The military and commercial avionics, as well as automotive, products have consistently used (and continue to use) a one-meter antenna distance for radiated emission. However, they have made improvements in the shielded-room locale by adding anechoic material to the ceiling and, at least, part of the wall surfaces in the chamber thus reducing reflections and increasing the accuracy of the test results over the past five decades.

It is also observed that there has been a trend over the last forty years towards making measurements on commercial products at antenna distances closer and closer to the Equipment Under Test. We have gone from an environment of making measurements at 30 meters on Class A commercial electronic products to an environment of making measurements at 3 and 10 meters.

The risk with moving closer to the product under test is that the receiving antenna can be immersed in the near-field environment of the EUT. When this happens, and it does at various distances and frequencies depending on the size and internal sources in the product, **predicting falloffs of electromagnetic energy with the inverse distance falloff formula (1/r distance factor) does not work and the fields measured at distances further from the product will, in general, be at a higher amplitude than that predicted with a 1/r falloff.**

CLASS B PRODUCTS TESTED AT 3-METERS

Since Class B products are already commonly tested at 3 meters for FCC regulations from 30 MHz to 1000 MHz and Class A and B products are tested at frequencies above 1000 MHz at 3-meters both in the USA and worldwide, it is obvious that 3-meter measurements are widely accepted around the world. If Class B products are tested at 3 meters as per CISPR 32, there would be no need for discussions relative to falloffs from 3 to 10 meters and the USA and International limits are very close which may lead to the desired goal of "harmonization."

CLASS B PRODUCTS TESTED AT 5-METERS

Class B products tested at 5 meters need to be investigated further as to their falloffs since there has been a limited amount of research done on the falloffs of fields from 3 to 5 meters and 5 to 10 meters over the frequency range 30 -1000 MHz.

CLASS A PRODUCTS TESTED AT 10-METERS

One alternative to the Class A issue is to mandate all Class A products be tested at 10 meters with no exceptions. Then, there would be no falloff debates since Class A products could not be tested at a closer distance.

However, if industry would like to test Class A products at 3-meters, as per the latest version of CISPR 32, there should be a correction factor applied to handle that situation. It is probably not 0 db (as was used in CISPR 11 in 1998) and it is probably not 10 dB (as used in CISPR 32 in 2015). It is some factor between those two theories and it should be frequency dependent.

A proposal along those lines would be a correction factor (not equal to the widely accepted 10 dB) that would be added to the 10-meter regulatory limit when the product is tested at three meters. As a first estimate, the following correction factors (instead of a de facto +10 dB) are proposed:

30 – 100 MHz - + 6 db

100 -300 MHz - + 3 dB

300 – 600 MHz - + 6 db

600 – 900 MHz - + 7 dB

900 – 1000 MHz - + 8 db

So, for example, at 120 MHz, the limit would be 40 plus 3 or 43 dBuV/m (instead of 40 plus 10 or 50 dBuV/m) when a Class A EUT is measured at a 3-meter antenna distance. (See Table A.2 of CISPR 32).

These proposed correction numbers are consistent with references[12] and[16]. This set of correction factors would cover the vertical field falloffs and would be even more conservative for the horizontal field falloffs (which are closer to the 1/r falloff curve).

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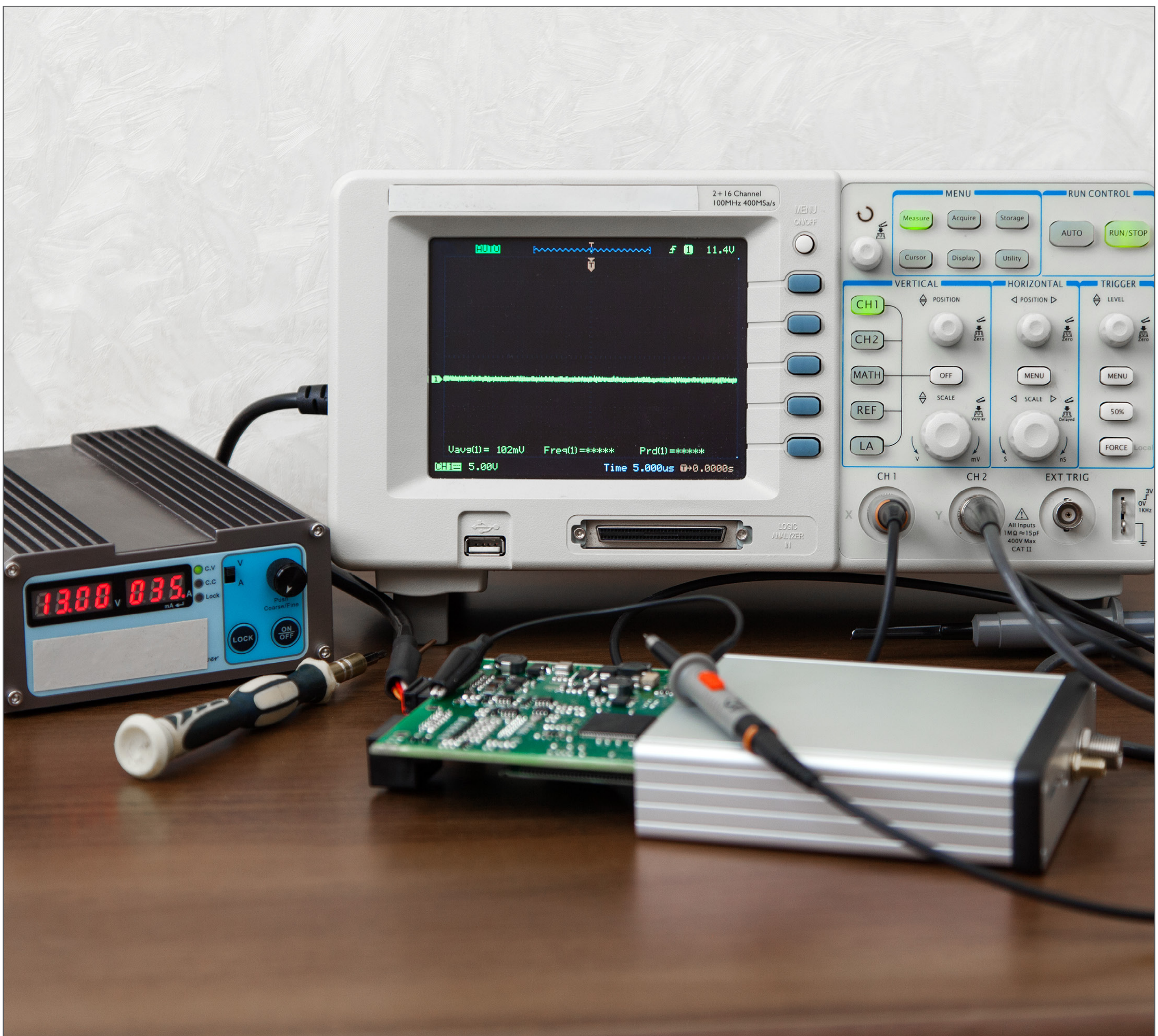

DETERMINING SEMI-ANECHOIC CHAMBER RESONANCE AS A SOURCE OF RADIATED EMISSION MEASUREMENT VARIATION BETWEEN CHAMBERS AND COMPARING TO OATS MEASUREMENTS

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Introduction

This article describes the lack of an acceptable correlation between anechoic chamber and open field test site radiated emission measurements, which were described in reference 1 in 2000, as well as a lack of correlation between chambers. It was found that emission measurements, which were over the limits in one facility, would pass in another.

The lack of a good correlation between OATS and chamber measurements and between chambers means that manufacturers may be over designing equipment for EMC, or equipment is passing radiated emissions at one site but would fail at another.

Although this would appear to be of great interest to manufacturers, up until now this has not been the case. It is not surprising when a manufacture tries a different facility for radiated emission or susceptibility (immunity) measurement in the hope that the equipment will pass in the second facility, where resonances may be lower or at different frequencies.

CASE STUDIES

The report in reference 1 report compared the test results over the 212 to 236 MHz frequency range between a 3m OATS, a 3m anechoic chamber, and a 10m OATS. The same EUT was tested on all sites and it was determined that, although often a determining factor, the cable orientation was not the cause of the large variation which was seen.

The Normalized Site Attenuation (NSA) of the 3m OATS in *Reference [1]* was measured from 200 to 300 MHz and the variation was 0.31 to 1.9 dB. Whereas the difference in measured level between the 3m anechoic chamber and the 3m OATS was as high as 14 dB. At some frequencies emissions were seen at one site and not at another and ambients were ruled out. This represented an error of up to 25 dB!

In radiated emission measurements on the aforementioned 3m OATS at 10m, reported in *Reference [2]* in 2010, the EUT manufacturer's customer had the same EUT measured in a 3m semi anechoic chamber with a very high 26.8 dB variance between the OATS and the chamber. *Table 1* shows the difference in measured levels between the OATS and chamber and it can be

seen that the emissions were much higher in the chamber at some frequencies. Also some levels measured on the OATS were not seen at all in the chamber, indicating a frequency where the fields inside the chamber cancel.

Table 1 - The same EUT measured on a 10m OATS versus the emissions measured in a 3m chamber with a 10.5 dB correction from the 10m to the 3m measurements.

Frequency (MHz) V = Vertical H = Horizontal	10m OATS dBuV/m	3m chamber dBuV/m	Delta (dB)
192V	13.5	40.3	26.8
192H	20.5	47.2	26.7
576V	25.1	40	14.9
576H	43.1	45.9	2.8

Even when the EUT was measured on a second 10m OATS, with a good correlation to the first 10m OATS, the customer insisted that the measurements made in the chamber were correct. The manufacture had to achieve emissions 6dB below the limit and so a massive margin was required in order to get the equipment to pass the customers measurement in the semi-anechoic chamber. This resulted in added engineering and manufacturing cost to the manufacturer. It also added the frustration in knowing that the EUT had almost certainly passed the requirements and a delay due to numerous levels of re-engineering.

OATS AND CHAMBER NORMALIZED SITE ATTENUATION CALIBRATION

ANSI C63.4 defines the theoretical normalized site attenuation

(NSA) for site validation. The requirement is met when measurements show that the site NSA is within the range of +/-4 dB of the theoretical. The antenna calibration method may affect the antenna calibration and therefore the NSA value. ANSI C63.5:2006 is cited in ANSI C63.4:2014 as the only permissible antenna calibration standard which includes requirements for antennas used for NSA measurements. Antenna uncertainty values may result in not achieving the required +/-4 dB range but not the huge variation between some semi anechoic chamber and OATS measurements.

ANSI C63.4 describes the standard OATS as well as alternative test sites which include RF absorber lined metal test chambers (semi-anechoic chambers), office or factory buildings, and weather protected OATS with covering structures. These alternative test sites shall comply with the volumetric NSA requirements of the standard over a volume occupied by the EUT, or the EUT arrangement. Thus the NSA measured on the OATS and the anechoic chamber measurements over this volume should be comparable, which is often not the case.

POSSIBLE SOURCES OF ERROR

The cable orientation and time spent in maximizing cable emissions plays a role but surely not to the extent of 25 and 26.8 dB as in the two examples. Also at high frequency where emissions may be sourced by seams in the enclosure the speed of the turntable does plays a role in detecting the emissions which occur over a narrow beam width.

The correction of 10.5 dB in going from a 10m to a 3m measuring distance is also not always correct, especially for large EUTs. Some test facilities make radiated emission measurements to commercial requirements, such as FCC Part 15 and EN55022, on class A equipment in a 3m chamber and then make the correction to 10m with a possible error.

CHAMBER RESONANCES

The major source of variation in anechoic chamber measurements is chamber resonances resulting in variation in the electric field level within the chamber.

The chamber is an enclosed box with reflective surfaces in which any electromagnetic wave bounces back and forth inside it, several resonant modes are generated and energy is stored within the chamber. These resonant modes generate standing waves and minimums and maximums in the field occur depending on frequency and location within the chamber. At resonance the field within the room may be higher than the field generated by the source in an open area test site. Several resonant modes may occur and when the room is lined with absorber these resonances are partially attenuated by the absorber.

ABSORBER

Likewise with absorber the reflections within the room are partially damped. However the attenuation due to the absorber is limited.

The absorber inside the room has to be effective enough to achieve the NSA requirement. The NSA calibration is made at the frequencies shown in *Table 2*.

Table 2 - NSA Calibration Frequencies

f(MHz)	
30	160
35	180
40	200
45	250
50	300
60	400
70	500
80	600
90	700
100	800
120	900
140	1000

The interval between frequencies is acceptable for testing on an OATS but we see that a typical resonance in a room covers only approximately 4 MHz, from *Figure 1*, and so in performing the NSA test any resonance may be missed if this falls between the spot frequencies tested for NSA.

Figure 1 shows the correlation between 20 MHz and 1 GHz and *Figure 2* is a close up of the resonances for a horizontally polarized field from 20 to 44 MHz.

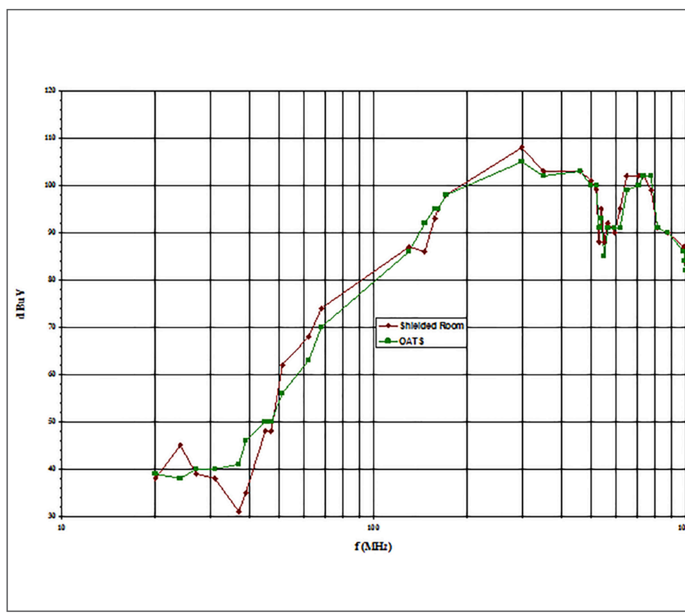

Figure 1 - Chamber to Open Area Test site correlation from 20 MHz to 1 GHz for a horizontally polarized field generated by a 10cm bow tie antenna and measured using a log periodic/biconical antenna compared to the Open Area Test Site measurement.

We saw that the field polarization affected the room resonance and *Figure 3* shows the correlation for a vertically polarized field from 20 to 50 MHz.

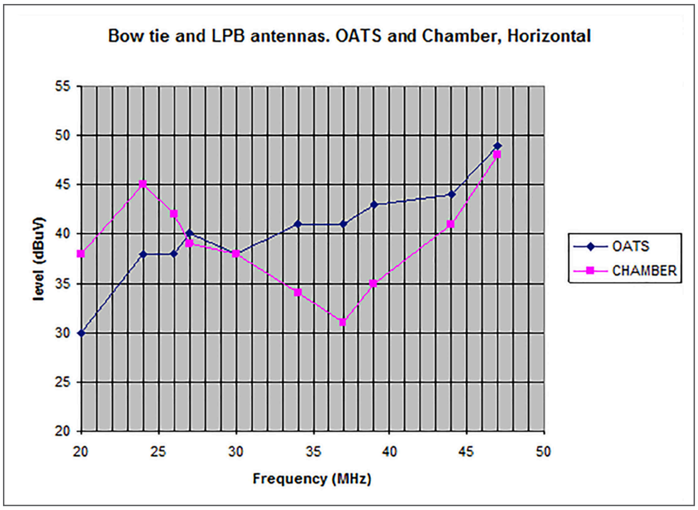

Figure 2 - Chamber resonance for horizontally oriented field generated by a 10cm bow tie antenna and a log periodic/biconical antenna compared to the Open Area Test Site measurement.

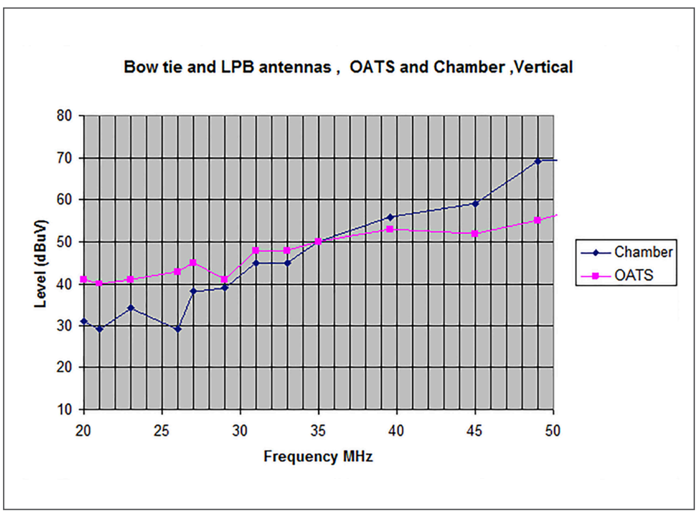

Figure 3 - Chamber resonance for vertically polarized field generated by a 10cm bow tie antenna and a log periodic/biconical antenna compared to the Open Area Test Site measurement.

TYPE OF ABSORBER

The type of absorber plays a large role in damping the resonances as seen in *Reference [3]*. *Reference [3]* identifies the influential parameters in CISPR 25 radiated emission setup. CISPR 25 is the reference standard in the automotive industry for performing measurements in a semi-anechoic chamber. Unlike other commercial radiated emission measurement, but similar to a MIL-STD-461 type test, the EUT is placed on an elevated ground plane connected to the chamber wall. Significant differences were seen between CISPR 25 compliant laboratories when measuring emissions on the same device under test. The paper makes an inter laboratory comparison across 17 laboratories with a special focus on the 30 to 100 MHz frequency range. A three dimensional model of the semi anechoic chamber was built and validated to analyze the influence of each of the parameters of the room and provide a reference for the measurements in the laboratories.

CISPR25 requires that the material absorption performance shall be greater than 6dB in the 70 to 2500 MHz frequency range. In a 5.33 x 6.53 x 3.63m chamber the first cavity resonance is at 36 MHz and so the absorber type used is important over the 30 to 100 MHz frequency range.

Table 3 - Foam and hybrid absorber reflectivity.

Frequency (MHz)	Reflectivity foam pyramidal (dB)	Reflectivity hybrid (dB)
30	0	11
40	0	13
100	12	12
200	28	11

These absorbers include ferrite tiles, foam absorbers, or hybrids (a combination of ferrite tiles and absorber which are matched). The ground plane in the CISPR 25 room can be connected either horizontally to the chamber wall or vertically to the floor ground plane. *Reference [3]* shows a -20 to + 10 dB variation between the two grounding techniques with the greatest variation seen with a vertical grounding. In a room without a ground plane this affect is not seen and it is the absorber type, which is important. Measurements on foam pyramidal absorber and hybrid show the reflectivity of the two, a comparison of which is shown in *Table 3*.

It is surprising that the foam absorber performance at 200 MHz is better than the hybrid, perhaps indicating that the matching of the ferrite and foam is not ideal. When designing a room, such as shown in *Figure 4* with foam mounted on top of ferrite tile, the manufacturer of both types of absorber recommended the types of absorber which were compatible. The effect of the absorber type alone can be extracted from the data for horizontal ground plane connection from *Reference [3]*.

In order to perform the inter-laboratory measurements between 17 laboratories, a reference was developed based on simulation with perfect absorbers and with a 1 x 2.5m elevated ground plane. This reference provides a theoretical maximum and minimum for the absorber types. Over the 5 to 84 MHz frequency range, the maximum variation in measurement results was 15 dB. For the measurements in the chambers a comb generator was used as the source of radiation.

Reference [3] show a plot of the field measured from this source from the 17 laboratories compared to the reference. This plot shows that the largest variation from the reference level was with rooms, which contained only pyramidal foam absorber. This variation was a worst case 34 dB at 20 to 26 MHz with the measurements from rooms with a hybrid absorber lying within the predicted maximum and minimum levels. Thus, based on the measurements the worst-case difference in radiated emission measurements between any two rooms was 22 dB.

Another technique used to achieve the results shown in *Figure 1* and described in *Reference [4]*, adds absorber loads placed in the room at strategic locations as well as a compatible combination of ferrite tiles with foam absorber on top, as shown in *Figure 4*, resulting in a very well damped room.

METODS OF DETERMINING CHAMBER RESONANCES

1) Antenna input power to develop a constant E-field level.

As the gain of the transmitting antenna and Antenna Factor (AF) of the receiving antenna are dependent on frequency, these factors must be corrected for when calculating the required input power for a given E-field at a specific frequency. A field uniformity test was performed to see if this could be used to identify a standing wave as it is expected that the E-field would vary significantly across the chamber. As these tests are typically performed above 80MHz the low frequency resonances shown in *Figures 2* and *3* would not be detected.

The field uniformity was tested over the area seen in *Figure 5*. From 80 to 200 MHz, a biconical antenna was used as the transmitting antenna but at a distance of 1m from the receiving antenna it was found that the field from the antenna was not sufficiently uniform. Instead an 80 MHz to 1 GHz double-ridged guide antenna was built which provided acceptable uniformity from the antenna at 1m when measured on the free space range.

The test in the chamber did not show any large variation in field level over the area of test, which is not surprising as Figure 1 shows a good correlation to the OATS above 50 MHz. As the room resonances are at frequencies below 80 MHz a monopole was used as the transmitting antenna and a small isotropic antenna, shown in *Figure 4* connected to a detector, digitizer and fibre optic driver was used as the receiving antenna as shown in *Figure 6*. As the detector has a logarithmic response the level of E-field was adjusted to be just above the noise floor for maximum sensitivity. The transmitting antenna input power was then adjusted so that the digital number read over the fibre optic link was constant and therefore the E-field was constant. At 24 MHz a room resonance is seen and indeed the level of input power required for a given E-field level is lower than at 20 MHz. The field was measured at locations 1 to 7 in *Figure 5* and the reduction in input power required for a constant E-field is shown in *Table 4*.

Table 4 - Reduction in input power in changing from 20 to 24 MHz.

Measurement Location	Reduction in antenna input power (dB)
1	17
2	18
3	19
4	18
5	16
6	16
7	16

When using antennas with a linear frequency response to the field, monitoring the E-field at a constant input power will show either an increase in the level of E-field or a decrease, and so after corrections for gain and AF, the resonance frequencies can be determined. The level of E-field is dependent on location and is typically different for vertically and horizontally polarized fields.

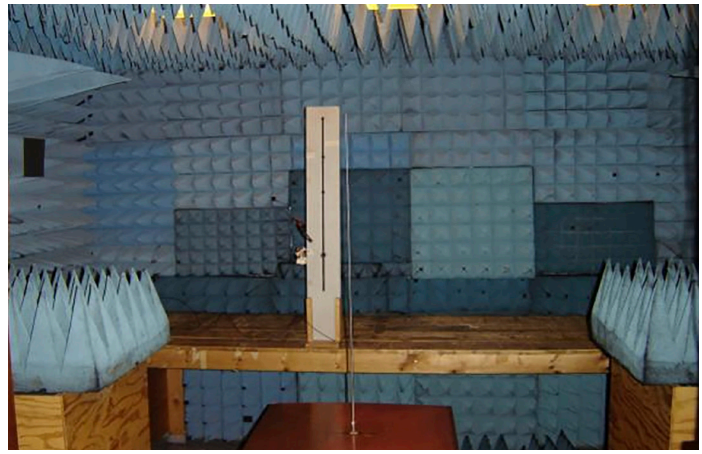

Figure 4 – A monopole and small isotropic bow tie antenna in a well-damped chamber.

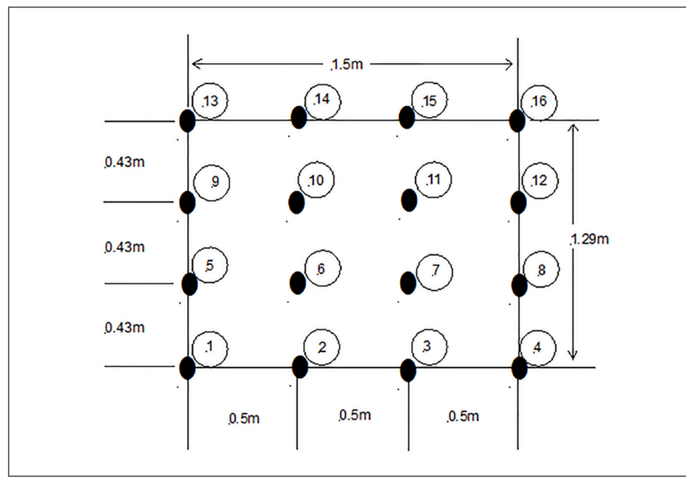

Figure 5 - Area over which measurement of the field uniformity was measured.

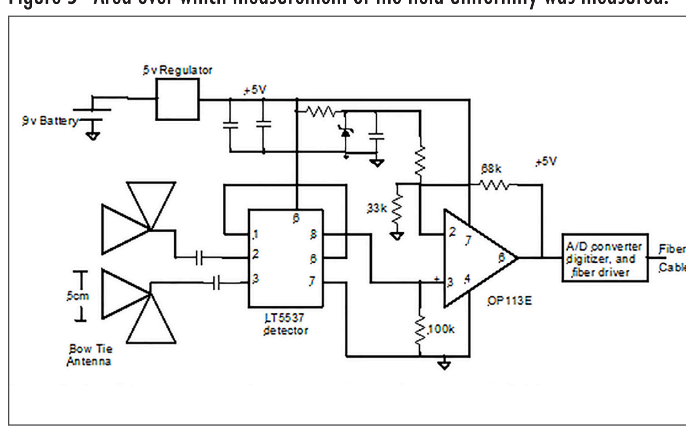

Figure 6 - Small isotropic bow tie connected to a detector and digitizer.

2) Comparison between free space range and chamber tests 20 to 50 MHz

The small monopole antenna was used to generate the E-field and a 1m rod monopole antenna was used as the receiving antenna. The fields generated were thus vertically polarized. The measurements were made with the antennas 1m apart on a free space range as well as the anechoic chamber. The same cables and signal source were used in both tests and the signal source was located on the ground and covered in a ferrite tile to reduce the impact of the proximity of the signal generator's metal enclosure on the measurement. The ground plane in the chamber was covered in ferrite tiles.

A comparison of the free space results and the chamber results are shown in *Figure 7*. A maximum at 23.7 MHz and a minimum at 30.2 MHz and 42.3 MHz can be seen from the plot.

At 23.7 MHz the measured field is 11 dB above the free space measurement and at 30.2 MHz the level is 29 dB lower. Thus, this measurement can be used to identify chamber resonances.

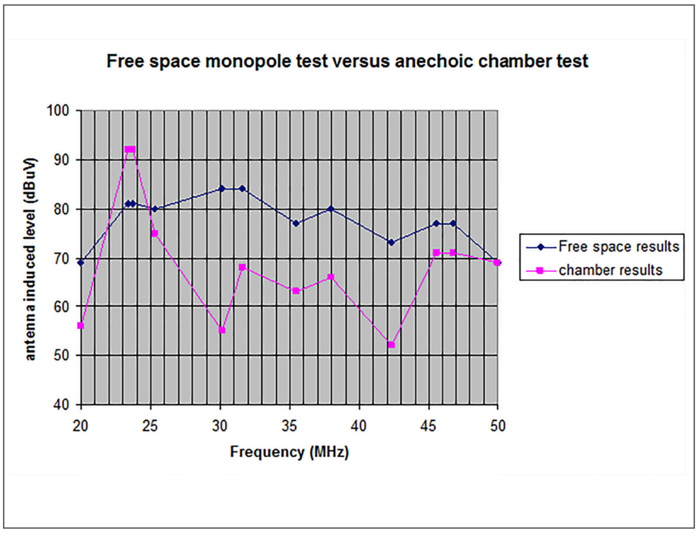

Figure 7 - Comparison between anechoic chamber and free space range measurements.

CONCLUSIONS

1) Errors detected

The huge variances seen in the OATS to chamber measurements of 25 dB and 26.8 dB were not seen in the measurements on 17 chamber reported in *Reference [3]* but a maximum variation of 22 dB was seen due to the different absorber used. It is possible to attribute the 26.8 dB difference to chamber resonance and poor absorber performance. There may be a simple alternative explanation, however the customer was not willing to make an investigation as he believes his results in the 3m chamber were correct. One facility reported a difference of 20 dB over the entire frequency range between measurements on an identical Equipment Under Test (EUT) compared to our measurements. The facility was requested to connect a signal generator to the spectrum analyzer input and indeed the spectrum analyzer measured a 20 dB higher signal than the input level. The spectrum analyzer contained a 20 dB preamplifier, which had been in circuit unknowingly from the day the instrument had been bought! This is most unusual as most instruments automatically correct the displayed level when an internal preamplifier is switched in circuit. If an external preamplifier is used then this may be forgotten in the calculation of the raw data to corrected data.

An error of this type could not be the explanation for the 26.8 dB difference as this positive difference should be seen at all frequencies. Also, it goes without saying that cable attenuation should be a part of the data correction, but would only reduce the measured level by a few dB.

2) Mitigation

Reference [3] does show that a facility with hybrid absorbers exhibits lower resonances than chambers with only foam pyramidal absorbers and so when choosing between facilities this should be a strong contributing factor.

A chamber may be selected before qualification testing by using the monopole antennas, as described, to make a free space or OATS measurement and repeating this in the chamber. Resonance frequencies may be identified in the difference between the measurements. If a free space measurement cannot be performed then an electromagnetic computational program may be used to predict the coupling between the two antennas. However it is important to adequately model the transmitting and receiving antenna cables in the analysis.

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EMC OF CONNECTORS

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EMC OF CONNECTORS

In the last years devices have gotten consistently smaller and less expensive. One reason for this is the "Internet of Things" or "Industry 4.0", the inter-networking of physical devices, and its related requirements. These requirements demand a significant amount of integration during device design and development. This integration, however, cannot be accomplished solely through the implementation of improved integrated circuits. Using modular designs, suppliers can quickly, and thus more cost-efficiently, develop or further develop their devices. Furthermore, the device's various modules can be designed and produced at different sites. When these modules are attached to one another via connectors they form a system and, with that system, a new device with numerous module transitions. The module interfaces have different parameters and layouts to ensure their quality and function. Generally not much thought is given to the EMC characteristics of a module, thus the entire system, when designing the layout of a connector. At the moment connectors are essentially chosen on the basis of a few electrical and mechanical characteristics required, for example, to ensure the transmission of LVDS signals without problems or divert high currents.

The current selection criteria for connectors include:

- Plug cycles
- Current-carrying capacity
- Cross talk
- Size
- Ect.

All devices must pass EMC tests guaranteeing operational capability in the operational environment.

At present these EMC tests are done after development is completed and, because they use a prototype, all single modules have to be assembled before being tested. This increases the risk that potential problems will only be found after the development stage. Correcting these problems at this point can require significant effort, time and costs.

The modular construction of the device offers the possibility to test the EMC characteristics of single submodules at their individual interfaces. This requires that single modules (components) have defined boundaries and EMC characteristics. Because they link the electronic modules, the boundaries and EMC characteristics of any connectors must also be known.

Currently, there are no parameters characterizing EMC-behavior of connectors. Additionally, this characterization should also apply to its interference/immunity and emissions.

Because of the current state of technology, the sizes of connectors exceed the signal distances attainable in the electronic board. Thus the board's signal lines can be shielded against parasitic effects much more effectively than connectors. For this reason the connectors are the weak spots within the modular systems.

The goal of development is to describe the EMC characteristics of connectors in order to improve the system's EMC quality.

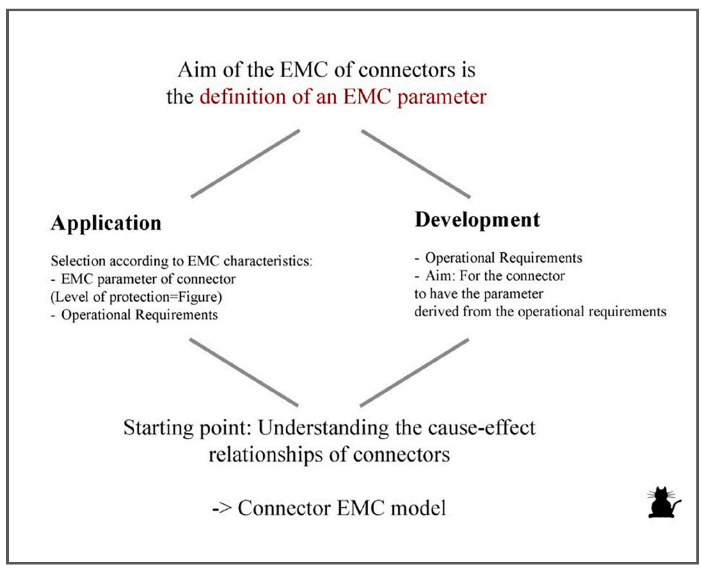


Figure 1: Goal of the Description

THE EMC PARAMETER OF CONNECTORS

A connector model is important both because of the physical commonalities of connectors and to be able to describe the coupling mechanisms of connectors.

This model consists of a simple structure: two assemblies attached by one connector. All elements are reduced to basic elements. *Figure 2* presents the "abstract connector model" resulting from this simplification. It shows a connection between the two assemblies (A and B) through a simplified connector. In this case all shielding/ground pins or surfaces are reduced to one pin. Furthermore only one signal pin driven from assembly A to a circuit receiver on assembly B is analyzed. If a parasitic current flows from assembly B to assembly A, it will be discharged via the shielding or the connector's ground connection. The resulting magnetic field induces a voltage at the signal pin by flowing via the loop created between the signal- and ground pins. The voltage drops at the high-resistance receiver, which can lead to disturbances of the electronic.

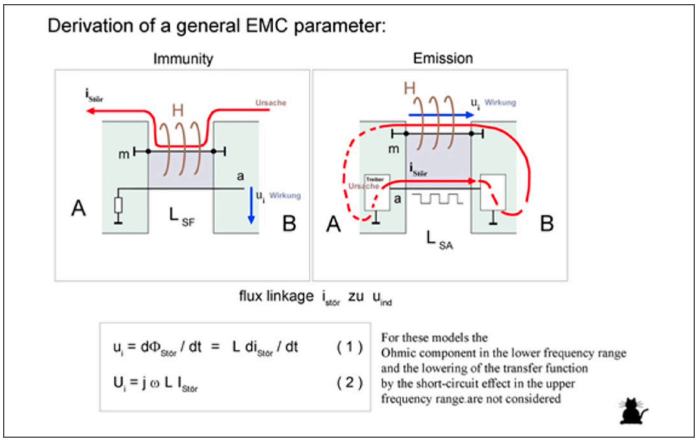


Figure 2: Abstract Connector Model

Coupling within the connector similarly affects interference. *Figure 2* shows the immunity conditions (left) and emissions conditions (right). The reverse current of a clocked system causes a reference potential shift between the assemblies A and B. The resulting potential difference is the driving force of the system's interference.

The mathematical description of the different effects is based on the law of induction.

$$u_{ind} = \frac{d\phi_{Stör}}{dt} = \boldsymbol{L}\frac{di_{Stör}}{dt} \quad (1)$$

u_{ind}:induced voltage
$i_{stör}$:parasitic current
w: circular frequency
L: coupling inductance

$$U_{ind} = j\omega \boldsymbol{L} I_{Stör} \quad (2)$$

The *Equations (1)* and *(2)* prove that only one figure (L) is required to describe coupling. L is coupling inductance. The parameter L is tightly linked to the mechanical construction of the connector and thus describes the connector and its layout. This means that connectors and/or signal-pin layouts can be chosen based on specific requirements.

DETERMINING COUPLING INDUCTANCE

Due to the mechanical structure of the connector the coupling inductance is neither a fixed figure nor valid for the whole connector. It is a signal-related variable. Different external influencing factors, such as close metal walls or other components, can influence the coupling inductance.

Quickly determining parameters while considering potential external influences during the developing stage is essential. This must be done using specially adapted measuring tools in order to reduce cross-sensitivities. The coupling inductance is a constant that only depends on the geometry of the connector and its determination can therefore be done at different frequencies. It is not necessarily required to determine the parameter at very high frequencies, which would presuppose an RF compliant structure up to some GHz. For that reason the chosen measurement setup is designed to achieve fast results. Furthermore, many different measuring configurations of the connector can be realized and analyzed in near real time. Such configurations include special modifications in the area around the connector to identify what influence any metallic bodies near the connector may have on the magnetic field distribution inside the connector and therefore how they may impact coupling inductance.

Figure 3 shows a connector's cycle of optimization. The connector is installed separately onto a special test PCB which is used to reduce cross-sensitivities and allow for comparability. It is equipped according to the manufacturer's restriction and is measured for the first time. In *Figure 3*, one can see what is required for measurement: a measuring tool, an injection probe, and a spectrum analyzer.

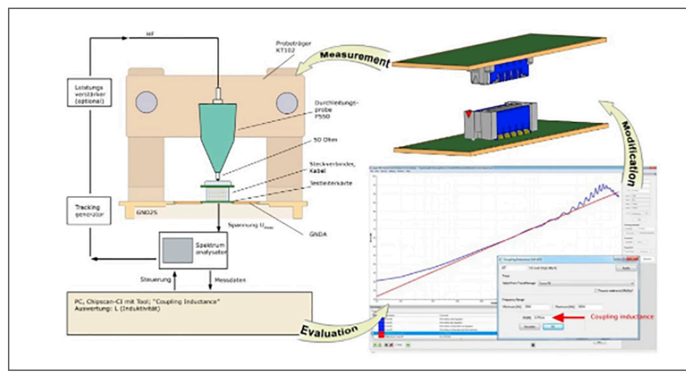


Figure 3: Measurement Cycle for Connector Modification

The spectrum analyzer generates a frequency-constant signal that is injected into the connector's shielding system by the injection probe. The voltage signal of the observed pin is measured and displayed via special software. Determining the coupling inductance is done using a software tool which calculates the coupling inductance from the measurement data. The measuring tool's frequency range (1MHz to 1 GHz) can be analyzed and is dependent on the size of the connector. Through a direct measurement of the voltage signal, effects of changes and modifications to the device or its environmental conditions can be seen in real time. Possible modifications include applying external mechanical pressure or reducing the distance to metal pieces. After only a few measurements, numerous measuring curves are available from which the successfully implemented changes can be noted. Connector users must be aware of the coupling values of different signal pins, which allow one to choose a connector with most appropriate signal-pin layout.

EMC-PARAMETER SAMPLE APPLICATION

The following example uses a simple transmission system as a real assembly to clarify the previous sections.

On the lower circuit board a square wave signal is generated and transmitted to the upper PCB via a header connector. The connector is set up in such a way that its layout can be changed by inserting new contact pins. The second PCB consists of a receiver with different possibilities to analyze the transmitted signals. The upper PCB is connected to the electronic reference system only through the connector. Parasitic current generated by a burst generator is fed into the system via a banana plug, which is also on the PCB, and its impact on the signal transmission is monitored. This test setup is comparable to connector module assemblies with attached peripheral devices.

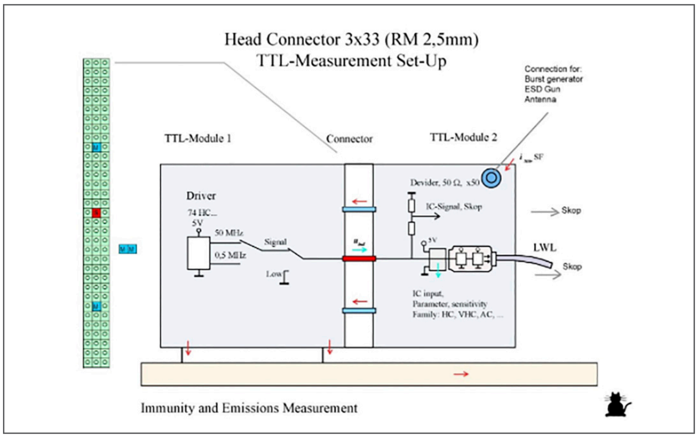


Figure 4: TTL Transmission System with Header Connector

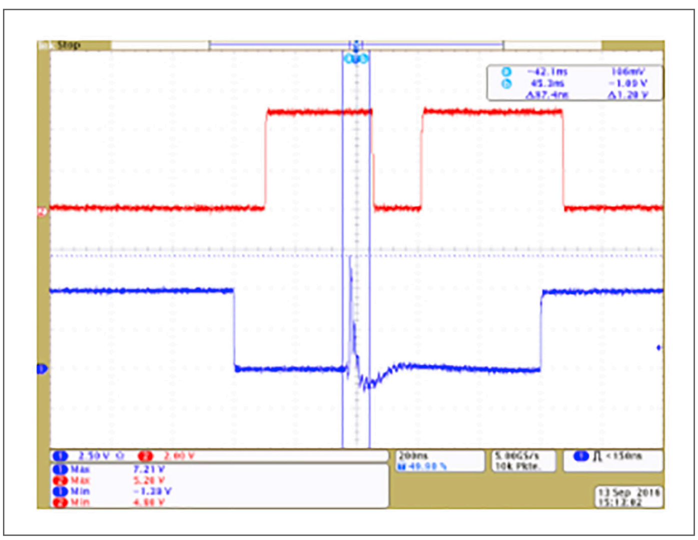


Figure 5: Effect of a Burst Pulse Ugen=500V with Coupling Capacity of approx. 8nH

First, burst pulses generated by a standard burst generator are supplied via laboratory connectors. By changing the connector's configuration, the coupling inductance is also changed. Thus, the burst pulses according to *Eq.1* are transmitted at different levels. *Figure 5* illustrates the effect of the disturbance on the rectangular signal. The blue line shows the signal at the input of the receiver. The rising edge of the burst pulse generates the positive peak of the clocked signal's low level. The interfering pulse at the receiver's input leads to a signal processing malfunction (a brief change of the switching state) shown as the red curve in *Figure 5*. As a result of the rise of the disturbance intensity the resulting currents and voltages at other signals also increase. To better compare the results, the pulse voltage is limited to 500 V. Four different connector configurations in the described system are measured and compared. The pulse levels are used to calculate the coupling inductance according to *Eq. 2*.

The inductance values are compared to those of coupling inductance measurements which have been performed at the same connector. For this model the same connector is utilized and measured using the coupling inductance measuring station. The following configurations were compared:

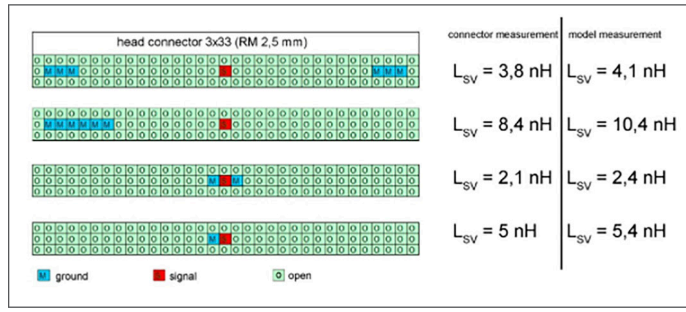


Figure 6: Compared Configurations and Measuring Values for the Coupling Inductance

The comparison reveals how closely the measuring results correspond. The values measured directly at a connector are more accurate than values measuring a complete system because of the system's rather high parasitic effects. However, all disturbances in the system can be described solely through the coupling inductance parameters.

Furthermore the generated signal levels can be calculated using the measured coupling inductance and a valuation of the device's maximum disturbance can be derived.

→ These results fulfil three requirements for a connector's EMC parameters

- Computability
- Measurability
- Applicability for immunity and emissions interference

Eq.1 can be used to calculate the limit value observation of the connector's applicability. Via *Eq.1*, application-related projects can be converted into limit curves of the connectors.

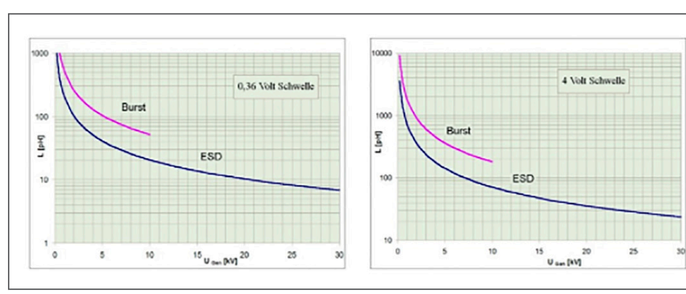


Figure 7: Coupling Inductance Limit Curves for Different Switching Thresholds (0.36 Volt threshold / 4 Volt threshold)

These curves show, in first approximation, what coupling inductance a connector requires to be error-free at different switching thresholds.

DIFFERENTIAL TRANSMISSION SYSTEMS AS A SPECIAL CASE

Inductance is closely linked to a connector's design. This is also true for differentially-operating transmission systems. However, two different couplings modes must be distinguished within these systems. This is shown in the following figure.

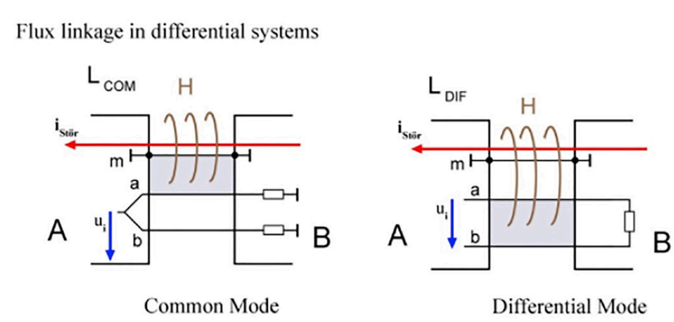


Figure 8: Various Coupling Types in Differential Systems

The common-mode influence on differential systems corresponds to the above described coupling in single signal systems. The coupling inductance equally affects both conductors of the differential transmission path. Both signal conductors' potentials are evenly shifted towards the electronic reference system via the coupling inductance.

The magnetic field that passes through the differential signals causes the transmission signal potentials to shift relative to one another. The description of this effect is analogous to that of the coupling inductance of the common mode ratio. Due to the typical setup of a differential transmission path, the differential-mode coupling inductances have a lower value than the common-mode coupling inductances. The following Figure describes the different modes of action for both types of inductive coupling.

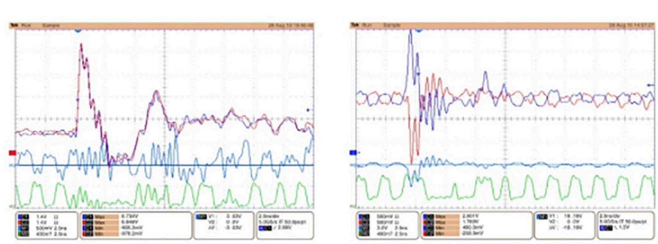


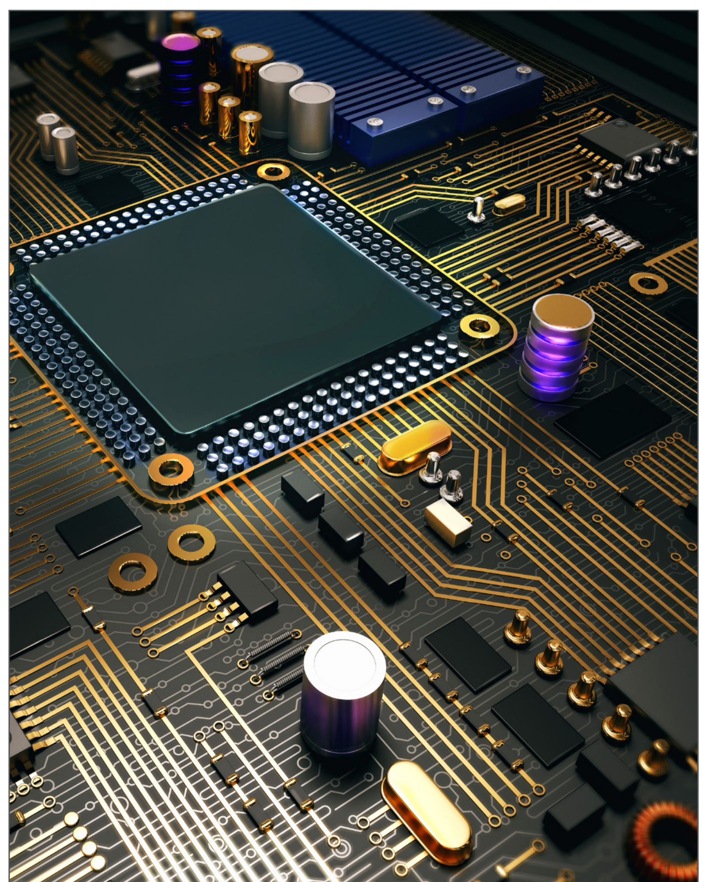
Figure 9: left, Common Mode Inductance; right, Differential Mode Inductance

Both graphs display the effect of an ESD (150 pF; 330 Ohm) on a low-voltage differential system (LVDS) transmission system. For these two measurements the two coupling types were realized using special adaptors, each of which generated one of the coupling types – common-mode and differential-mode. This measurement must be done with two adaptors to show the different effects because real-world effect is, in fact, the sum of both coupling types. The inverse signals (red, blue) are the two differential data lines of the LVDS system. The green signal displays the measurement of the output signal of the receiver. The left image shows the uniform increase of both differential signals. The pulse shape of the interference illustrates a differentiation of the ESD-gun's disturbance-current curve. This underlines the transformational transfer characteristic of coupling inductance. The receiver's output signal is also disturbed during the entire disturbance period. The figure on the right shows the potential shift of the differential signal pairs, which is caused by a total coupling of the ESD current into the signal lines via the differential-mode coupling adaptor. Both signal wires are deflected into different directions. Thus the transmission system is stressed beyond its limit leading to the interference of the output signal.

CONCLUSION

A connector with poor EMC characteristics can act as a bottleneck between otherwise well-designed devices, causing them to fail. By measuring coupling inductance, the connector's effect on the closed signals can be preemptively determined. With the aid of real system measurements, the accuracy of our model can be proved and interfaces (connectors) of entire assemblies can be designed for better EMC characteristics. This will lead to faster and simpler EMC testing in the future, so that assemblies will no longer be required only to be tested as a complete system.

When a module's limits are defined, it's EMC quality can be independently measured allowing problems to be identified early in the development stage and solved without the construction of a prototype.



SIMULATION IN EMC

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Introduction

Digitization and the spread of pervasive computing is at the forefront of the technology innovation that will shape our modern universe and it is already manifesting itself in IoT, 5G and autonomous vehicle spaces, to name just a few areas. As this spread of technology increases, so does the need to regulate it – in terms of how these devices and systems communicate (allocation of frequency spectrum, bandwidth, etc.), but also with respect to how they radiate unintended emissions and respond to interference. As more regulations and stricter requirements are put in place, electromagnetic compatibility (EMC) is becoming more relevant than ever before. Technology coexistence is of the essence.

SIMULATION AS A DRIVER IN THE EMC PROCESS

Typically, EMC testing is performed towards the end of product or system development cycle. One of the biggest risks is that an unexpected problem is uncovered during the testing phase, forcing a design modification and a delay in the product release until certification has been achieved. This raises the question: why wait until the end of the development cycle? EMC measurements are either carried out on-site or using certified test laboratories – and in many cases these measurements can be both time consuming and expensive.

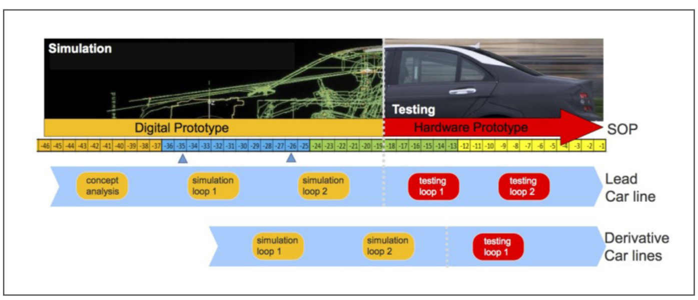

Figure 1: Simulation as a product development driver reduces hardware prototyping and facilities the EMC process

And here within lies the true value of incorporating electromagnetic simulation into the EMC process. Simulation can be applied throughout the product development cycle, making it possible to compare different concepts and design variations – not only from a performance perspective, but also with respect to EMC ability. As the product evolves, EMC aspects can be analyzed, e.g. comparing different component locations in a system or optimizing cable routing paths to minimize coupling. Rather than considering EMC as an afterthought, this approach will help predict and mitigate potential EMC issues much earlier in the process. Furthermore, simulations can give in-depth insight into the root cause of EMC issues (for example through visualization of the near-fields and surface currents) and in the development of more robust solutions.

CHALLENGES IN EMC SIMULATION

Of course, EMC simulation is not without its own set of challenges. Typically, EMC problems must be analyzed over a broad frequency range, often deal with multidimensional geometry, and finally contain multilevel complexity, e.g. components, connectors, cables, housing, antennas, radomes and the platform where everything is integrated. Each of these aspects implies certain numerical challenges, which must be addressed accordingly. For example, FEKO [altairhyperworks.com/feko] is a comprehensive electromagnetic simulation platform for antenna design, placement and EMC analysis. It has been developed with the goal of addressing the abovementioned simulation challenges. In short, several different solvers are available, offering true hybridization, model decomposition and special formulations for cables – all of which is towards providing seamless workflows for EMC analysis. Validation is also extremely important, and in[1] FEKO was validated for a variety of typical EMC applications.

The following section includes several industrial case studies where we will discuss some of these typical EMC challenges in more detail and describe how simulation was applied to solve them.

CASE STUDIES

Radiated Emissions & Immunity:

In the automotive industry, two types of EMC cases are primarily of interest: radiated emission and immunity tests. Radiated emission tests (component and vehicle level) deal with ensuring the emitted fields are below the required levels in the specified frequency bands.

Radiated Emissions - *Figure 2* shows simulations of the 10m radiated emissions for an electronic control unit (ECU) in a vehicle. Note that the geometric information of the ECU could not be disclosed by the supplier in order to protect their intellectual property. In this case, measurements were made for the ECU, which were imported into FEKO as an equivalent source and used for the vehicle level simulations. The figure shows that for most frequencies the ECU emissions from the vehicle are below the required level except between 500-600MHz where only one polarization meets the requirement. In addition to comparing the emission levels for different ECU locations in the vehicle, the coupling to a cable and a DAB windscreen (operating at 200MHz) were also considered.

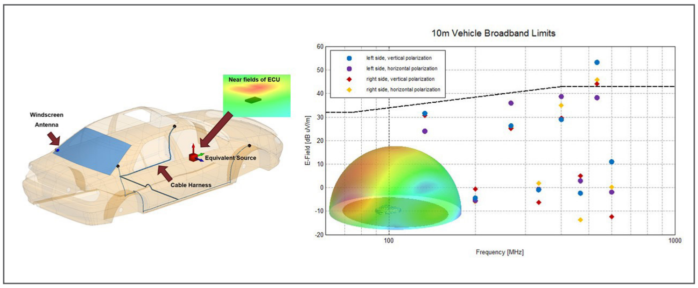

Figure 2: Vehicle level radiated emissions for an ECU – calculated at 10m on the left and right side of the vehicle, horizontal and vertical polarizations.

Radiated emissions are also specifically of interest in the context of electric and hybrid electric vehicles due to the high-power cables. In this case, radiation of harmonics generated by switching circuits in the IGBTs and DC-DC converters can increase the emissions. FEKO can be used to simulate how different cable path routing and cable shielding configurations can reduce these emissions.

Radiated Immunity - Radiated immunity involves ensuring that the vehicle sub-systems continue to operate with expected behavior under the influence of external electromagnetic disturbances, for example, testing that the airbags still deploy correctly when the vehicle is radiated by high intensity fields. In these cases, simulation can help to determine the optimum locations for a sensitive ECU or best routing cable paths.

As an example of real use case, FEKO is used for the simulation of the automotive immunity tests according to the ISO 11451-2 substitution method[2]. In *Figure 3*, one can see the model of a sedan in FEKO and the considered simulation cases.

The comparison between measurements and FEKO simulations for one of the considered positions, i.e. P10, and when considering the transmitting antenna polarized vertically and placed in front of the vehicle (Front – Vertical). In the measurements two log-periodic antennas were used; the first one from 20 MHz to 200 MHz, and the second from 200 MHz to 1 GHz. In the simulation, a set of six dipoles represented each antenna, and the size of the dipoles was changed depending on the frequency band.

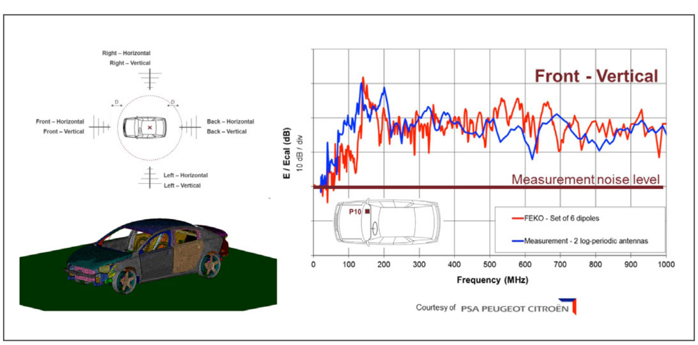

Figure 3: Full vehicle simulation test with ISO 11451-2 substitution method: Simulation cases (top left) and view of meshed vehicle in FEKO (bottom left). Simulations vs Measurements for Position P10. (right).

To obtain comparative results, the simulation and measurement data were normalized with their calibration values, respectively (E/Ecal). The comparative study between simulations and measurements shows a nice agreement up to 450 MHz, and for higher frequencies, there are some differences between simulation and measurement results caused by the effect of non-metallic parts of the structure that are not represented in the simulation model.

HIRF & LIGHTNING ANALYSIS:

While similar arguments for simulation can be used for aerospace applications, the physical size of the airplanes means that the cost, complexity and time needed for measurement is significantly higher. All of these factors further strengthen the idea of a simulation based EMC approach.

HIRF - In aerospace EMC, one area of great importance is understanding the field effects in and around the plane when it is exposed to an external field source – here the source could include high power transmitters (as covered by High Intensity Radiated Fields (HIRF)), or a direct lightning strike on a plane. Typically, the focus is to determine how external fields and currents induced on the airframe couple into the fuselage to electronic equipment and cables.

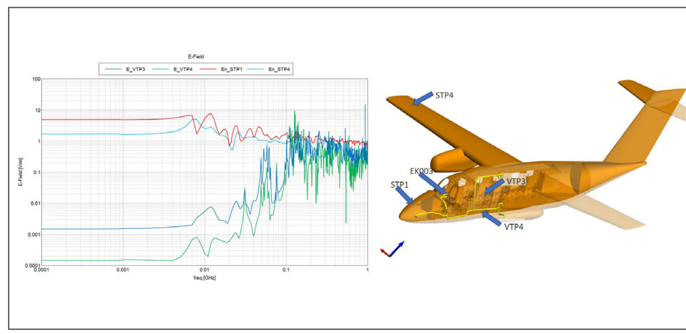

Figure 4: Aircraft geometry in FEKO (right) and corresponding HIRF results (left) at various points on and in the aircraft - part of the CEMEMC workshop and corresponds to a morphed version of EV55, Intellectual Property of EVEKTOR, spol. s r.o. and the HIRF SE Consortium (HIRF-SE FP7 EU project)

Figure 4 shows an example of an analysis carried out for a HIRF benchmark. The goal here was to simulate the induced fields at various locations on and in a small aircraft, and to calculate the induced currents at cable terminals inside the fuselage. The plane was illuminated by a plane wave excitation and the analysis was required to cover a broad frequency range from 100kHz up to 1GHz. The challenge here is that the largest electrical dimensions of the plane are approximately 50 wavelengths at the highest frequency. In order to solve the benchmark efficiently, the frequency range was divided into five frequency sub-ranges, such that different mesh densities could be assigned to each range. FEKO's Method of Moments (MoM) solver was used for the first two frequency ranges up to 100 MHz, while the MLFMM solver was used for the remaining 3 frequency ranges. This proved to be the most efficient approach to analyze the benchmark. From the simulated responses we can see that below ~5MHz the fields are constant. As the frequency increases we can see some resonant effect occurring, as well as an increase in the amplitudes of the 2 points inside the plane as the coupling of the external fields through the windows increases.

Lightning - Lightning analysis is conceptually similar to the above benchmark, but differs in two aspects, namely the frequency range and excitation type. Typically, lightning pulses are assumed to have a maximum bandwidth of a few MHz. The lightning pulse currents are mostly introduced into the simulation model using current sources fixed at 2 points on the plane fuselage – the strike point and exit point. Figure 5 shows such a simulation setup and the associated waveforms. FEKO offers time analysis capabilities enabling different pulse variations to be compared in a postprocessing step.

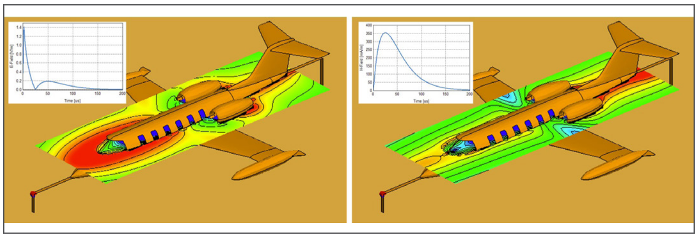

Figure 5: Lightning analysis of an aircraft showing the E(t) and H(t) fields 10us after the lightning pulse current is injected at the nose of the plane. The graphs show the fields waveforms probed near the cockpit windshield.

The increased use of lightweight and composite materials, like carbon fiber and radar absorbing material (RAM), has further motivated the need to use simulation for aerospace applications to help understand and predict the increasingly complex field interactions and couplings that occur when these materials are used. Materials like carbon fiber can be modeled in FEKO, making it possible to analyze, for example, how the fiber orientation influences coupling into the fuselage.

SHIELDING EFFECTIVENESS:

With the ever-increasing digital processor and bus speeds in electronic systems, unintended radiation from components and PCBs is becoming a more relevant issue. Designing electronics shielding for these systems is often a tradeoff between suppressing radiation and still providing sufficient airflow for heat transportation and cooling of the electronics. *Figure 6* shows the simulated shielding effectiveness for a PC tower from 100MHz-12GHz. While the behavior between 3-12GHz is relatively predictable (varying between -15 and -30dB), the behavior in the lower band is more interesting. For example, strong resonance phenomena can be seen at 334MHz and 1.78 GHz.

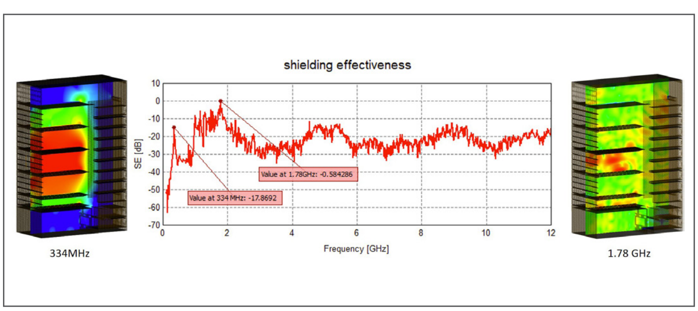

Figure 6: Shielding effectiveness for a PC tower calculated up to 12 GHz - the field distributions at two resonant frequencies are also shown.

Upon further inspection of the field distributions in the PC tower, it can be seen that these are caused by cavity modes that is are resonant in the tower. This is clearly visible at the lower frequency and less at the high frequency due to higher order modes. This example once again illustrates the advantage of a simulation-based approach – insight into the root cause of the problem was obtained through inspection of the near-fields (which in this case would be complex to measure). Based on this insight a design modification can be made to suppress resonant modes and improve the shielding effectiveness in this frequency range.

For some shielding applications, material models with more advanced properties are required, like ferrites and frequency selective surfaces (FSS). FEKO offers extensive material modeling possibilities, including the ability to handle ferrite materials, and also offers special features to design FSS structures efficiently.

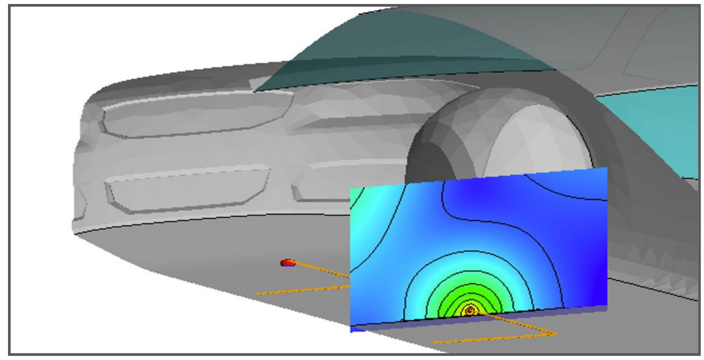

Figure 7: Magnetic field generated from a cable inside a vehicle, the simulation shows the shielding ability of the steel chassis at 10kHz.

In addition to the electronics applications shown here, FEKO is also used to calculate shielding in automotive applications. Here the analysis is typically related to calculating how the vehicle chassis suppresses the magnetic fields that are radiated, for example, from battery cables in electric and hybrid-electric vehicles. In this case, the frequencies of interest are typically much lower, in the kHz range. In this range the skin depth of the steel is comparable to the thickness of the chassis. From a numerical point of view, it is important that this is modeled correctly, something that FEKO also offers a special formalization for. *Figure 7* shows the simulated magnetic field radiated from a cable inside a vehicle at 10kHz.

CONCLUSIONS

While a broad range of different EMC applications from various industries were shown in this article, the main goal was to demonstrate how companies are embracing the use of simulation in the EMC process. While EMC was previously considered a verification step that was required at the end of the product development, simulation offers a platform to incorporate EMC during the product development, whereby increasing the likelihood of passing the final EMC certifications and at the same time reducing the number of physical prototypes. In the broader scheme of things this is our understanding of simulation driven design – it is a paradigm that we are seeing many of our customers are embracing going forward in their product designs.

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BASICS OF PASSIVE FILTERS FOR EMC COMPLIANCE

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Introduction

One of the roles of the practicing EMC engineer or product designer is to be able to design filters to add to circuits in order to get them to pass various EMC immunity and emissions standards such as IEC 61000-4-2 for ESD immunity, IEC 61000-4-3 for Radiated RF immunity and IEC 61000-4-4 for Electrical Fast Transient/Burst immunity and other various international standards covering Radiated Emissions (RE) or Conducted Emissions (CE). EMI filters are often used along with proper shielding in order to achieve EMC compliance. The purpose of a filter is to establish either a low-impedance path for RF current to return back to the local source of energy, and/or to provide a high impedance to prevent RF currents from flowing on a cable. However, selecting the proper filter for a given situation may be confusing to some, especially if they are new to the EMC field or have not dealt with the subject in some time. EMC practitioners may be asking themselves what filter configuration is the best one to use for any given application or how to correctly choose the values of components given the frequency, circuit impedance, and other parameters of the circuit. They may also want to know how they can get more attenuation out of their filter design in order to pass an emissions or immunity test. The time to learn how to properly design filters for EMC compliance is not when schedules are tight, and the product's ship date is rapidly approaching. If you find yourself stuck in any of the above situations, this article on passive filter basics for EMC compliance should help remove the mystery, and allow you to quickly find the best passive component filter solution that allows product to ship on time.

PASSIVE LOW-PASS FILTERS

Fortunately, designing filters for EMC compliance is not as difficult as it may seem. For most cases, in order to achieve EMC compliance, we really only need to know how to apply passive low-pass filter types to our circuits. The other types of passive filters, such as high-pass, band-pass, and band-reject are not as common as the low-pass filter is for EMC work and will not be covered in this paper. Consult the references for more information on these other filter types.

Unfortunately, circuit impedances are not always well understood or impossible to know, making it more difficult to determine which values of passive low-pass filter components to choose from in order to pass the EMC compliance tests. This is the situation with common mode emissions emanating off of a cable during a RE test where the impedance of the cable changes as it is rearranged in order to maximize emissions (*Reference [1]*).

It is impossible to model the filter exactly if the load impedance is not known. The only way to know if a low-pass filter design is adequate or not is by trial and error experiments performed during EMC compliance testing, or more preferably, by trying out different low-pass filter component values very early in the product development cycle. In order to be most effective, this experimental work should occur during pre-compliance testing performed in your own test facility prior to going out of house for full-compliance testing. See *Reference [3]* for a detailed description on how to setup an in-house pre-compliance EMC test facility.

A low-pass filter is one in which the frequencies below a certain significant frequency are easily let-through and those above this same significant frequency are heavily attenuated. A passive low-pass filter is a simple voltage divider; non-amplifying device composed of a combination of resistors and capacitors, inductors (or ferrites) and capacitors or in some instances, may be composed of just one of these components. For instance, a single capacitor placed across a line to reference ground without the resistor or inductor installed may be all that is required in order to suppress an unwanted signal.

The benefit to using a single component filter is that only one physical device is required which in turn requires less board space and also helps keep parts costs down. Multi-element filters are useful in situations where the range of frequencies involved is too large and impossible for a one component filter to fully attenuate.

RC LOW-PASS FILTER

One of the most basic forms of a low-pass filter is comprised of just one resistor and one capacitor, an RC filter. In an RC low-pass filter, the cutoff frequency occurs at resonance, where the capacitive reactance (X_c) equals the resistance (R) and where $X_c = 1/2\pi fC$ (*Reference [4]*).

A simple RC low-pass filter and the equation for determining its cutoff frequency is shown in *Figure 1*. Note that the filter shown in *Figure 1* is also known as an L filter due to its resemblance to the letter L. It is also considered a single-pole filter because there is only one reactive component, the capacitor.

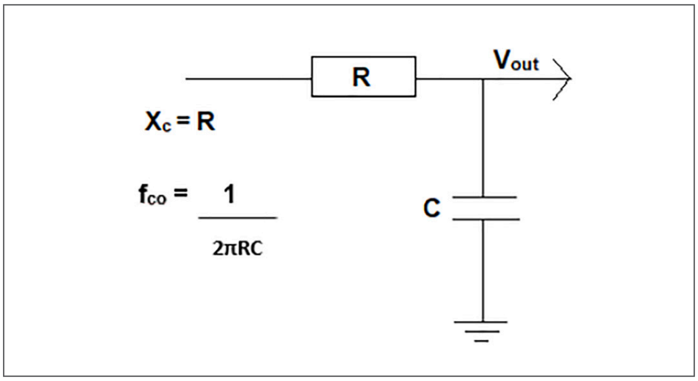


Figure 1: Basic RC Low-Pass Filter (L Type)

A low-pass filter has an ideal, theoretical response where all signals contained below a so-called critical frequency (the 3 dB down point) are easily let-through the device and above which frequency, all signals are heavily attenuated. An ideal low-pass filter response curve is shown in *Figure 2*.

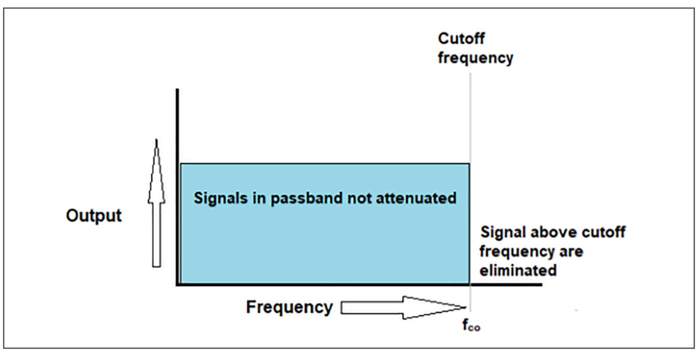


Figure 2: Ideal low-pass filter response curve

In actual practice, the output of the filter will not go to zero as abruptly as shown in the ideal curve of *Figure 2*. In actuality, the output will gradually roll off at a 6 dB/octave or 20 dB/decade rate as shown in *Figure 3*.

EMC APPLICATION OF LOW-PASS FILTERS

Reference [3] suggests applying a low-pass filter in order to fix an EMC problem such as a fast transient or ESD discharge immunity issue and that a good starting point in putting together a low-pass filter that will work for most situations is to start out by using a 47 to 100Ω series resistor placed in the signal line, with a 1 to 10nF capacitor placed in the signal or power return line. If we take this information and select R = 100Ω and C = 10nF as a starting point, the cut-off frequency (f_{co}) will equal approximately 159 kHz, and the low-pass filter response curve should look like that shown in *Figure 3*. Very little of the signals that are greater than 1.59 MHz will be let through the filter as they are 20 dB lower than any of the signals that at the filter's cutoff frequency of 159 kHz.

As another example, if we leave R = 100Ω and select C = 1nF, the cutoff frequency at the 3 dB down point moves out to roughly 1.59 MHz, the 6 dB down point is at 3.2 MHz, and the signal is almost completely attenuated at 15.9 MHz. Signals greater than 15.9 MHz are heavily attenuated and not let through the filter.

Table 1 contains a matrix of the various R-C low-pass filter values discussed so far plus some others that might be useful, and their low-pass filter characteristic responses at the 6 dB and 20 dB down points.

When attempting to suppress an unwanted high-frequency signal, one may find out that a filter containing only a single reactive component (i.e. one capacitor or one inductor) may not provide enough attenuation. Adding a second reactive component will increase the roll off to 12 dB/octave or 40 dB/decade (*Reference [4]*). These types of filters are called various names such as double-pole, two-stage, two-element, or second-order filters. Filters with three reactive components will provide 18 dB/octave or 60 dB/decade attenuation. Four reactive component filters will provide 24 dB/octave or 80 dB/decade attenuation and so on (*Reference [2]*).

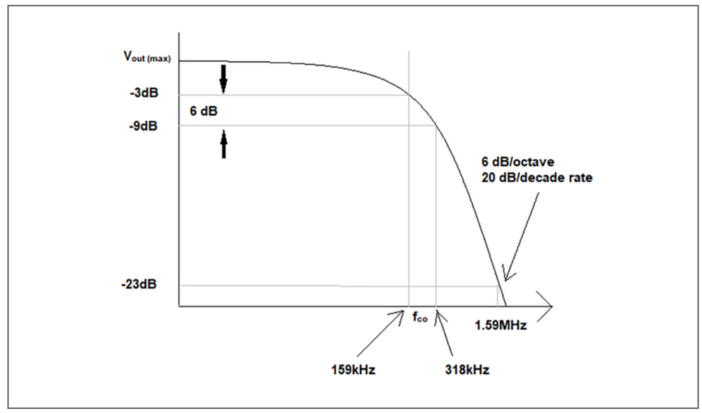


Figure 3: Realistic low-pass filter response curve

R	C	f_{co} (-3 dB Point)	-6 dB Point	-20 dB Point
200	10nF	79.6 kHz	159.2 kHz	795.8 kHz
100	10nF	159 kHz	318 kHz	1.59 MHz
49	10nF	325 kHz	650 kHz	3.3 MHz
20	10nF	796 kHz	1.6 MHz	7.9 MHz
200	1nF	796 kHz	1.6 MHz	7.9 MHz
100	1nF	1.59MHz	3.2 MHz	15.9 MHz
49	1nF	3.3 MHz	6.5 MHz	32.5 MHz
20	1nF	7.9 MHz	15.9 MHz	79.6 MHz
200	100pF	7.96 MHz	15.9 MHz	79.6 MHz
100	100pF	15.9 MHz	31.8 MHz	159.2 MHz
49	100pF	32.5 MHz	65 MHz	325 MHz
20	100pF	79.6 MHz	159.2 MHz	796 MHz

← Plotted in Figure 3 (row R = 100, C = 10nF)

Table 1: Matrix of R-C Values and Low-Pass Filter Reponses

SELECTION OF F_{CO}

When selecting a cut-off frequency for a low-pass filter, it is important to take into account the fundamental frequency of the intended data, clocks, and other purposeful signals present on the filtered line. If the cut-off frequency chosen is too low in frequency, then the intended signals will be attenuated along with the higher frequency signals that you want to suppress. Try to maintain at least the 5^{th} harmonic of the intended signal, with the 10^{th} harmonic being ideal (*Reference [3]*). Many I/O signals that are used with unshielded cables require some form of filtering in order to be in compliance with EMC standards. These signals usually have a frequency of 1 MHz or less (*Reference [1]*). It is important to also ensure that by adding a filter's impedance to circuit that it does not in turn create a signal integrity problem.

Once the filter's component values are chosen, carefully consider where it is going to be placed in the circuit or system. The most benefit is obtained when the filter is placed as close to the item to be protected as possible, one centimeter is ideal for most designs

(*Reference [1]*). In order to keep any extra unwanted inductance from affecting performance of the filter, be sure to keep lead lengths as short as possible. Additional layout and placement concerns will be covered later in this article.

USE OF FERRITES

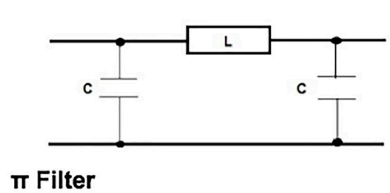
If the voltage drop across the series resistor cannot be tolerated, a device such as a ferrite, which acts as a high-frequency resistor with minimal voltage drop, can be used instead of the resistor. Because the ferrite presents the circuit with high AC impedance, while also not affecting signal quality, they are most optimal for filtering at frequencies greater than 30 MHz. Carefully consider the amount of DC or low-frequency current present in the circuit when using ferrites. They can become easily saturated with too much current present in the circuit which renders them ineffective (*Reference [5]*).

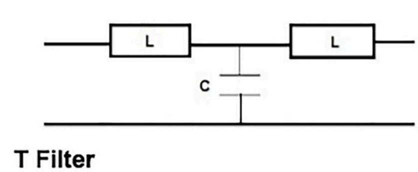
USE OF INDUCTORS

An inductor can also be considered for the series element in a low-pass filter instead of a resistor or ferrite, particularly if dealing with a signal in the 10 to 30 MHz range. When using inductors, beware of the effect that their inductive reactance ($XL = 2\pi fL$) and parasitic capacitance will have at these higher frequencies. You may be actually creating a high-pass filter when you are attempting to create a low-pass one, and not even realize it.

BASIC FILTER TOPOLOGIES

The following diagrams show two more of the basic filter configurations available for impedance mismatching between circuit source and load input and output impedances and filter input and output impedances. Both are named after their shapes. The first is called a π filter because it looks like the Greek letter π and the second is called the T filter because it looks like the letter T. Note that there are three reactive elements present in these filters which means they an attenuation curve of 18 dB/octave and 60 dB/decade. They are considered third-order filters (*Reference [5]*).





IMPEDANCE MISMATCHING

Source and load impedances must be considered in selecting the proper filter configuration. If order to work properly, the source driving the input to the low-impedance shunt element (i.e. capacitor), should be a high-impedance. If the output of the source is a low-impedance, it should face the high-impedance series component. This same concept applies to load input impedances versus the filter's output impedances. In general, a source or load impedance less than 100 Ω is considered low and great than 100Ω is considered high impedance (*Reference [5]*). *Table 1* provides a matrix of source versus load impedances and their associated correct filter topologies.

Source Z	Load Z	Filter Configuration	Analysis
High (>100Ω)	High (>100Ω)	Shunt Element (Capacitive) or π Filter	Use π filter if greater roll-off is required.
High (>100Ω)	Low (<100Ω)	L Filter	The shunt element should face the High Z source and this element should face the Z load.
Low (<100Ω)	Low (<100Ω)	Series Element (Inductive) or T Filter	Use T filter if greater roll-off is required.
Low (<100Ω)	High (>100Ω)	L Filter	The shunt element should face the High Z load and the series element should face the Low Z source.

DIFFERENTIAL MODE (DM) AND COMMON MODE (CM) CURRENTS

There are two different types of current modes, and hence noise sources capable of creating interference. It is important to know which mode is prevalent so that proper filtering can be applied. The two types of signals we are referring to are differential mode (DM) and common-mode (CM) signals.

DM signals carry useful information whereas CM currents provide no useful information what-so-ever and are the main source of RE and CE issues. A DM signal travels down one side of a circuit path, and an equal and opposite DM signal travels back on the other side of the path. If no circuit discontinues exists, then complete canceling of these two DM signals occur, and no CM current is developed. Placing capacitors across the outgoing and return lines and/or an inductor in series with either outgoing or return line is called DM filtering.

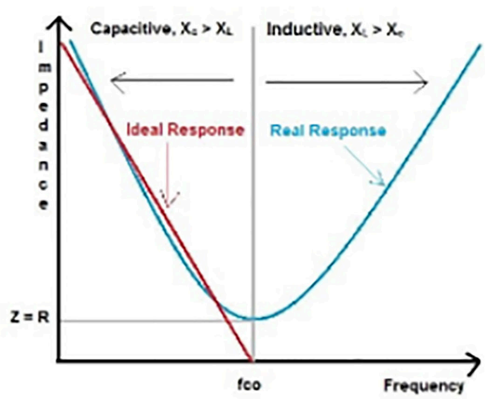
CM signals are in-phase signals present in both outgoing and return lines of a circuit. They do not cancel each other out but add up, often to a level substantial enough to cause EMI issues. CM filtering involves placing capacitors across each signal line to ground reference and sometimes also using a CM inductor in the circuit. The CM inductor only acts on the CM signals that are present. It does not affect the DM signals.

PARASITICS

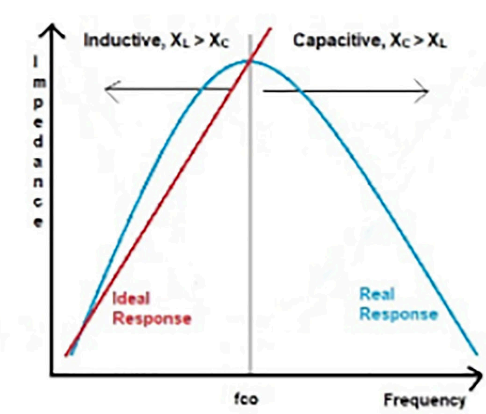
The non-ideal behavior of the elements that make up our filter must be addressed. Unexpectedly, we will find that real capacitors and inductors possess both capacitance and inductance which limits the bandwidth that they are useful over. The amount of parasitics present in a circuit can be reduced through proper component selection and layout techniques, but cannot be eliminated entirely. As frequency increases, the reactance of a capacitor decreases until it reaches its self-resonant frequency. Up to this point, the capacitor is behaving as it should – it behaves like a resistor. Above its self-resonant frequency point the capacitor becomes inductive and it acts like an inductor because of the parasitic inductance found in its metal plates. This parasitic effect is greater in leaded types of capacitors than it is with the surface mount technology (SMT) types that have almost no lead length.

The opposite effect occurs with an inductor where its reactance becomes capacitive above its self-resonant frequency point, and where the inductor now acts like a capacitor. At the self-resonant frequency, capacitors are intended to provide a very low impedance and inductors should provide a high impedance. For inductors, their limiting factors are related to the parasitic capacitance present between each winding and overall capacitance located between one lead and the other.

The inductor's inter-winding parasitic capacitance is not as big a deal in regards to effectiveness for EMI suppression as is a capacitor's parasitic inductance. The main factors that change the intended behavior of capacitors is the parasitic inductance of the circuits in which they are installed, not necessarily the construction of the capacitor. Therefore, proper layout and placement then becomes the critical factor when attempting to effective utilize passive low-pass filters for EMI suppression.



Capacitor Characteristics



Inductor Characteristics

LAYOUT AND PLACEMENT CONCERNS

Because there is going to be unknown and hidden parasitics involved, do not expect your filter design to work one-hundred percent the first time. As mentioned earlier, expect the need to perform some trial and error design and troubleshooting in the lab. If not available already, have on hand a selection of various components that you want to try out. Do not wait until the last minute to obtain the SMT capacitors, inductors, or ferrites that you want to use. Make sure the components selected are designed for the bandwidths involved. Create your own matrix of values, critical frequencies, and 6- and 20-dB roll-off curves.

In reviewing the layout, look for longer than necessary trace lengths that add extra inductance and impedance. When applying fixes, be sure keep connections short. If an R-C filter is added to the reset pin of a micro-controller, place it as close to the pin as possible and do not overlook the length of its return trace. In general, it is best to locate the filter as close to the offending signal source as possible, not some obscure location far away.

Watch out for trace or wire routing that allows for too much capacitive and inductive coupling to other noisy signal or traces. Filter components should be placed right at an entry connector (I/O and power inputs). Placement of a filter deeper inside a circuit or system allows EMI to enter the system (*Reference [6]*). If separation is not maintained, improper routing of input and output sections can mean that filter elements are essentially bypassed and no longer effective. On PCBs, capacitors should shunt unwanted signals to chassis not line to line or line to return (*Reference [6]*). It is best to understand the path of current flow and to not necessarily rely on "ground" as being the ultimate zero-ohm impedance and sole problem savior.

Finally, although they appear to be useful and easy to troubleshoot with, do not expect too much out of clamp-on ferrite common-mode chokes as they only provide about 10 dB of attenuation (*Reference [3]*).

CONCLUSION

The need to utilize passive low-pass filters to obtain EMC compliance is a given. They provide a low-impedance path for RF currents to return back to the local source of energy or provide a high impedance to prevent unwanted RF currents from flowing. A filter that does both is ideal. Designing low-pass filters for EMI suppression is not that difficult. Proper knowledge and planning before the need for them arises can save developers some time and headaches.

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WHAT IS THE DIFFERENCE BETWEEN CISPR 13/22 AND CISPR 32?

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Introduction

CISPR 32 was finally published in 2012 and the 2nd Edition was published in 2015. CISPR 13 and CISPR 22 were withdrawn by the IEC in March of 2017. CISPR 32 replaces CISPR 13 (broadcast receivers) and CISPR 22 (ITE) for emissions limits. What changed?

As a quick look back, why was CISPR 32 written in the first place? Back over 15 years ago there was a convergence in television receivers where the old broadcast receiver and the computer were placed in the same box – the digital television receiver. As the digital television receiver contained both a broadcast receiver and a computer in the same box two emissions standards applied. CISPR 13 was the standard for broadcast receivers and CISPR 22 was the standard for Information Technology Equipment (ITE), a fancy term for computers and their peripheral devices. Manufacturers of digital television receivers now had two emissions standards to which they had to test. This led to different limits and different test setups and twice the testing. Management was not pleased.

In 2001 CISPR SC E (Broadcast receivers) and CISPR SC G (ITE) were merged into CISPR SC I (Broadcast receivers, ITE and multimedia equipment. CISPR SC I was tasked with the maintenance of existing standards for SC E and SC G (CISPR 13, 20, 22 and 24) and the creation of new standards to merge them (CISPR 32 and CISPR 35). What started out as a several year project turned into an 11 year project (CISPR 32, Ed 1) and a 14 year project (CISPR 35). CISPR 32 Ed 2 was published in 2015 with a few important changes. When CISPR 32 was published the people who were used to CISPR 13 seemingly had a number of changes to test setups and limits, while users of CISPR 22 had only a few changes to accommodate.

COMPARISON BETWEEN CISPR 13 AND CISPR 32

Limits and Types of Tests

What changed here? Just about everything. Well, not quite, but labs used to testing to CISPR 13 had some significant differences to deal with.

CISPR 13 had limits for the "disturbance voltage at the mains terminals". These covered the frequency range of 150 kHz to 30 MHz. CISPR 32 has limits for "conducted emissions from the AC mains power ports of Class B equipment", also covering the frequency range of 150 kHz to 30 MHz. The limits are the same for CISPR 13 and Class B devices in CISPR 32. The key difference is that CISPR 13 had, as an alternative to the quasi-peak and average detector limits the option of using the RMS-average detector, something not presently allowed under CISPR 32.

CISPR 13 had limits for "disturbance voltage at the antenna terminals" and "wanted signal and disturbance voltage at the RF output of equipment with incorporated or with add-on RF video modulator". These limits (and their frequency range) were dependent upon the type of EUT and whether the signal being measured was a wanted signal or not. The frequency ranges covered were dependent upon the type of EUT, but ran (worst case) from 30 MHz to 2.15 GHz for both tests. CISPR 32 terms these a bit differently and, for Class B devices, breaks them down into "asymmetric mode conducted emissions" and "conducted differential voltage emissions". The "asymmetric mode conducted emissions" limits cover the frequency range of 150 kHz to 30 MHz and the "conducted differential voltage emissions" limits cover the frequency range of 30 MHz to 2.15 GHz. While there is similarity in the types of ports covered, a careful reading of CISPR 32 is required to make the switch.

CISPR 13 had limits for "disturbance power", measured with an absorbing clamp over the frequency range of 30 MHz to 300 MHz. There is no corresponding test in CISPR 32.

CISPR 13 had limits for "radiated disturbances" measured at a distance of 3 meters over the frequency range of 30 MHz to 1 GHz. Different limits were provided for the fundamental of the local oscillator, harmonics of the local oscillator and "other" emissions. CISPR 32 provides limits for "radiated emissions at frequencies up to 1 GHz", "radiated emissions at frequencies above 1 GHz" and "radiated emissions from FM receivers". The CISPR 13 limits for radiated emissions from "other" are the same as the Class B limits measured at 3 meters in CISPR 32 up to 1 GHz, while CISPR 32 has limits from 1 GHz to 6 GHz that did not exist in CISPR 13. The limits for radiated emissions from FM broadcast receivers are the same in both standards.

CISPR 13 had limits for radiated power of "tuner units of direct to home satellite receivers" and radiated power of "outdoor units of direct to home satellite receivers". There were no comparable limits in CISPR 32, Edition 1, but CISPR 32, Edition 2 added limits for "outdoor units of home satellite receiving systems. There are key differences, however. CISPR 13 has limits for radiated power in dB(pW) for both tuner units and outdoor units. CISPR 32 has limits for radiated field strength in dB(uV/m) for outdoor units, with the option noted below for conducted power measurement for local oscillator leakage. CISPR 13 had limits covering the frequency range of 1 GHz to 3 GHz for tuner units and 0.9 GHz to 18 GHz for local oscillator leakage and 1 GHz to 18 GHz for equivalent radiated power from the outdoor unit including the local oscillator leakage. CISPR 32 has limits for radiated emissions from the outdoor unit from 30 MHz to 18 GHz. The limits from 30 MHz to 1 GHz are the same as the radiated emissions limits for all Class B devices as given in that table (A.4). Local oscillator leakage has the option of being measured as a radiated emissions at a distance of 3 meters or as a conducted power. In either case the emissions are measured from 1 GHz to 18 GHz.

EUT AND TEST METHOD DIFFERENCES

One bone of contention that came up in the discussions that lead to the creation of CISPR 32 was a difference in EUT configuration between CISPR 13 and what ultimately was included in CISPR 32. Specifically, the treatment of unused ports on the EUT. There was concern that CISPR 13 required that unused ports be left unterminated during disturbance power measurements and that CISPR 32 would follow the model in CISPR 22 where each type of port must be terminated. This, ultimately, was not an issue as CISPR 32 does not contain disturbance power measurements in the range of 30 MHz to 300 MHz. This matter is not addressed in the section of CISPR 13 discussing radiated emissions testing from 30 MHz to 1 GHz, allowing for some confusion, but in the section discussing testing of radiated emissions from 1 GHz to 18 GHz the text requires that "The unused output terminals, if any, of the equipment under test shall be terminated with their nominal impedance by means of non-radiating leads".

The measurement methods for radiated emissions testing are similar, but not identical for the two standards. CISPR 13 and CISPR 32 use different means of determining the acceptability of a test site. CISPR 13 has site attenuation measurements conducted over the frequency range of 80 MHz to 1 GHz, where CISPR 32 requires normalized site attenuation measurements over the frequency range of 30 MHz to 1 GHz. CISPR 32 also has requirements for the site from 1 GHz to 6 GHz. CISPR 13 provides specific dimensions for the ground screen, which differ from what CISPR 32 requires. CISPR 13 does not provide guidance on the size of the clear area surrounding the ground screen, where CISPR 32 does (and experience has shown that the dimensions in CISPR 32 are too small). CISPR 13 requires the use of a ½ wave tuned dipole antenna from 80 MHz to 1 GHz and a dipole tuned to 80 MHz for testing from 30 MHz to 80 MHz. The option of using biconical, log periodic or other linearly polarized antennas, as allowed in CISPR 32, does not exist in CISPR 13. CISPR 13 requires a height scan of 1 meter to 4 meters for horizontal polarity and 2 meters to 4 meters for vertical polarity, where CISPR 32 requires a height scan of 1 meter to 4 meters for both polarities with the caveat that the antenna shall not be closer to the ground plane than 0.25 meters (thus limiting the lower height of the antenna depending on the frequency of interest when a dipole antenna is used).

CISPR 13 has a statement in Clause 6.1 that says that once a detector (or detectors) has been selected "it shall be used for all phenomena". So, if you use the peak/quasi-peak/average detector for one test, you must use it for all tests. Likewise, if you use the RMS-average detector for one test, you must use it for all of them. Likewise, the clause requires that a re-test of the product must be performed with the same detector as shown in the original test report.

COMPARISON BETWEEN CISPR 22 AND CISPR 32

Limits and Types of Tests

The limits and types of tests are very similar between CISPR 22 and CISPR 32, except that CISPR 32 Edition 2 provides limits for radiated emissions from FM receivers and outdoor units of home satellite receiving systems and for conducted differential voltage emissions (which deal with emissions from local oscillators and their harmonics). The limits, where the same tests are called out, are the same, except that CISPR 22 allows testing at lesser distances than 10 meters for small class B devices and CISPR 32 specifically calls out limits for testing radiated emissions at either 3 meters or 10 meters. CISPR 32 calls out limits based on the concept of "ports", which had previously been called out in CISPR 24 for immunity of ITE devices. Much detail is provided in showing how ports are defined and how modules which are sold separately from the host system are to be tested. The means of determining the maximum frequency for radiated emissions testing based on the highest frequency used internally in the EUT is the same between CISPR 22 and CISPR 32.

EUT AND TEST METHOD DIFFERENCES

A couple of key differences between CISPR 22 and CISPR 32 are the test message on displays and the determination of the point of the EUT to which the measurement distance is determined.

CISPR 22 (and ANSI C63.4 in the US) calls for a test pattern or message on a display consisting of the letter H, repeated across the screen and then for each successive line. This is commonly referred to as "scrolling Hs". While this is still acceptable for CISPR 32, it is listed as the 3rd level of complexity and is limited to use for "POS terminal, computer terminal without graphic capability". A standard computer display is to use color bars with a moving picture element. This preference comes from the need in CISPR 35 for a display that has a moving element to detect a freeze on the part of the circuits updating the display during immunity testing and the requirement that as much commonality as possible between CISPR 32 and CISPR 35 be provided. This move away from scrolling Hs for the test message for displays is causing a great deal of discussion within CISPR SC I, as well as in the industry, as it presently requires double testing of products using a display, much to the consternation of test engineers and managers. About the only real winners are the test labs as their business has increased. There is work on-going in CISPR SC I to deal with this issue.

The other key difference is in how the measurement distance is determined. CISPR 22, clause 10.3.1 Antenna-to-EUT distance states, "Measurement of the radiated field shall be made with the antenna located at the horizontal distance from the boundary of the EUT as specified in Clause 6. The boundary of the EUT is defined by an imaginary straight-line periphery describing a simple geometric configuration encompassing the EUT. All ITE intersystem cables and connecting ITE shall be included within this boundary (see also *Figure 2*)." CISPR 32, clause C.2.2.4 Boundary of the EUT, local AE and associated cabling and measurement distance for radiated emissions measurements states, "The measurement distance is the shortest horizontal distance between an imaginary circular periphery just encompassing this arrangement and the calibration point of the antenna. See *Figure C.1* and Figure *C.2*." How is this different?

The method called out in CISPR 22 (and never followed in any laboratory the author has seen) requires that as the turntable is rotated the antenna mast must be moved forward and backward to maintain the measurement distance between the boundary of the EUT and the antenna. The method called out in CISPR 32 does away with this and simply defines a circle which encompasses the EUT, its peripheral devices and cables. The measurement distance is simply the distance between this circle and the antenna. No movement of the antenna mast is required as the turntable is rotated. While the method in CISPR 22 might have been "more accurate", the method in CISPR 32 is far more practical. The other alternative, used in some labs in the past, was to measure from the center of the turntable to the antenna. This resulted in a shorter measurement distance than called out in the standard and allowed for a built-in margin that the lab didn't need to disclose to the design team. Sneaky, but effective at times.

CONCLUSION

CISPR 32 is more closely aligned with CISPR 22 than with CISPR 13. The limits, where commonality exists, are very similar, if not identical, between all three standards. The differences lie in the details and in tests that were required in CISPR 13 that are not contained in CISPR 32. CISPR 13 and CISPR 22 were withdrawn by the IEC in March 2017, so they can be expected to disappear from national regulations over time and be replaced by CISPR 32. In the EU, for example, EN 55022:2010 was replaced by EN 55032:2012. This occurred on March 5, 2017. Note that EN 55032:2012 is based on CISPR 22 Edition 1 and that a version of EN 55032 based on CISPR 32 Edition 2 has not yet been published in the Official Journal (OJ) of the EU under the EMC Directive.

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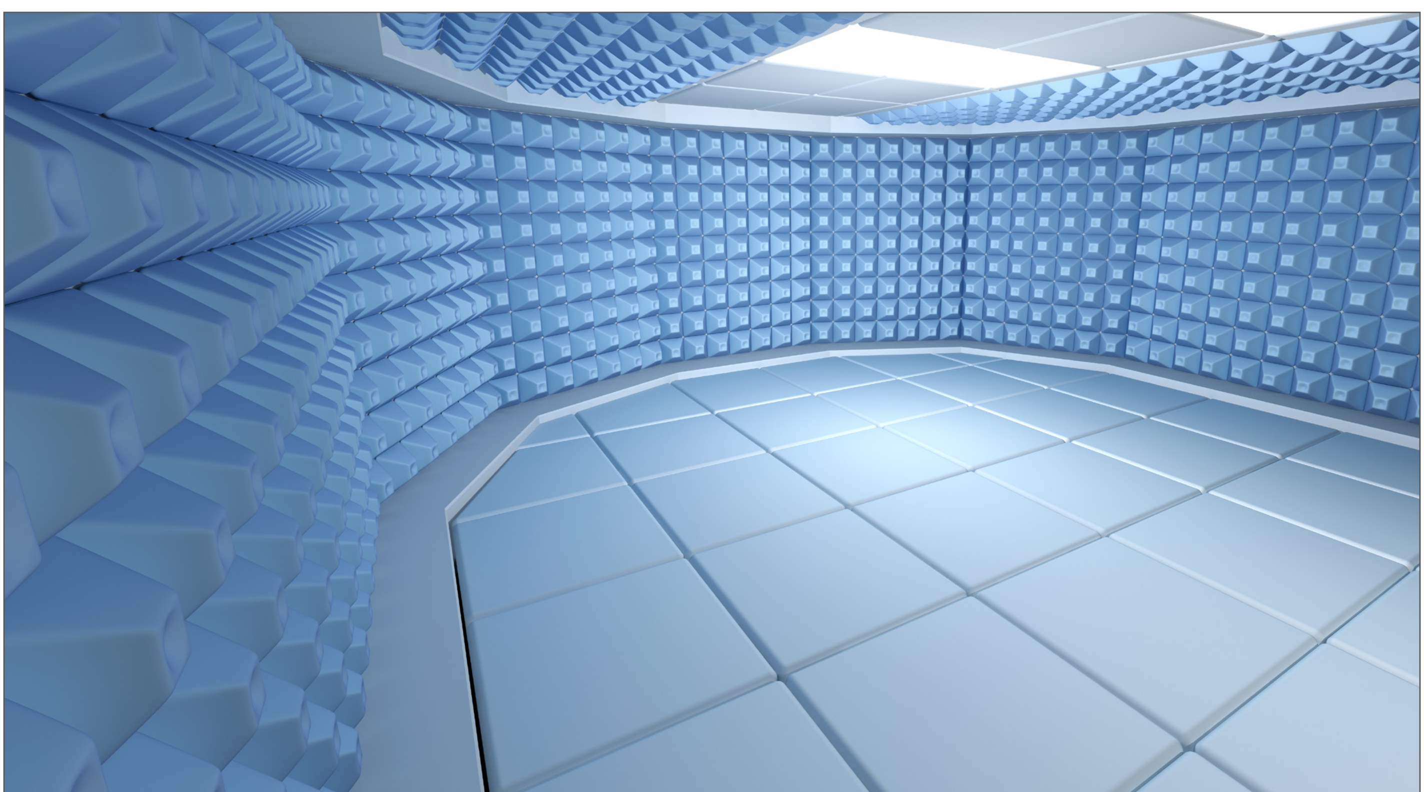

ESD AND DIGITAL ISOLATORS

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Introduction
Digital isolators are commonly used in the automotive, aerospace and medical industries. These isolators are usually rated to withstand up to 5kVrms/1min isolation. Datasheets for digital isolators usually have specifications for transient immunity. This specification can be easily misinterpreted as an ESD rating, but it is not. Transient immunity is the amount of transient energy seen on signals across the barrier when the transients cross over from one side to the other. Some manufacturers of digital isolators have specifications for ESD, but most of them are tested per the Human Body Model (HBM) standard.

Though HBM is usually adequate for the controlled ESD environments such as the manufacturing assembly lines, complying with HBM is not sufficient enough for system level testing. ESD strike levels, voltages and currents, can be much greater in the product's environment of use during its lifecycle. System level ESD tests must be considered when selecting a digital isolator in a particular design. The design engineer needs to be familiar with the industry preferred ESD standard, IEC 61000-4-2 for system level ESD compliance. Understanding the ESD tests, methods and pulse shapes will help in deciding on layout, component placement, appropriate ESD protection methods, etc. The most significant difference between the HBM standard and the IEC 61000-4-2 is the peak current level during a discharge associated with a differing voltage, discharge capacitor and the series resistance.

Frequency (MHz)	Peak Current (A) Human Body Model	Reflectivity hybrid (dB)
2	1.33	7.5
4	2.67	15.0
6	4.00	22.5
8	5.33	30.0
10	6.67	37.5

The table above compares the current released during the IEC 61000-4-2 test vs. the Human Body Model [1]. If the ESD rating for a semiconductor on manufacturer's datasheet sates 8kV and does not specify the standard, it is most likely tested to HBM. 8kV HBM ESD immunity is not the same as the 8kV IEC 61000-4-2 ESD immunity. The peak current released during an 8 kV HBM discharge is less than the peak current discharged during a 2 kV IEC 61000-4-2 strike and, at 8 kV (a common system level ESD requirement), the peak current for an IEC 61000-4-2 discharge is over 22 times higher than the level most high performance semiconductors are designed to withstand [1]. It is important to read the datasheet thoroughly and reach out to manufacturer representatives for clarifications on their ESD ratings. For example, Texas Instruments (TI) had an isolator, ISO764x that had an ESD rating per HBM. However, they realized that testing to HBM was not sufficient enough and released an updated part, ISO784x which is rated to 8kV contact discharge (according to IEC 61000-4-2) at the pins of the isolator. It is a direct replacement for ISO764x series. Similarly, Analog Devices updated their ADuMxxxx digital isolator series with enhanced ESD protection. Analog Device's application note [2] goes over details of their improvements, tests, and design recommendations for the best ESD proof isolator integration into a particular design.

Even if the ESD protection at the pins of the isolator can withstand contact 8kV strike, it does not mean it is immune. The fact that digital isolators are used across isolation barriers makes them more susceptible to the broadband noise emitted by high level ESD pulses. For example, a 15kV air discharge ESD current pulse can cross isolation barriers that are less than 14mm wide through the barrier capacitance. As the ESD currents cross the barrier, charge currents form to fill up the barrier capacitance. These currents oscillate because of the transient effect of the IEC 61000-4-2 ESD pulse, which has less than a 1ns rise time, and which excites inductances and parasitic capacitances that form a tank circuit. The Ampere value of currents crossing the barrier depends on the capacitance of the barrier. The smaller the capacitance the larger the voltage, but there is a cutoff point. Digital isolators that transfer data from side 1 to side 2 using RF/capacitive coupling are susceptible to interference. Some isolators use On/Off keying to mimic 1s and 0s. ESD currents or voltages that form near isolators can radiate in the amount of 1kV/mm or 1kA/mm2 [3]. When the RF interference couples into the receiver inside the isolator that may leave the input to the receiver in an unknown state. Depending on the type of isolator (inverting vs. non-inverting) the output driver will either pull the line low or high during an unknown input state.

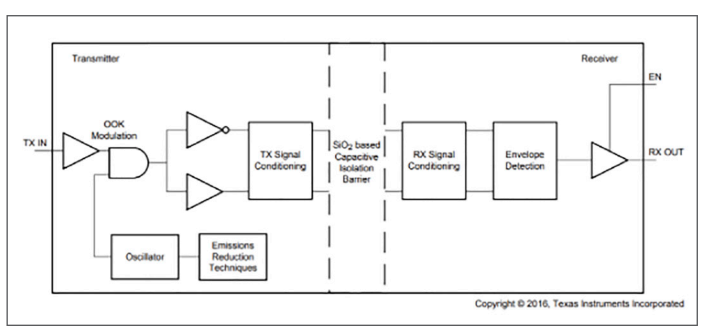

Figure 1 - ISO7841 Isolator Block Diagram. Figure, Courtesy Texas Instruments [4].

The ESD pulse creates ringing. The amplitude of the ringing and the frequency will be determined by the parasitic capacitances and inductances in the path of the ESD. *Figure 2* shows an example of a susceptible to ESD system and its equivalent parasitic circuit schematic

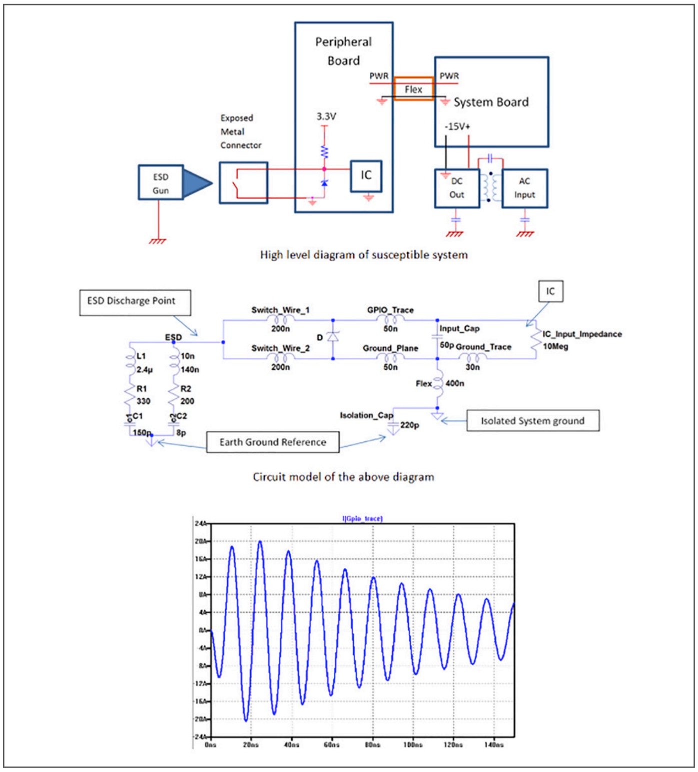

Figure 2 – Example Parasitic Capacitances and Inductances and Simulated Circuit Oscillation

Figure 3 compares the actual IEC 61000-4-2 pulse to the ringing that happens when the ESD pulse excites the hidden parasitic circuits.

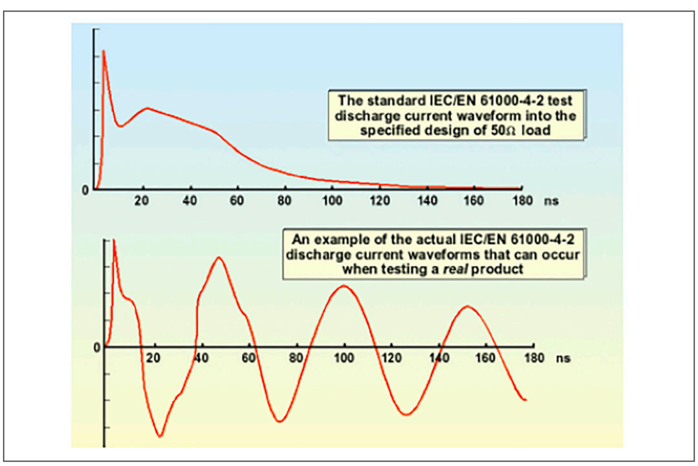

Figure 3 – IEC 61000-4-2 Pulse and Example Ringing Pulse. Figure, Courtesy of Keith Armstrong [3].

Flex cables, no matter how well a ground shield they have, are seen as inductors from the point of ESD current. The Silicon Dioxide (SIO2) based capacitance that provides the isolation is also part of the tank circuit. The capacitive isolation not only has capacitance between the TX and RX. There is also relative capacitance from the SIO2 to the ground. High levels of ESD will pass through the barrier. 8kV requires 14mm wide gap to not pass across. Most isolation zones are wide enough to withstand the dielectric strength voltage requirements such as 5kV for 1 minute. In that case 4mm of gap is enough. However for ESD at 8kV or higher that gap is small enough to create large enough capacitance for the ESD charge to fill the gap and cross over. When this happens the ESD charge will also fill the SIO2 based capacitance for a very short time and will disturb the ON/OFF keying modulation scheme. This makes the input at RX an unknown. Depending on the particular isolator part, if the input is unknown the output driver will either default to High or Low. If the isolator is used to carry control signal (such as reset) or communication signal (such as UART) then care must be taken to properly filter these lines. Otherwise a short glitch in the ON/Off keying modulation scheme can cause the output to drop or go high which may reset processors or cause break conditions in communications such as UART or SPI bus.

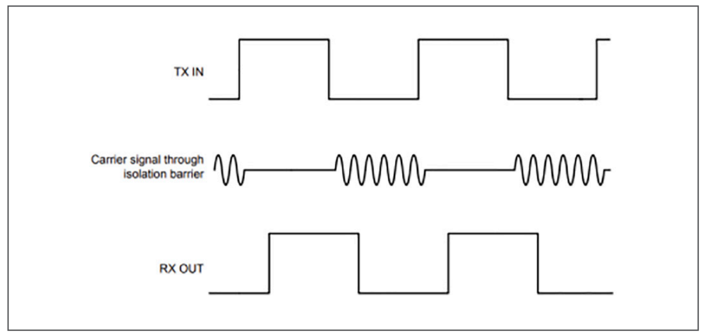

Figure 4 - ON/OFF Keying Modulation Scheme of ISO7841. Figure, Courtesy of Texas Instruments [4].

PLACEMENT OF DIGITAL ISOLATORS

Protecting digital isolators from ESD becomes a very challenging task when the isolator is used in a medical device. Physical placement of the isolator is very important. Even the most ESD robust digital isolator in the industry will break if not placed properly. Consider *Figure 5* on next page. 15kV air discharge is performed on the exposed connector that is part of a peripheral circuit. The circuit is isolated. The digital isolator is physically placed close to the grounding connector that leads to Board 1. Board 1 connects to the AC/DC power supply that has a 1nF capacitance to ground. The ESD current will intend to get back to earth if it sees a path. Once the current enters the Iso board it creates a voltage on the edge of the barrier. Due to the barrier capacitance, capacitance between the inter-windings of the transformer and the capacitance of the capacitive SiO2 barrier of the digital isolator, charge currents form and fill-up the capacitances. The SiO2 capacitive layer of the digital isolator breaks down faster than the capacitance of an 8mm wide air gap or the transformer inter-winding capacitance. As the current crosses over the barrier through the digital isolator it creates differential voltages inside the isolator and can destroy CMOS devices creating shorts. Shorts inside the isolator will lead to excessive power consumption and burn up the chip. Even ESD robust digital isolators break if not laid out properly.

PROTECTION OF ISOLATED CIRCUITS

Additional ESD protection should be considered by either shunting the ESD current from the isolated circuit ground to the system ground (non-isolated ground) or by providing a captive bank larger than 150pF (IEC 61000-4-2 ESD discharge capacitor is 150pF) and referenced to system ground to absorb all of the ESD charge.

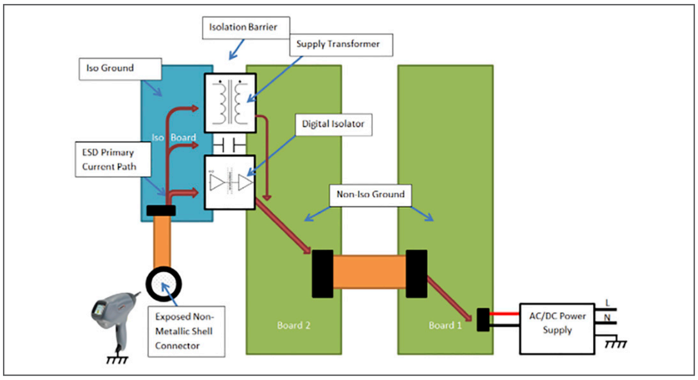

Figure 5 – Digital isolator in the path closest to ground (shown with relative ESD current paths)

SHUNTING THE CHARGE

Gas Discharge Tubes

Before silicon based devices were capable of handling high levels of ESD gas discharge tubes were commonly used. Gas discharge tubes are made of two conductive plates separated by a combination of various gases such that the ionization is controlled. In other words, gas discharge tubes are made to be open circuit until the voltage potential goes above the rated DC withstand voltage. For example, Littelfuse offers a variety of gas discharge tubes that are rated for high voltage DC operation. The CG36.5LD004 gas discharge tube has a capacitance of less than 1.5pF and can withstand 6.5kV, which is sufficient to be used across the isolation barrier and meet the UL 1577 voltage withstand requirement of 5kV rms for 1 minute. It is equally crucial to properly place the gas discharge tube. *Figure 6* below shows an ideal placement for the gas discharge tube based on layout shown in *Figure 5*.

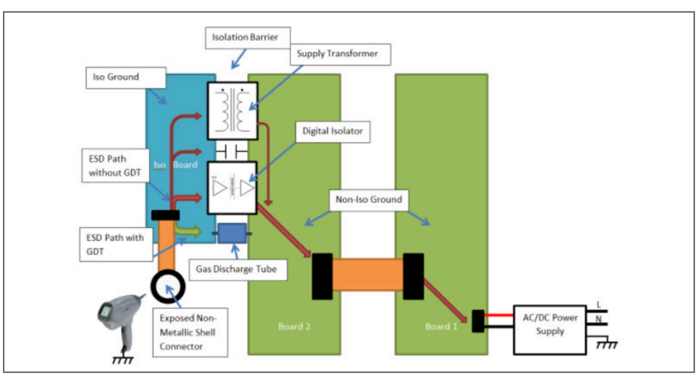

Figure 6 – Proper placement of a gas discharge tube.

There is a drawback to GDTs and it is the variability in the DC breakdown and impulse breakdown voltages. CG36.5LD004 GDT's DC breakdown may vary from 5.2kV to 7.8kV and the impulse breakdown may not happen until 10kV[5]. The 6.5kV rating can easily be misinterpreted as the GDT's breakdown voltage of 6.5kV and above. Note that GDTs may not be appropriate to use if the isolated circuit consists of very sensitive analog electronics. For example the CG36.5LD004 may prevent component hard failures by not letting the ESD voltages exceed its maximum impulse breakdown voltage of 10kV, but developing common mode 10kV peak ringing at analog IC pins can cause latch-up or reset conditions.

HIGH VOLTAGE DIODES

Depending on the leakage current requirements of the isolation barrier, high voltage diodes can be used across the barrier. Diodes are much more precise than GDTs at maintaining their working reverse voltage. Diodes' break down voltage is also much more precise. For example the high voltage diode MR50FF3 by Voltage Multipliers is rated to 5kV with peak reverse avalanche energy of 25mJ and leakage current of 10uf at 100C°[6]. This diode would work much better at shunting the ESD current from the isolated ground to the system ground. The 25mJ reverse avalanche energy capability is suited for ESD since the energy released by IEC 61000-4-2 ESD gun at 15kV is 16.5mJ (0.5*150pF*15kV2). In order to maintain the barrier isolation resistance to 5kV per UL 1577, two diodes must be used in series either anode to anode or cathode to cathode.

CAPACITIVE BANK

High Voltage Capacitors

High voltage capacitors can also be used across the barrier to absorb all of the ESD charge. It is important to pick the right capacitance in order to maintain the 5kV isolation requirement per UL 1577. However, for this technique to work, at the minimum, the capacitance needs to be around 150pF to equal the capacitance of the ESD discharge capacitor.

CONCLUSION

Designing isolated circuits is challenging. There is plethora of requirements that needs to be met and maintained. Circuit layout design and component placement are one of the most crucial stages of isolated circuit design because they can make a big difference in passing EMC tests and particularly ESD. In order to create a system that will comply with level 4 or higher ESD requirements several protection points need to be considered such as:

- The front end of the circuit shall have an adequate ESD protection mechanisms
- Sensitive components shall be placed such that they are as much out of the ESD primary current path as possible
- Digital isolators must be placed properly
- Additional ESD protection methods must be considered
- Increasing the barrier widths and the use of wider digital isolator packages shall be considered

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