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Mobile Generations Explained

FEATURED SECTIONS AND COUNTRIES

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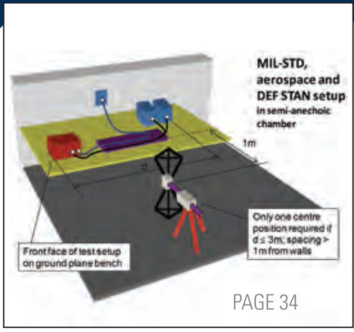
All articles are available online in English at www.interferencetechnology.eu



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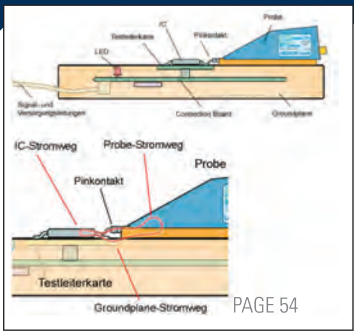

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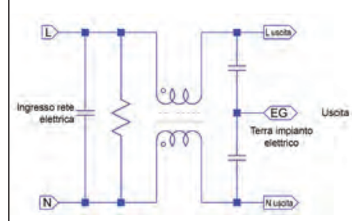

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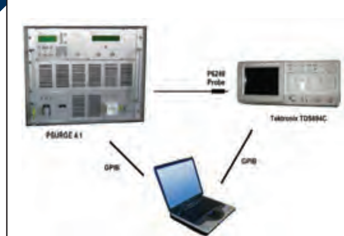

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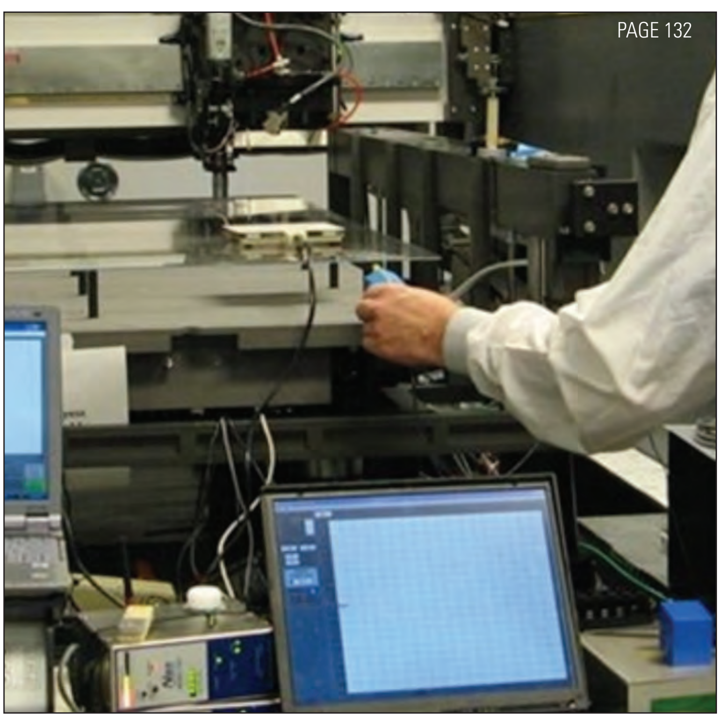

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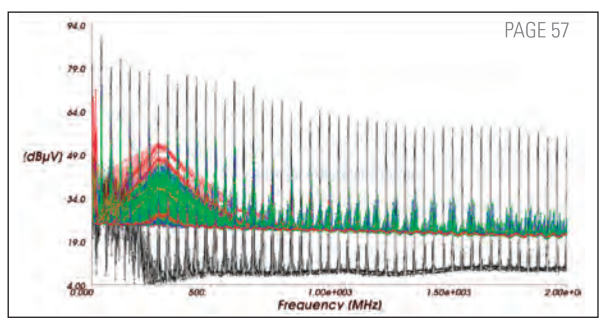

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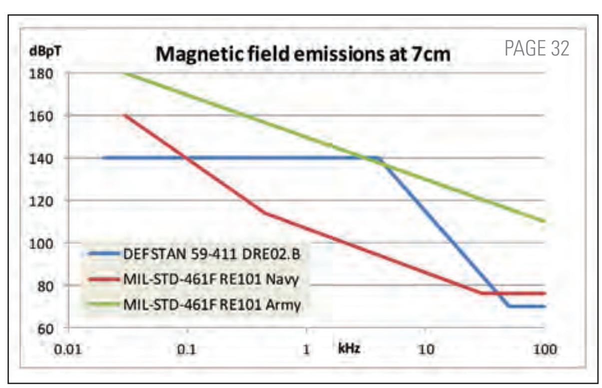

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Important Standards And Directives for 2016

DEAR READERS,

Welcome to the 2016 EMC Europe Guide. We welcome you to a new year in EMC and continue, as always, to provide you with the most current EMC information in our eighth annual guide dedicated to Europe.

This upcoming year presents quite a few new standards and directives that are important for electronics engineers to be aware of. Below are a few, with additional information and resources.

In February 2014, the European Parliament and Council issued a number of remodelled Directives aligned to the New Legislative Framework ("NLF," Decision 768/2008/EC, see http://ec.europa.eu/growth/single-market/goods/new-legislative-framework/index_en.htm).

All of these new Directives will apply from 20 April 2016 (or soon afterwards) – even for products that have already been sold in Europe under the existing versions of those Directives and have not changed – and some manufacturers or their supply chains may have some work to do to comply.

The EMC Directive 2004/108/EC will be replaced by 2014/30/EU.

The Radio and Telecommunication Terminal Equipment (1999/5/EC) will become the Radio Equipment Directive 2014/53/EU, and *Interference Technology* previously ran an article on this. The article looks briefly at the history of the requirements, the changes in the product and regulatory landscape and what it means to equipment manufacturers. Visit www.interferencetechnology.com/radio-equipment-directive to learn more.

Directive 2006/95/EC will become the new LVD Directive 2014/35/EU, aligned to the NLF. Although it keeps much the same scope and safety objectives, it will require documented Risk Analyses and Assessments – which could mean that some manufacturers have quite a lot to do in the next six months!

More information can also be found at http://ec.europa.eu/growth/sectors/electrical-engineering/directives/index_en.htm.

On the standards front, CISPR 32:2015, "Electromagnetic compatibility of multimedia equipment - Emission requirements" is expected to be released in summer 2016, replacing both CISPR 13 and 22. This standard came about due to a major development in consumer electronics, the digital television receiver, according to a recent article in *Interference Technology*. To learn more, visit http://www.interferencetechnology.com/cispr-32-what-is-it-why-was-it-written-and-where-is-it-going, or read the article in French on page 64.

In this issue, we list some of the important standards, as well as events and articles, in each country's specific language. To read all of these articles in English, visit www.interferencetechnology.com/category/articles.

We hope that you have had the opportunity to attend EMC Live this past year. If not, all webinars from this online event have been recorded and are archived for viewing at your convenience at www.emclive2014.com and www.emclive2015.com. Quite a few of these webinars are related to standards in Europe, and provide important information that you may need to know. One webinar from our 2014 event discusses European wireless devices: "2.4 GHz Wireless Devices to Europe – Big Changes to EN 300 328 Next Year (2015)" can be viewed at http://emclive2014.com/selling-wireless-devices-europe-need-know-changing-requirements. At our 2015 event, one presentation covered many different standard areas: "Resolving Uncertainty in CISPR, MIL-STD and Emissions Testing by Reducing Limitations of Active Rod Antennas." Watch this webinar here: http://3d.emclive2015.com/narda-presents-limitations-of-active-rod-antennas-in-emission-testing. And, of course, watch our other free webinars while you're on the website and stay tuned for next year's event; you can learn more about our third annual program at www.emclive2016.com.

Interference Technology is committed to providing the most accurate, up-to-date articles and information in the industry. If you have any questions, suggestions or ideas please email me at bstas@item-media.net. Thanks for reading!

Belinda Stasiukiewicz Sharr
Editor

2016 EUROPE EMC GUIDE

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2015-16 STANDARDS UPDATE EUROPE

Compliance with standards can make or break any new product. This section recaps some of the major new and revised EMC standards in the last year from the European standards organizations: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI). Standards are sorted by reference number. Standards information and updates are featured in our weekly Interference Technology eNews; and we also have a vast list of standards at interferencetechnology.com - just click on the Standards section.

The European Committee for Standardization (CEN)

EN 4652-110:2015

Committee: Cen

Status: Published

Date of Publication: 2015-09-09

Title: Aerospace series - Connectors, coaxial, radio frequency - Part 110: Type 1, BNC interface - Clamp nut assembly version - Straight plug - Product standard.

Scope: This European Standard specifies the characteristics of bayonet coupling (BNC interface) coaxial straight plugs – 50 ohms. The cable to connector assembly is a clamp technology.

Info: http://standards.cen.eu/dyn/www/f?p=CENWEB:110:0::::FSP_ORG_ID,FSP_PROJECT:6378,59312&cs=12C5D9B939C8E6EEEE132920724FE0D29

European Committee for Electrotechnical Standardization (CENELEC)

EN 61290-4-3:2015

Committee: Cenlec

Status: Work In Progress

Date of Publication: 2015-06-09

Title: Optical amplifiers - Test methods - Part 4-3: Power transient parameters - Single channel optical amplifiers in output power control.

Scope: IEC 61290-4-3:2015(E) applies to output power controlled optically amplified, elementary sub-systems. It applies to optical fibre amplifiers (OFA) using active fibres containing rare-earth dopants, presently commercially available, as indicated in IEC 61291-1, as well as alternative optical amplifiers that can be used for single channel output power controlled operation, such as semiconductor optical amplifiers (SOA). The object of this standard is to provide the general background for optical amplifier (OA) power transients and its measurements and to indicate those IEC standard test methods for accurate and reliable measurements of the following transient parameters: - Transient power response; - Transient power overcompensation response; - Steady-state power offset; - Transient power response time. The stimulus and responses behaviours under consideration include: - Channel power increase (step transient); - Channel power reduction (inverse step transient); - Channel power increase/reduction (pulse transient); - Channel power reduction/increase (inverse pulse transient); - Channel power increase/reduction/increase (lightning bolt transient); - Channel power reduction/increase/reduction (inverse lightning bolt transient). These parameters have been included to provide a complete description of the transient behaviour of an output power transient controlled OA. The test definition defined here are applicable if the amplifier is an OFA or an alternative OA. However, the description in Annex A of this document concentrates on the physical performance of an OFA and provides a detailed description of the behaviour of OFA; it does not give a similar description of other OA types. Keywords: output power controlled optically amplified elementary sub-systems, optical fibre amplifiers, rare-earth dopants.

Info: http://www.cenelec.eu/dyn/www/f?p=104:110:243889166411001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258127,58376,25

EN 60974-10:2014/A1:2015

Committee: Cenlec

Status: Work In Progress

Date of Publication: 2015-08-07

Title: Arc welding equipment - Part 10: Electromagnetic compatibility (EMC) requirements.

Info: http://www.cenelec.eu/dyn/www/f?p=104:110:243889166411001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1257225,59212,25

EN 61755-3-31:2015

Committee: Cenlec

Status: Published

Date of Publication: 2015-09-04

Title: Fibre optic interconnecting devices and passive components - Connector optical interfaces - Part 3-31: Connector parameters of non-dispersion shifted single mode physically contacting fibres - Angled polyphenylene sulphide rectangular ferrules.

Scope: IEC 61755-3-31:2015 defines certain dimensional limits of an angled PC rectangular polyphenylene sulphide (PPS) ferrule optical interface in order to meet specific requirements for fibre-to-fibre interconnection. Ferrules made from the material specified in this standard are suitable for use in categories C, U, E, and O as defined in IEC 61753-1. Ferrule interface dimensions and features are contained in the IEC 61754 series, which deals with fibre optic connector interfaces. Keywords: dimensional limits of an angled PC rectangular polyphenylene sulphide (PPS) ferrule optical interface, fibre-to-fibre interconnection.

http://www.cenelec.eu/dyn/www/f?p=104:110:243889166411001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258371,47814,25

EN 60512-29-100:2015

Committee: Cenlec

Status: Published

Date of Publication: 2015-09-18

Title: Connectors for electronic equipment - Tests and measurements - Part 29-100: Signal integrity tests up to 500 MHz on M12 style connectors - Tests 29a to 29g.

Scope: IEC 60512-29-100:2015 specifies the test methods for transmission performance for M12-style connectors up to 500 MHz. It is also suitable for testing lower frequency connectors if they meet the requirements of the detail specifications and of this standard. The test methods provided herein are: - insertion loss, test 29a; - return loss, test 29b; - near-end crosstalk (NEXT) test 29c; - far-end crosstalk (FEXT), test 29d; - transverse conversion loss (TCL), test 29f; - transverse conversion transfer loss (TCTL), test 29g. For the transfer impedance (ZT) test, see IEC 60512-26-100, test 26e. For the coupling attenuation see ISO/IEC 11801. All test methods apply for two and four pair connectors. Key words: Connectors, Signal Integrity, M12 Style Connector.

Info: http://www.cenelec.eu/dyn/www/f?p=104:110:243889166411001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1258221,51899,25

EN 60601-1-2:2015

Committee: Cenlec

Status: Published

Date of Publication: 2015-09-18

Title: Medical electrical equipment - Part 1-2: General requirements for basic safety and essential performance - Collateral Standard: Electromagnetic disturbances - Requirements and tests.

Scope: IEC 60601-1-2:2014 applies to the basic safety and essential performance of Medical Equipment (ME) equipment and ME systems in the presence of electromagnetic disturbances and to electromagnetic disturbances emitted by me equipment and me systems. This collateral standard to IEC 60601-1 specifies general requirements and tests for basic safety and essential performance with regard to electromagnetic disturbances and for electromagnetic emissions of ME equipment and ME systems. They are in addition to the requirements of the general standard IEC 60601-1 and serve as the basis for particular standards. This fourth edition cancels and replaces the third edition of IEC 60601-1-2, and constitutes a technical revision. The most significant changes with respect to the previous edition include the following modifications: - specification of immunity test levels

STANDARDS ORGANIZATIONS

- **CEN**
  The European Committee for Standardization

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  B-1000 Brussels, Belgium
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- **IEC**
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  IEC's EMC Zone: www.iec.ch/zone/emc/emc_entry.htm

- **CISPR**
  International Special Committee on Radio Interference

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  IEC's EMC Zone: ; www.iec.ch/zone/emc/emc_cis.htm

- **International Organization for Standardization**

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  ch. de la Voie-Creuse, Case postale 56
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  www.iso.org

according to the environments of intended use, categorized according to locations that are harmonized with IEC 60601-1-11: the professional healthcare facility environment, the home healthcare environment and special environments; - specification of tests and test levels to improve the safety of medical electrical equipment and medical electrical systems when portable RF communications equipment is used closer to the medical electrical equipment than was recommended based on the immunity test levels that were specified in the third edition; - specification of immunity tests and immunity test levels according to the ports of the medical electrical equipment or medical electrical system; - specification of immunity test levels based on the reasonably foreseeable maximum level of electromagnetic disturbances in the environments of intended use, resulting in some immunity test levels that are higher than in the previous edition; and - better harmonization with the risk concepts of basic safety and essential performance, including deletion of the defined term 'life-supporting'. This new edition includes the following main additions: - guidance for determination of immunity test levels for special environments; - guidance for adjustment of immunity test levels when special considerations of mitigations or intended use are applicable; - guidance on risk management for basic safety and essential performance with regard to electromagnetic disturbances; and - guidance on identification of immunity pass/fail criteria.

Info: http://www.cenelec.eu/dyn/www/f?p=104:110:243889166411001::::FSP_ORG_ID,FSP_PROJECT,FSP_LANG_ID:1257161,44445,25

International Special Committee on Radio Interference (CISPR)

CISPR 16-1-5 ed2.0

Committee: CIS/A

Status: Published

Date of Publication: 2014-12-17

Title: 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.

Scope: CISPR 16-1-5:2014 specifies the requirements for calibration sites in the frequency range 5 MHz to 18 GHz used to perform antenna calibrations according to CISPR 16-1-6. It also specifies the requirements for reference test sites that are used for the validation of compliance test sites in the frequency range 30 MHz to 1 000 MHz according to CISPR 16-1-4. It has the status of a basic EMC standard in accordance with IEC Guide 107. Measurement instrumentation specifications are given in CISPR 16-1-1 and CISPR 16-1-4. Further information and background on uncertainties in general is given in CISPR 16-4, which can also be helpful in establishing uncertainty estimates for the calibration processes of antennas and site validation measurements. This second edition cancels and replaces the first edition published in 2003, and its Amendment 1 (2012). It constitutes a technical revision which includes the following significant technical changes with respect to the previous edition:

– site validation methods for other sites covered in CISPR 16-1-6 are added;

– smaller step sizes are specified for swept frequency measurements;

– the minimum ground plane size is increased;

– and other miscellaneous technical and editorial refinements are included. Keywords: electromagnetic compatibility.

Info: http://www.interferencetechnology.com/cispr-16-1-5-ed2-0/#sthash.xDfTLVUV.dpuf

CISPR 15 ed8.1 Consol. with am1

Committee: CIS/A

Status: Published

Date of Publication: 2015-03-27

Title: Limits and Methods of Measurement of Radio Disturbance Characteristics of Electrical Lighting and Similar Equipment.

Scope: CISPR 15:2013+A1:2015 applies to the emission (radiated and conducted) of radiofrequency disturbances from:

– all lighting equipment with a primary function of generating and/or distributing light intended for illumination purposes, and intended either for connection to the low voltage electricity supply or for battery operation;

– the lighting part of multi-function equipment where one of the primary functions of this is illumination;

– independent auxiliaries exclusively for use with lighting equipment;

– UV and IR radiation equipment;

– neon advertising signs;

– street/flood lighting intended for outdoor use;

– and transport lighting (installed in buses and trains). Excluded from the scope of this standard are:

– lighting equipment operating in the ISM frequency bands (as defined in Resolution 63 (1979) of the ITU Radio Regulation);

– lighting equipment for aircraft and airports;

– and apparatus for which the electromagnetic compatibility requirements in the radio-frequency range are explicitly formulated in other CISPR standards. The frequency range covered is 9 kHz to 400 GHz. This eighth edition cancels and replaces the seventh edition published in 2005, its Amendment 1 (2006) and Amendment 2 (2008). It is a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

– inclusion of LED light sources and luminaires, clarification of test supply voltage and frequency, and improvements to clause 5 relating to the application of limits to the various types of lighting equipment covered under the scope of CISPR 15;

– introduction of requirements for flashing type emergency lighting luminaires utilizing xenon lamps;

– introduction of requirements for neon and other advertising signs;

– and clarification of the requirement for radiated disturbances between 30 MHz and 300 MHz in case the operating frequency of the light source is below 100 Hz. The contents of the interpretation sheet 1 and 2 of June

2013 have been including in this copy. This consolidated version consists of the eighth edition (2013) and its amendment 1 (2015). Therefore, no need to order amendment in addition to this publication.

Info: http://www.interferencetechnology.com/cispr-15-ed8-1-consol-with-am1/#sthash.kG4gnQIV.dpuf

CISPR 24 ed2.1 Consol. with am1

Committee: CIS/A

Status: Published

Date of Publication: 2015-04-17

Title: Information Technology Equipment – Immunity Characteristics – Limits and Methods of Measurement.

Scope: CISPR 24:2010+A1:2015 applies to information technology equipment (ITE) as defined in CISPR 22. The object of this publication is to establish requirements that will provide an adequate level of intrinsic immunity so that the equipment will operate as intended in its environment. The publication defines the immunity test requirements for equipment within its scope in relation to continuous and transient conducted and radiated disturbances, including electrostatic discharges (ESD). Procedures are defined for the measurement of ITE and limits are specified which are developed for ITE within the frequency range from 0 Hz to 400 GHz. For exceptional environmental conditions, special mitigation measures may be required. Owing to testing and performance assessment considerations, some tests are specified in defined frequency bands or at selected frequencies. Equipment which fulfils the requirements at these frequencies is deemed to fulfill the requirements in the entire frequency range from 0 Hz to 400 GHz for electromagnetic phenomena. The test requirements are specified for each port considered. This second edition cancels and replaces the first edition published in 1997, and its Amendments 1(2001) and 2(2002). It is a technical revision.

Info: http://www.interferencetechnology.com/cispr-24-ed2-1-consol-with-am1/#sthash.AlcSxgei.dpuf

CISPR 24:2010+AMD1:2015 CSV

Committee: CIS/A

Status: Published

Date of Publication: 2015-04-17

Title: Information technology equipment – Immunity characteristics – Limits and methods of measurement.

Scope: CISPR 24:2010+A1:2015 applies to information technology equipment (ITE) as defined in CISPR 22. The object of this publication is to establish requirements that will provide an adequate level of intrinsic immunity so that the equipment will operate as intended in its environment. The publication defines the immunity test requirements for equipment within its scope in relation to continuous and transient conducted and radiated disturbances, including electrostatic discharges (ESD). Procedures are defined for the measurement of ITE and limits are specified which are developed for ITE within the frequency range from 0 Hz to 400 GHz. For exceptional environmental conditions, special mitigation measures may be required. Owing to testing and performance assessment considerations, some tests are specified in defined frequency bands or at selected frequencies. Equipment which fulfills the requirements at these frequencies is deemed to fulfill the requirements in the entire frequency range from 0 Hz to 400 GHz for electromagnetic phenomena. The test requirements are specified for each port considered. This second edition cancels and replaces the first edition published in 1997, and it's Amendments 1(2001) and 2(2002). It is a technical revision. This edition includes the following significant technical changes with respect to the previous edition:

– dated references updated;

– option of using a 4 % step size for continuous conducted immunity test deleted;

– revision of Annex A for telephony equipment including methodology for measuring the demodulation from a speaker/hands free device;

– inclusion of new annex related to DSL equipment. The contents of the corrigendum of June 2011 have been included in this copy.

This consolidated version consists of the second edition (2010) and its amendment 1

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- **European Commission**
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- **European New Legislative Framework for marketing of products**
  http://ec.europa.eu/enterprise/policies/single-market-goods/regulatory-policies-common-rules-for-products/new-legislative-framework

- **European Environment Agency**
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  http://www.efta.int

- **Rapex - Rapid Alert System for non-food dangerous products**
  EU consumer alerts about unsafe products
  European Commission, Health & Consumers
  Directorate-General, B – 1049 Brussels,
  Belgium; http://ec.europa.eu/consumers/dyna/rapex/rapex_archives_en.cfm

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(2015). Therefore, no need to order amendment in addition to this publication.

Info: http://www.interferencetechnology.com/cispr-242010amd12015-csv/#sthash.8p2aId0T.dpuf

CISPR 11:2015

Committee: CIS/A

Status: Published

Date of Publication: 2015-06-09

Title: Industrial, Scientific and Medical equipment – Radio-Frequency Disturbance Characteristics – Limits and Methods of Measurement.

Scope: CISPR 11:2015 is available as CISPR 11:2015 RLV which contains the International Standard and its Redline version, showing all changes of the technical content compared to the previous edition. CISPR 11:2015 applies to industrial, scientific and medical electrical equipment operating in the frequency range 0 Hz to 400 GHz and to domestic and similar appliances designed to generate and/or use locally radio-frequency energy. This standard covers emission requirements related to radio-frequency (RF) disturbances in the frequency range of 9 kHz to 400 GHz. Measurements need only be performed in frequency ranges where limits are specified in Clause 6.

Info: http://www.interferencetechnology.com/cispr-112015/#sthash.v6yTOULk.dpuf

European Telecommunications Standards Institute (ETSI)

ETSI EN 300 386 V2.1.0

Committee: ETSI

Status: Work In Progress

Date of Publication: 2015-09

Title: Telecommunication network equipment; Electromagnetic Compatibility (EMC) requirements; Harmonized Standard covering the essential requirements of the Directive 2014/30/EU.

Scope: This draft Harmonized European Standard (EN) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM), and is now submitted for the combined Public Enquiry and Vote phase of the ETSI standards EN Approval Procedure. The present document has been prepared to provide a means of conforming to the essential requirements of Directive 2014/30/EU [i.31] of the European Parliament and of the Council of 26 February 2014 on the harmonization of the laws of the Member States relating to electromagnetic compatibility and repealing Directive 2004/108/EC. Once the present document is cited in the Official Journal of the European Union under that Directive, compliance with the normative clauses of the present document given in table A.1 confers, within the limits of the scope of the present document, a presumption of conformity with the corresponding essential requirements of that Directive, and associated EFTA regulations.

Info: http://www.etsi.org/deliver/etsi_en%5C300300_300399%5C300386%5C02.01.00_20%5Cen_300386v020100a.pdf

ETSI ES 201 468 V1.5.1

Committee: ETSI

Status: Work In Progress

Date of Publication: 2015-09

Title: Additional Electromagnetic Compatibility (EMC) requirements and resistibility requirements for telecommunications equipment for enhanced availability of service in specific applications.

Scope: This final draft ETSI Standard (ES) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM), and is now submitted for the ETSI standards Membership Approval Procedure. The present document defines the EMC requirements of telecommunication network equipment for an increased reliability and the resistibility requirements.

Info: http://www.etsi.org/deliver/etsi_es%5C201400_201499%5C201468%5C01.05.01_50%5Ces_201468v010501m.pdf

ETSI EN 300 019-2-3 V2.3.7

Committee: ETSI

Status: Work In Progress

Date of Publication: 2015-09

Title: Environmental Engineering (EE); Environmental conditions and environmental tests for telecommunications equipment; Part 2-3: Specification of environmental tests; Stationary use at weather protected locations.

Scope: The present document specifies test severities and methods for the verification of the required resistibility of equipment according to the relevant environmental class. The tests in the present document apply to stationary use of equipment at weather protected locations covering the environmental conditions stated in ETSI EN 300 019-1-3 [1].

Info: http://www.etsi.org/deliver/etsi_en%5C300001_300099%5C3000190203%5C02.03.07_20%5Cen_3000190203v020307a.pdf

International Electrotechnical Commission (IEC)

IEC 61000-4-36 ed1.0

Committee: IEC

Status: Published

Date of Publication: 2014-11-07

Title: Electromagnetic compatibility (EMC) – Part 4-36: Testing and measurement techniques – IEMI immunity test methods for equipment and systems.

Scope: IEC 61000-4-36:2014(E) provides methods to determine test levels for the assessment of the immunity of equipment and systems to intentional electromagnetic interference (IEMI) sources. It introduces the general IEMI problem, IEMI source parameters, derivation of test limits and summarizes practical test methods. Keywords: EMC, electromagnetic compatibility.

Info: http://www.interferencetechnology.com/iec-61000-4-36-ed1-0/

IEC 61169-51 ed1.0

Committee: IEC

Status: Published

Date of Publication: 2015-02-05

Title: Radio-frequency connectors – Part 51: Sectional specification for RF coaxial connectors with inner diameter of outer conductors 13,5 mm with bayonet lock – Characteristic impedance 50 Ω (type QLI).

Scope: IEC 61169-51:2015 provides information and rules for the preparation of detail specifications (DS) for type QLI R.F. coaxial connectors with quick lock. The connectors are normally used with 50 Ohms corrugated cable and flexible cables for middle power applications in an operating range up to 6 GHz. It describes the interface dimensions for general purpose connectors with gauging information and the mandatory tests selected from IEC 61169-1 applicable to all detail specifications relative to type QLI connectors. This specification indicates the recommended performance characteristics to be considered when writing a DS and covers all tests schedules and inspection requirements."

Info: http://www.interferencetechnology.com/iec-61169-51-ed1-0/

IEC 60940 ed2.0

Committee: IEC

Status: Published

Date of Publication: 2015-03-10

Title: Guidance information on the application of capacitors, resistors, inductors and complete filter units for electromagnetic interference suppression.

Scope: IEC 60940:2015 provides guidance applicable to information on application of capacitors, resistors, inductors, and complete filter units for electromagnetic interference suppression. This second edition cancels and replaces the first edition published in 1988. This second edition is a result of maintenance activities related to the previous edition. All changes that have been agreed upon can be categorized as minor revisions. http://www.interferencetechnology.com/iec-60940-ed2-0/#sthash.YdixZD7E.dpuf

IEC 60384-14-1:2015 PRV

Committee: IEC

Status: Published

Date of publication: 2015-10-23

Title: Fixed capacitors for use in electronic equipment - Part 14-1: Blank detail specification - Fixed capacitors for electromagnetic interference suppression and connection to the supply mains - Assessment level DZ

Scope: This Final Draft International Standard is an up to 3 months' pre-release of the official publication. It is available for sale during its voting period: 2015-10-23 to 2015-12-25. By purchasing this FDIS now, you will automatically receive, in addition, the final publication.

Info: https://webstore.iec.ch/publication/23572

IEC 60384-23:2015

Committee: IEC

Status: Published

Date of Publication: 2015-04-29

Title: Fixed capacitors for use in electronic equipment – Part 23: Sectional specification – Fixed metallized polyethylene naphthalate film dielectric surface mount D.C. capacitors.

Scope: IEC 60384-23:2015 is applicable to fixed surface mount capacitors for direct current, with metallized electrodes and polyethylene naphthalate dielectric for use in electronic equipment. These capacitors have metallized connecting pads or soldering strips and are intended to be mounted directly onto substrates for hybrid circuits or onto printed boards. These capacitors may have "self healing properties" depending on conditions of use. They are primarily intended for applications where the a.c. component is small with respect to the rated voltage. This edition includes the following significant technical changes with respect to the previous edition:

a) Revised all parts of the document based on the ISO/IEC Directives, Part 2:2011 (sixth edition) and harmonization between other similar kinds of documents.

b) Revised tables and Clause 4 so as to prevent duplications and contradictions.

Info: http://www.interferencetechnology.com/iec-60384-232015/#sthash.SfmzufEH.dpuf

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  +32274 32980; www.efndt.org
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  www.ilac.org/home.html

IEC 60384-20:2015

Committee: IEC

Status: Published

Date of Publication: 2015-07-22

Title: Fixed Capacitors for Use in Electronic Equipment – Part 20: Sectional Specification – Fixed Metallized Polyphenylene Sulfide Film Dielectric Surface Mount D.C. Capacitors.

Scope: IEC 60384-20:2015 applies to fixed surface mount capacitors for direct current, with metallized electrodes and polyphenylene sulfide dielectric for use in electronic equipment. These capacitors have metallized connecting pads or soldering strips and are intended to be mounted directly onto substrates for hybrid circuits or onto printed boards. They may have "self healing properties" depending on conditions of use and are primarily intended for applications where the a.c. component is small with respect to the rated voltage. This edition includes the following significant technical changes with respect to the previous edition:

a) Revision of the structure in accordance with ISO/IEC Directives, Part 2:2011 (sixth edition) to the extent practicable, and harmonization between other similar kinds of documents.

b) In addition, Clause 4 and all the tables have been reviewed in order to prevent duplications and contradictions."

Info: http://www.interferencetechnology.com/iec-60384-202015/#sthash.gHGd7rEn.dpuf

IEC TR 61000-4-38:2015

Committee: IEC

Status: Published

Date of Publication: 2015-08-24

Title: Electromagnetic Compatibility (EMC) – Part 4-38: Testing and Measurement Techniques – Test, verification and calibration protocol for voltage fluctuation and flicker compliance test systems.

Scope: IEC TR 61000-4-38:2015(E) defines a test protocol for flicker test systems designed to perform compliance tests in accordance with IEC 61000-3-3 and IEC 61000-3-11. It is intended to provide test system manufacturers and testing laboratories with systematic methods to determine if the flicker test system meets the IEC design specifications for a wide range of voltage fluctuations and fluctuation frequencies, as specified in IEC 61000-4-15:2010, Table 5, that have been observed in product testing. It has the status of a basic EMC publication in accordance with IEC Guide 107.

Info: http://www.interferencetechnology.com/iec-tr-61000-4-382015/#sthash.f8U61O4S.dpuf

IEC 62153-4-15:2015 PRV

Committee: IEC

Status: Work In Progress

Date of Publication: 2015-09-11

Title: 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.

Scope: This Final Draft International Standard is an up to 3 months' pre-release of the official publication. It is available for sale during its voting period: 2015-09-11 to 2015-11-13. By purchasing this FDIS now, you will automatically receive, in addition, the final publication.

Info: http://www.interferencetechnology.com/iec-62153-4-152015-prv/#sthash.AxRfVE53.dpuf

IEEE 1547.1a-2015

Committee:

Status: Published

Date of Publication: 2015-05-01

Title: IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems – Amendment 1.

Scope: Interconnection equipment that connects distributed resources (DR) to an electric power system (EPS) must meet the requirements specified in IEEE 1547. Standardized test procedures are necessary to establish and verify compliance with those requirements, so this IEEE P1547. 1a Amendment 1 establishes test regimens to verify interconnection systems conformance to IEEE 1547 Amendment 1 for voltage regulation, and response to area EPS abnormal conditions of voltage and frequency. It may also consider other testing changes that may be necessary in response to updates under the 1547 Amendment 1.

Info: http://www.interferencetechnology.com/ieee-1547-1a-2015/#sthash.JHnUrna4.dpuf

International Standards Organization (ISO)

ISO/IEC/IEEE 8802-22:2015

Committee: ISO

Status: Published

Date of Publication: 2015-04-28

Title: Information technology -- Telecommunications and information exchange between systems -- Local and metropolitan area networks -- Specific requirements -- Part 22: Cognitive Wireless RAN Medium Access Control (MCA) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands.

Scope: This standard specifies the air interface, including the cognitive medium access control layer (MAC) and physical layer (PHY), of point-to-multipoint wireless regional area networks comprised of a professional fixed base station with fixed and portable user terminals operating in the VHF/UHF TV broadcast bands between 54 MHz to 862 MHz.

Info: http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=67402

2016 IEEE INTERNATIONAL SYMPOSIUM ON ELECTROMAGNETIC COMPATIBILITY (EMC 2016)

FEATURING AN EMBEDDED CONFERENCE FOR 2016 IEEE INTERNATIONAL CONFERENCE ON SIGNAL AND POWER INTEGRITY (SIPI 2016)

EMC 2016

25 - 29 July 2016 Ottawa, Canada

The 2016 IEEE International Symposium on Electromagnetic Compatibility, sponsored by the IEEE EMC Society, featuring an embedded Signal and Power Integrity conference, is the must-attend event for EMC engineers of all levels and specialties.

Join us in Ottawa, Canada as we bring compatibility to the capital in the region known for technological enterprise and government research making this an ideal location to discuss, exchange, and collaborate with the EMC and SIPI Communities.

Shaw Centre

TOP 5 REASONS YOU SHOULD SUBMIT TECHNICAL PAPERS TO EMC 2016 AND SIPI 2016!

1. Experience a week of professional development in a beautiful venue with other like-minded individuals.
2. Gain recognition and prestige among your peers.
3. Team up with other experts in the field to exchange ideas and share experiences.
4. The opportunity to share your knowledge with others and to have an immediate and significant impact on the future of EMC and SIPI.
5. A chance to be published! Authors of accepted papers will be invited to submit an extended version of their symposium paper for possible publication in a special issue of the IEEE Transactions on Electromagnetic Compatibility.

CALL FOR PAPERS

Get Your Ideas Published! EMC 2016 is a Technical Symposium. Technical Papers are the essence of our Technical Program. Original, unpublished papers on all aspects of EMC & SIPI are invited.

- Preliminary Full Paper Manuscript:
  1 November 2015 to 15 January 2016
- Notification of Acceptance: **21 February 2016**
- Final Paper Due: **1 May 2016**

Call for Experiments & Demonstrations

Experiments and demonstrations utilize hardware and software to demonstrate a principle or phenomena of EMI/EMC. The presentations are informal and non-commercial; they are usually conducted in specific areas within the Exhibit Hall.

To schedule, contact:
Bob Scully - *bob.scully@ieee.org*
Sam Connor - *sconnor@ieee.org*

Call for Abstract Reviewed Papers

New for 2016! Abstract Reviewed Papers provide opportunities to exchange experiences and ideas. Only an abstract is required for initial submission, papers are included in the conference proceedings; however, these papers are not published in the IEEE XPlore.

Proposals Accepted: **1 November 2015-21 February 2016**
Acceptance Notification: **27 March 2016**
Final Paper Due: **1 May 2016**

Call for Special Sessions

Special Sessions focus on areas of interest not addressed in Technical Papers. Acceptance criteria are the same as for Technical Papers.

Proposals Accepted: **1 November - 20 December 2015**
Notification of Acceptance: **8 January 2016**
Preliminary Papers Due: **21 February 2016**
Final Papers Due: **1 May 2016**

Call for Workshops & Tutorials

Workshops and Tutorials are informal, interactive educational presentations, typically addressing the practical side of understanding and solving EMC issues. These sessions are held on Monday and Friday.

Proposals Accepted: **1 November 2015**
Submission Deadline: **15 January 2016**
Notification of Acceptance: **15 February 2016**
Presentation Materials Due: **1 May 2016**

Commercial Vendor Demonstrations

Please note: Commercial Demonstrations are presented by vendors and are not committee reviewed.

To schedule, contact:
Peter Patterson – ppatterson@plptech.com

www.emc2016.emcss.org

IEEE

EMC SOCIETY

2016 EMC EVENTS

Keep up on important events in the electromagnetic compatibility community in this section. Visit Interference Technology online at www.interferencetechnology.eu for even more listings. If you would like to add an event, e-mail details to editor Belinda Stasiukiewicz at bstas@item-media.net.

World Radiocommunication Conference 2015

WHEN: 2-27 November 2015

WHERE: Geneva, Switzerland

WHAT: The WRC reviews and, if necessary, revises the Radio Regulations, the international treaty governing the use of the radio frequency spectrum and the geostationary-satellite and non-geostationary orbits.

INFORMATION: www.itu.int/en/ITU-R/conferences/wrc/2015/Pages/default.aspx

EMC Compo 2015

WHEN: 10-13 November 2015

WHERE: Edinburgh, UK

WHAT: The 11th International Workshop EMC Compo 2015 is intended to be a place for researchers from industry and academia to exchange the latest achievements and experiences in integrated circuit-level EMC.

INFORMATION: www.emccompo2015.org

EMC Live Test Bootcamp

WHEN: 12 November 2015

WHERE: Online

WHAT: This is a 1-day, highly focused event for test engineers and electronics engineers alike, dedicated to pre-compliance and compliance testing for EMC. Learn the latest on standards, equipment, setups and test techniques, hosted by Interference Technology.

INFORMATION: www.emclive2015.com

ESD Device Design Essentials

WHEN: 11-12 November 2015

WHERE: Munich, Germany

WHAT: This two-day seminar consists of concentrated versions of twelve ESDA tutorials which comprise the ESDA Device Design Certification Program. Topics include: fundamentals of ESD testing, high-current physics, and ESD modeling. The focus is on device-level (HBM, CDM, MM, TLP) and system level testing, impact of technology scaling on ESD high current phenomena, as well as circuit modeling and simulation for on-chip protection. ESD on-chip protection in advanced technologies, SPICE-based ESD protection design utilizing diodes, and active MOSFET rail clamp circuits, Charged Device Model (CDM) phenomena and design, on-chip ESD protection in RF Technologies, latch-up physics and design, and EOS/ESD failure models and mechanisms.

INFORMATION: http://www.cvent.com/d/6rq2b6

Advanced ESD Characterization and Test Methods

WHEN: 13 November 2015

WHERE: Munich, Germany

WHAT: Learn how to gain accurate insight in the electrical behavior of protection elements and of elements to be protected. Topics include: DC characterization, electrothermal characterization, (very fast) transmission line pulsing, repetitive ps-Pulsing. View results using the Agilent 62 GHz Single Shot Oscilloscope, and more.

INFORMATION: http://www.cvent.com/d/6rq2b6

52nd Annual AOC International Symposium

WHEN: 1-3, December 2015

WHERE: Washington, DC

WHAT: Premier Event for Electronic Warfare and Information Operations Professionals.

INFORMATION: https://www.crows.org/conventions/2015.html

ESD Program Development and Assessment – ANSI/ESD S20.20 Seminar

WHEN: 7-8 December, 2015

WHERE: Rome, NY

WHAT: The S20.20 Seminar is intended to bring all the aspects of the Program Manager Curriculum to a final focal point. The concepts of electrostatic control are discussed within the context of designing, implementing and maintaining an effective ESD control program plan that meets the requirements of the standard. Preparing a documented ESD Control Program Plan that can withstand a 3rd party ISO9000 Certification Body audit is a major element of the certification process.

INFORMATION: http://www.cvent.com/events/esd-program-development-and-assessment-ansi-esd-s20-20-seminar-/event-summary-7dd9f3cdc2fe455cbf7f9f070ef666f9.aspx

EMV 2016

When: 23-25 February 2016

Where: Düsseldorf, Germany

What: The bi-annual EMV conference reflects these requirements and provides a comprehensive program. Specialists from all over the world report on the latest products and developments and are available for technical discussions. This is the ideal platform for the dialogue between research, product development and application.

INFORMATION: https://www.mesago.de/en/EMV/The_Conference/Welcome/index.htm

International Workshop on Antenna Technology

WHEN: 29 February – 2 March 2016

WHERE: Hilton Cocoa Beach Oceanfront, FL, U.S.A.

WHAT: The International Workshop on Antenna Technology (iWAT) is an annual forum for the exchange of information on the research and development in innovative antenna technologies. It especially focuses on small antennas and applications of advanced and artificial materials to the antenna design.

INFORMATION: http://www.iwat2016.org/

Smart Systems Integration

WHEN: 09-10 March 2016

WHERE: Munich, Germany

WHAT: Smart Systems Integration is the international communication platform for research institutes and manufacturers to exchange know-how on Smart Systems Integration and to create the basis for successful research cooperations with focus on Europe.

INFORMATION: https://www.mesago.de/en/SSI/The_conference/Welcome/index.htm

International Applied Computational Electromagnetics Society (ACES) Symposium

WHEN: 13-17 March 2016

WHERE: Honolulu, Hawaii, USA

WHAT: The International Applied Computational Electromagnetics Society (ACES) Symposium serves as a forum for developers, analysts, and users of computational techniques applied to electromagnetic field problems for all frequency ranges. The symposium includes technical invited plenary and regular presentations, software tutorials, vendor booths, and short courses.

INFORMATION: http://www.aces-society.org/conference/2016/

GeMiC 2016 - German Microwave Conference

WHEN: 14-16 March 2016

WHERE: Bochum, Germany

WHAT: Following the success of previous events, the German Institute for Microwave and Antenna Technologies (IMA) in association with the German Association for Electrical, Electronic & Information Technologies (VDE) plus the European Microwave Association (EuMA) and the Institute of Electrical and Electronics Engineers (IEEE), through its Germany Section MTT/AP Joint Chapter, are pleased to announce this Conference.

INFORMATION: http://www.ruhr-uni-bochum.de/gemic2016/

Design, Automation & Test in Europe Conference (DATE) 2016

WHEN: 14-16 March 2016

WHERE: Dresden, Germany

WHAT: DATE is the major international event for design and engineering of Systems-on-Chip, Systems-on-Board and Embedded Systems Software and states a unique networking opportunity, bringing together designers and design automation users, researchers and vendors, as well as specialists in hardware and software design, test and manufacturing of electronic circuits and systems.

INFORMATION: http://www.date-conference.com/

ExpoElectronica 2016

WHEN: 15-17 March 2016

WHERE: Moscow, Russia

WHAT: ExpoElectronica is one of the largest exhibitions for electronic components and technologies in Russia and Eastern Europe, and consists of three smaller trade fairs. The largest, ExpoElectronica, is an international trade fair for components, PCBs and electronic productions while ElectronTechExpo Focuses on electronics manufacturing technology. The newest trade fair, LEDTechExpo, covers LED solutions, chips and production facilities.

INFORMATION: http://www.expoelectronica.ru

Microwave & RF

WHEN: 23-24 March 2016

WHERE: Paris, France

WHAT: The trade show of radiofrequency, microwave, wireless, Fibre Optics EMC, features exhibits, seminars and professional networking opportunities devoted to all aspects of the EMC industry.

INFORMATION: http://www.microwave-rf.com

European Conference on Antennas & Propagation (EuCAP) 2016

WHEN: 10-15 April 2016

WHERE: Davos, Switzerland

WHAT: EuCAP is supported by top level worldwide associations on Antennas and Propagation, and provides a forum on the major challenges faced by these communities. Contributions from colleagues from European and non-European industries, universities, research centres and other institutions are most welcome. The conference will provide an overview of the current state-of-the-art in Antennas, Propagation and Measurements topics, highlighting the latest developments and innovations required for future applications.

INFORMATION: http://www.eucap2016.org

EDI CON China 2016

WHEN: 19-21 April, 2016

WHERE: Beijing, China

WHAT: EDI CON brings together leading RF, microwave, high-speed analog and mixed signal

components, semiconductor, test and measurement equipment, materials and packaging, EDA/CAD and system solution providers in the exhibition.

INFORMATION: http://www.ediconchina.com/

EMC Live 2016

WHEN: 26-28 April 2016

WHERE: Online

WHAT: This is a practical, free 3-day online event on everything related to EMC hosted by Interference Technology. Program highlights include EMC/EMI Testing, HEMP/ IEMI Threats, Troubleshooting EMI, Standards Updates, Compliance Testing, Designing for EMC, MIL-STD 461 and more!

INFORMATION: www.emclive2016.com

2016 IEEE Radar Conference

WHEN: 02-06 May 2016

WHERE: Philadelphia, PA, USA

WHAT: The IEEE Radar 2016 conference is themed "Enabling Technologies for Advances in Radar." In addition to the presentation of contributed technical papers in high quality oral and poster sessions, the committee has planned a conference agenda that includes invited talks from leading experts within our community, an excellent selection of tutorials, exhibits and more.

INFORMATION: http://radarconf16.org

POWER CONVERSION INTELLIGENT MOTION (PCIM) 2016

WHEN: 10-12 May 2016

WHERE: Nuremberg, Germany

WHAT: PCIM is the international leading exhibition for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management.

INFORMATION: https://www.mesago.de

SVIAZ-EXPOCOMM 2016

WHEN: 10-13 May 2016

WHERE: Moscow, Russia

WHAT: The International Exhibition for Telecommunications, Control Systems, IT and Communication Services is an information technology and telecommunication event used by many overseas IT manufacturers to promote their products and develop their business in Russia. The conference showcases the latest innovative products, technologies and services.

INFORMATION: http://sviaz-expo.ru/en

APEMC 2016

WHEN: May 18 – 21, 2016

WHERE: Shenzhen, China

WHAT: This is the 7th Asia-Pacific International Symposium on Electromagnetic Compatibility & Signal Integrity and Technical Exhibition. This exhibition offers an excellent opportunity for all segments of the Microwave and EMC community to meet, providing an international gathering for everyone involved in technologies associated with RF, Microwave, Antenna, EMC Instrumentation and Analysis Software.

INFORMATION: http://www.apemc.org/

European Wireless 2016

WHEN: 18-20 May 2016

WHERE: Oulu, Finland

WHAT: The European Wireless Conference Focuses on all aspects of telecommunications, including ongoing research, new products and technology.

INFORMATION: http://ew2016.european-wireless.org

2016 ESA Workshop on Aerospace EMC

WHEN: 23-25 May 2016

WHERE: Valencia, Spain

WHAT: The main topics to be discussed include: Measurement Techniques and Test methods, EM Environment and EMI Effects, EMI Analyses and Predictions, EMC Control, Management and Standardization, EMC of Communication and Data Systems and Magnetic cleanliness. The main goals of the workshop are to establish a forum opportunity for EMC researchers and engineers involved in aerospace, give a wide picture of the present state of EMC technology and trends, encourage awareness of, and foster discussion in future developments.

INFORMATION: http://congrexprojects.com/2016-events/16A01

16th IEEE Conference on Environmental and Electronics Engineering (EEEIC 2016)

WHEN: 7-10 June 2016

WHERE: Florence, Italy

WHAT: EEEIC is an international forum for the exchange of ideas and information on energy systems both today and in the future. The conference provides a unique opportunity for designers and industrial people in general to interact directly with university researchers, manufacturers and distributors of energy equipment and to discuss a wide variety of topics related to energy systems and environmental questions.

INFORMATION: http://eeeic.eu

Euroem 2016 European Electromagnetics Symposium

WHEN: 11-15 July 2016

WHERE: Imperial College London, UK

WHAT: Find out about the latest applications, technologies and research ideas at this international technical forum for exchanging knowledge in the field of High Power Electromagnetics.

INFORMATION: http://conferences.theiet.org/euroem/index.cfm

2016 IEEE International Symposium on Electromagnetic Compatibility

WHEN: 25 July- 29 July 2016

WHERE: Ottawa, ON, Canada

WHAT: To provide a forum for networking and exchange of current EMC information.

INFORMATION: http://www.ieee.org

IRMMW-THz 2015

WHEN: 25-30 September 2016

WHERE: Copenhagen, Denmark

WHAT: The International Conference on IRMMW-THz, begun in 1974, is the oldest and largest continuous forum specifically devoted to the field of ultra high frequency electronics and applications.

INFORMATION: http://www.irmmw-thz.org

UNITED KINGDOM

PRODUCTS AND SERVICES

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AMPLIFIERS

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EMC Project Management and COTS

TIM WILLIAMS
Consultant
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INTRODUCTION

ONE FEATURE OF THE ELECTRONICS INDUSTRY that has become apparent, over the years of advising companies on EMC aspects of their designs, is the difficulty that many project managers seem to have in anticipating the problems that EMC requirements will cause to their project. Although it's a universal feature – and you could say that an EMC consultant is going to bump into it fairly often, given his vocation – it seems to be especially prevalent in industries where large projects with detailed customer specifications are the norm. In such cases the requirements flow down from prime contractor to sub-contractor and further, and in so many cases, the understanding of what the requirements mean doesn't flow down in parallel.

Many industry sectors suffer from this myopia: railway, automotive, telecom and aerospace are all affected. But the one which seems to suffer the most is the military sector. It has perhaps become more obvious in recent years, because of the squeeze on military spending, the expectation that the military should have access to the latest technology in the shortest timescale, and consequently the need to adapt commercial products for military use at the lowest cost – commercial-off-the-shelf (COTS).

In the EMC context, it works like this: the designer sees a functional requirement at the definition stage, and sees that it can be met by a commercially-available product. Along with the functional requirement, there is a whole stack of environmental requirements: such as shock and vibration, temperature and consequent heat dissipation, ingress protection, and of course EMC. The mechanical stuff is understood and can mostly be coped with, but EMC is a foreign country. They do things differently over there. As a result, the EMC requirements get pushed to one side in the early stages of project definition, with the expectation that they are simply an "engineering problem" that can be solved at a later date, if at all. There is a pious hope that when it comes to the scheduled EMC compliance test, the product will sail through without difficulty – or at least, any difficulties that arise can be offloaded onto someone else's part of the system, or negotiated for a waiver, or at the most, dealt with by throwing in a few ferrites or filters, as one might apply a sticking plaster to a scratch.

The EMC consultant tends to get a phone call with an undercurrent of desperation when the EMC test has gone wrong and

no such sticking plaster is obviously on the table. And this is, of course, the worst time to be involved in the project. Usually, the sales negotiators have bargained away any room for manoeuvre with the client. The most obvious engineering approach might be to find a sensible compromise between, for instance, discovered emissions that are "over the limit" and any expected susceptible frequencies in the eventual installation. (This is one implication of the "EMC Assessment" provision of the EMC Directive – one that's never used, since product developers will go the extra mile, sometimes taking a company to the edge, to get that magic word "Pass" on the test certificate.)

Some standards – the US MIL-STD-461 is one of them – allow limits and levels to be tailored. Some users might want to "tailor" by reducing the severity of the requirement to meet the test result, which in some circumstances might actually be acceptable. But this is where the lack of understanding along the whole contractual chain is most pernicious. If a sub-contractor has signed up to meeting "the spec", he can't then renege on that, whatever the engineering practicalities, without substantial commercial penalties. And no project manager is going to put their career on the line for that.

COTS

A lot of the issues arise because commercial products – IT equipment, power supplies, instrumentation and so on – are pressed into service against EMC requirements they were never designed to meet. Or, as MIL-STD-461F puts it,

> *The use of commercial items presents a dilemma between the need for EMI control with appropriate design measures implemented and the desire to take advantage of existing designs which may exhibit undesirable EMI characteristics.*

There has been considerable effort over the last few years to try and devise a way forward in such a situation. This has resulted in the concept of a "gap analysis", in which the commercial specifications which a product is said to meet – usually under the CE Marking regime – are compared with the more stringent project specifications such as the military standards or the railway standards, and the identified "gaps" are filled by extra tests which may show the need for "mitigation measures". Such a process has been described in for instance Cenelec TR 50538:2010, which works in the other direction – i.e. applying gap analysis to military equipment to prove that it meets the EMC Directive.

This process, while initially attractive, can fall at either of two hurdles:

- The product in question, despite its promises, doesn't actually meet the detail of the specifications that it claims, or else it simply doesn't claim enough of such detail to be useful. The CE Marking regime is so inherently lax that it would be surprising if it were otherwise;
- The "mitigation measures" which turn out to be necessary make the product unuseable in its intended application. For instance, the required extra filtering might double its size and weight, or the extra shielding might mean no-one could open the door to reach the front panel.

It may also be that the gap analysis simply isn't able to identify all the gaps, which only eventually show up once the compliance test is done. Consequent delays to the project make it late and over budget, and the company ends up with the unhappily familiar project manager shuffle.

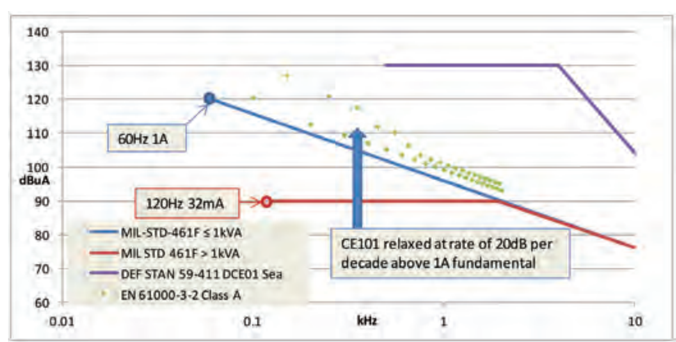
You might expect that companies which specialise in such projects would have learnt long ago of the dangers of postponing an analysis of EMC requirements, and indeed there are many such organizations that have EMC experts in house who can flag issues at an early stage. But there are also many who don't, and even in the best organizations the in-house EMC specialist doesn't always get the chance to offer the analysis that is required.

It doesn't have to be like this. Some degree of early understanding of what the stringent specifications mean can save a lot of delay at the back end. Here are a few thoughts which come from a generalised fund of experience. Most of the issues arise from application of military standards to commercial products, so that will be the focus here: not to say that other areas don't have their own issues, and some of these will also be mentioned. The two main military EMC standards are MIL-STD-461F in the US and DEF STAN 59-411 in the UK, and this article will look at their most common test requirements.

POWER SUPPLY CONDUCTED EMISSIONS

Before we even get into high frequency issues, a lot of headaches arise at the low frequency end, particularly for AC power supplies. For large cabinet-mounted equipment, as in naval systems, it is common to try to use commercial power supplies, which have met EMC requirements according to the CE Marking standards. But military standards have a number of not-always-obvious requirements which conspire to trip the inexperienced.

Supply harmonics: CE101



The first conducted emissions standard you come to is, in fact, mainly a limitation on supply harmonic currents: MIL-STD-461F CE101.

There are different requirements for aircraft and for naval applications. The above graph shows the CE101 limits for surface ships and submarines, alongside the UK DEF STAN limit for sea service, and the commercial Class A limits in EN 61000-3-2. The trick to understanding this is to see that different limits apply for equipment rated above and below 1kVA: and it's counter-intuitive, in that more relaxed limits apply to the lower power rating. CE101 starts at the 60Hz fundamental and the harmonic limits

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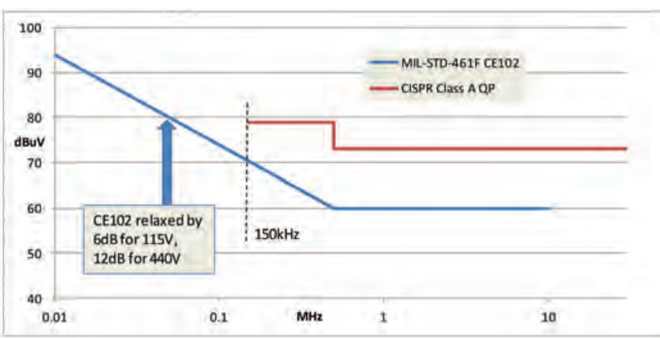
are related to this value for equipment that takes more than 1A fundamental current, that is they become more relaxed for higher currents; but once your equipment takes more than 1kVA, suddenly the lower levels (adjusted upwards for actual fundamental current) kick in. For most electronic power supplies, this will mandate power factor correction.

Such a requirement is not unknown for commercial power supplies, and for European requirements at 50Hz, EN 61000-3-2 applies. But it doesn't apply to 115V or 440V 60Hz supplies; and perversely, neither does it apply a limit to "professional equipment with a total rated power greater than 1kW". And as can be seen from the graph, the 61000-3-2 limits are higher than the CE101 1A ≤ 1kVA limits.

The upshot of this is that if you know that CE101 will apply, make sure that the combination of all your specified power supplies can meet it – probably this will mean power factor correction on most of them. Don't expect that a late change to do this will be easy – while it's theoretically possible to apply a series choke at the input, any such choke will probably be bigger than the power supply itself.

Finally, notice that DEF STAN 59-411's equivalent DCE01 requirement is much more relaxed, although as pointed out later, it uses a different LISN. But there are other military requirements which describe harmonic limitations, DEF STAN 61-5 and STANAG 1008 among them.

Supply harmonic limitations are related just to the AC supply



frequency, and CE101 only extends up to 10kHz, though it will catch any other audio-frequency modulation or intermodulation effects on the supply. But then we get into the effects of the switchmode operating frequency itself.

Conducted RF on the supply: CE102, DCE01

Looking at the above graph, which compares the MIL-STD-461F CE102 basic curve (28V) requirement with the commercial CISPR Class A limit, firstly it's clear that the CISPR limit is less stringent. In fact the MIL limit can be relaxed for higher supply voltages, and many supplies actually meet the CISPR Class B limit, which is around 10dB tighter; but on the other hand the CISPR limit applies the quasi-peak detector, which relaxes the measurement by contrast to the MIL's peak detector. So a direct comparison is somewhat more complicated.

But the real issue is the extension of the MIL STD down to 10kHz. This is potentially devastating for the higher power commercial switchmode supplies whose switching frequencies are in the 20-150kHz range. Low power units generally have switching frequencies above 150kHz so that both the fundamental and its harmonics are controlled by the CISPR curve. There is normally no content below the fundamental, unless the emissions from several supplies with different frequencies are intermodulating. But commercial supplies with higher power and lower frequencies will not have applied filtering below 150kHz, because for their intended applications they don't have to. (This is, in fact, a matter of some concern in the wider EMC context – see for instance Cenelec TR 50627:2015, Study Report on Electromagnetic Interference between Electrical Equipment/Systems in the Frequency Range Below 150 kHz).

This means that there will almost certainly be emissions below 150kHz which will be over the CE102 limit, and which may not be obvious from a commercial test report, which won't show these lower frequencies. The identified mitigation measures would mean extra filtering on the supply input. But low frequency, high power filters are massive. Large chokes and large capacitors are needed. Space and weight penalties are inevitable.

That's not the only problem: add-on filter design for frequencies of a few tens of kHz will encounter at least two other issues. One is earth leakage current. Capacitors to earth, to deal with common mode emissions, also cause supply frequency leakage. This can be a safety issue and also upsets earth leakage detection circuits, so there is usually a limit on the maximum capacitance that can be allowed. With regard to naval systems, MIL-STD-461F para 4.2.2 says

> *The use of line-to-ground filters for EMI control shall be minimized. Such filters establish low impedance paths for structure (common-mode) currents through the ground plane and can be a major cause of interference in systems, platforms, or installations because the currents can couple into other equipment using the same ground plane. If such a filter must be employed, the line-to-ground capacitance for each line shall not exceed 0.1 microfarads (μF) for 60 Hertz (Hz) equipment or 0.02 μF for 400 Hz equipment.*

Then there's the problem of filter resonance. A mismatch between an add-on filter and the existing filter in the equipment can create a resonance, typically at a few kHz, which actually amplifies the interference around that frequency. Rarely a problem for commercial products, it can cause unexpected difficulties when you are trying to meet low frequency emission limits: you put in a filter and it makes the emissions worse. To anticipate this, the best approach is to model the total filter circuit in a circuit simulation package such as Spice. But that requires knowledge of the filter component values, which is often not available.

The above comments apply particularly to MIL-STD-461F CE102. This measures voltage to the test ground plane across a 50μH LISN, just like the commercial test does, and so some comparison can be made. The UK DEF STAN 59-411 DCE01 test is different. It measures current to ground on each supply line, into a 5μH LISN. This makes a comparison with commercial standards harder. And, it covers a much wider frequency range:

down to 500Hz (20Hz for aircraft), and up to 100MHz (150MHz for aircraft). The most stringent specifications are Land Class A or ship above decks, which apply a limit of 0dBµA (that's 1 microamp!) from 1MHz (2MHz Land) to 100MHz. If you see this appearing in your specification, you can be sure that high frequency filtering requirements will be extreme; any switchmode noise, or microprocessor clock or data, cannot be allowed to get out into the power input. Careful mechanical grounding design as well as HF filtering and shielding of the supply will be essential.

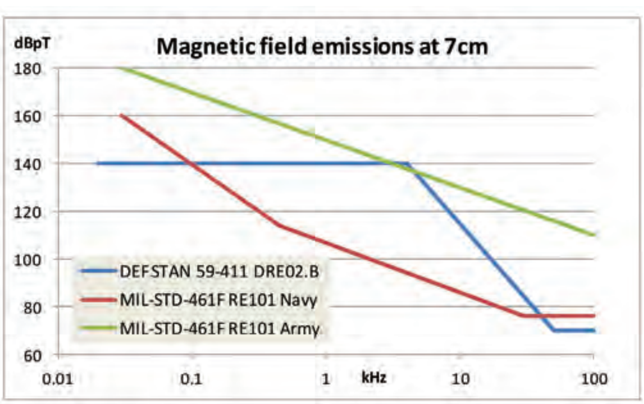
SIGNAL LINE CONDUCTED EMISSIONS

MIL-STD-461F does not have a test for signal line emissions. DEF STAN 59-411, on the other hand, does – DCE02. This is a common mode current measurement with the same limits as for the power lines, and it applies both to external cables and intra-system cables longer than 0.5m. If your cables are screened, then this test will exercise the quality of the screening; if there are any unscreened cables, then the interfaces to them will need to be filtered to prevent RF common mode noise. The test is not dissimilar to CISPR 22's telecom port emissions test, but over a much wider frequency range and with a more universal application, not to mention generally tighter limits.

Although the US MIL STD doesn't explicitly test signal line emissions, don't make the mistake of thinking that the signal lines can therefore be ignored as a coupling path. They will contribute to radiated emissions and the radiated tests will pick these up. Whatever your test programme, the cable interfaces are a critical part of the overall test setup. One common error, having put a reasonable amount of effort into the design of the equipment enclosure(s), is to ditch all the good work by throwing in any old cable that comes to hand when the EMC test is looming. Always ensure that you are using, if not the actual cables that will be used on the final installation, at least a cable set that is equivalent in screening terms.

RADIATED EMISSIONS

The military standards divide the radiated emissions requirements into two parts, for magnetic field and for electric field. Most of the commercial standards don't: they only measure the electric field, from 30MHz upwards. There are some exceptions to this, which also measure the magnetic field below 30MHz, generally down to 9kHz. Certain lighting products under CISPR 15 are one example; marine equipment is another; and some users of CISPR 11 (industrial, scientific and medical) are also subject to this.



Magnetic field: RE101, DRE02

The military magnetic field emissions test is quite different from any other radiated test (except for the complementary magnetic field susceptibility test). The method relies on a search coil being swept over the surface of the EUT to find regions of high field strength, and the field is then measured at a distance of 7cm from the surface. This method depends very much on the skill of the test engineer in finding the locations of highest emission. Both the UK DEF STAN and the US MIL STD use the same method, but their limits are different; for naval applications the MIL STD is generally more stringent, but otherwise the DEF STAN is.

The measurement is a test of low frequencies (up to 100kHz) in the near field. As such, the most likely sources will be magnetic components, particularly mains or switchmode transformers, or solenoids or motors, with high leakage flux. Commercial components almost never have to worry about emissions at these frequencies, so you will mostly have no handle on whether or not a particular component will actually be a threat, unless you do your own pre-compliance measurements in advance.

Mitigation measures in case of excess levels are fairly limited. Screening would require a thickness of magnetic material such as mu-metal or in milder cases, steel; occasionally a copper tape shorted turn around the outside of an offending magnetic core can help. If the emission can be traced to a particularly poor wiring layout – that is, high currents passing around a large loop area – then re-routing the wiring or using twisted pair will help. Otherwise, it's a matter of finding an equivalent component with lower leakage flux than the culprit, or tackling the client for a waiver, based on the distance away from the EUT (greater than 7cm) where the unit does meet the limit.

Electric field: RE102, DRE01, DRE03

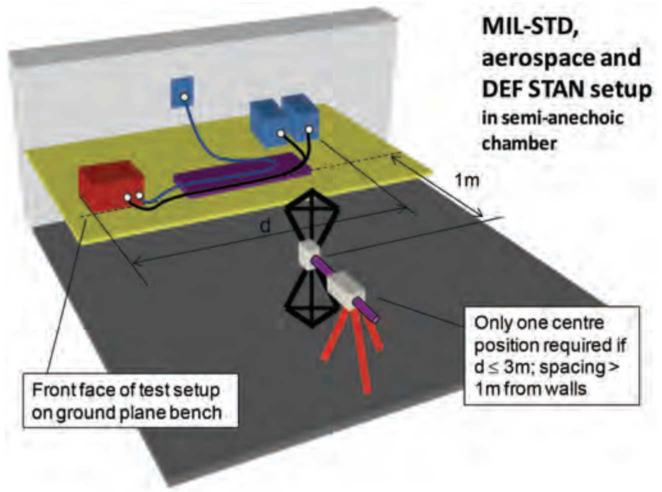
The military E-field measurement is more comparable to the well-known (in commercial circles) CISPR test, but only slightly. There are so many differences that a direct comparison of the two is really a mug's game, even though in the context of gap analysis it would be highly desirable. We can visit the differences roughly as follows.

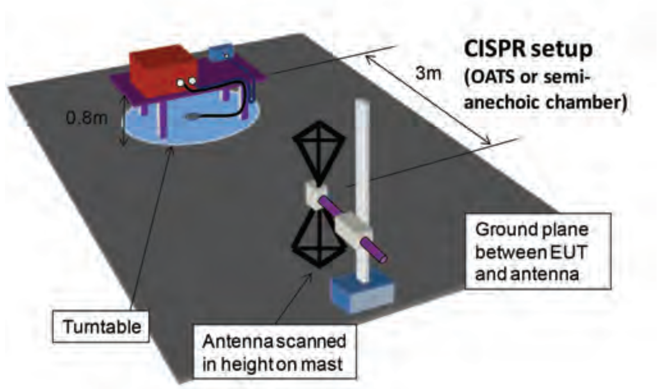
Physical layout, test distance and procedure

The CISPR test deliberately tries to ensure that the measuring antenna is in the far field of the EUT, with a minimum distance of 3m and a preferred distance of 10m – although the latter is not so common, given the much higher cost of suitable chambers that can accommodate it. This will indicate the interference potential of the EUT in the majority of commercial situations, when the vicitm's antenna is well separated from the source. By contrast, the military and aerospace requirements place the measuring antenna at a fixed 1m from the EUT. The usual justification for this is that on many such platforms (aircraft, land vehicles and ships) the victim antennas are much closer. It also makes the measurement easier and, with low emission limits, aids in the fight against the noise floor of the test instrumentation.

It might be assumed that converting measurements from a far-field 3 or 10m to a near-field 1m, in order to directly compare

a commercial result to a military limit, would be a simple matter of adding 9.5 or 20dB, on the assumption that the signal strength is inversely proportional to distance. In rare cases this might actually be true, but it certainly isn't generally the case – the "conversion" factor can swing widely either side of this figure. So the default approach, using the above assumption, already





introduces substantial errors. To understand why, you need to have a detailed insight into the electromagnetic field equations, which isn't the purpose of this article.

Distance is just the start. The MIL-STD and DEF STAN test layout requires the EUT to be mounted on, and grounded to (if appropriate) a ground plane bench with its cables stretched out for 2m at a constant height of 5cm above the plane, before terminating in LISNs for power cables or in appropriate support equipment or the wall of the chamber, for signal cables. The CISPR radiated emissions test is different in every one of these aspects.

As well as this, the CISPR test requires the EUT to be rotated to maximise the emissions in azimuth. This isn't a requirement of the military method, although it does leave open a requirement for maximization in orientation, without specifying how, other than "encouraging" the use of a pre-scan to identify the face of maximum emission.

Frequency range

The CISPR frequency range for radiated emissions starts at 30MHz and extends upwards to 1GHz or beyond, to 6GHz, depending on the highest internal operating frequency of the EUT. The military range is 10kHz to 18GHz, although not all applications require the whole range. Below 30MHz and above 6GHz there will be no data on commercial equipment performance.

Detector type and bandwidth

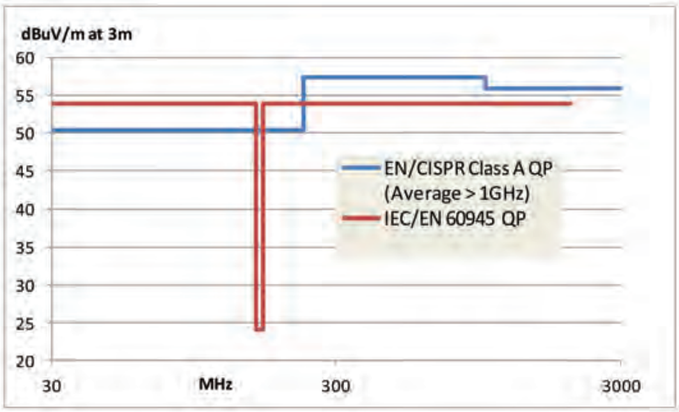
The military tests use the peak detector; the CISPR tests use quasi-peak (QP) for radiated emissions up to 1GHz, and peak above this. Both types give the same result on continuous interference signals but the QP gives up to 43.5dB relaxation to pulsed signals, depending on their pulse repetition frequency (prf). So, if a unit emits low-prf signals which rely on the QP detector to pass CISPR limits there will be a significant extra burden in converting these results to the military limits. To do so quantitatively, you would need to know the characteristics of interference sources at each frequency.

The measurement bandwidths are also different: 100kHz for the military standards from 30MHz to 1GHz, versus 120kHz for CISPR. Above 1GHz both use 1MHz. By comparison with other sources of error, the extra fraction of a dB potentially measured by CISPR below 1GHz is negligible and can be safely ignored.

Limits

In general, the CISPR limit lines are well established and for the majority of applications there are really only two sets: Class A and Class B, the latter being more onerous by 10dB and applicable to residential or domestic situations, Class A being applicable to nearly everything else. Military standards have many more variations depending on application, added to which the frequency ranges and levels can be modified by the customer's contract. Because of these variations, it's not generally possible to say that one set of standards is more or less onerous than the other, although it's to be expected that any equipment mounted externally to the platform will have much more strict requirements than any commercial application. Additionally, DEF STAN 59-411 has a separate test, DRE03 between 1.6MHz and 30MHz (88MHz for man-worn equipment) – intended to mimic the use of equipment in close proximity to Combat Net Radio (CNR) installations used by the Army – which uses a tuned antenna representative of the Army's radios. The antenna is "significantly more sensitive than the broadband antennas used in Test Method DRE01" and this allows even lower limits to be put in place for this application.

In summary, though, it is very difficult to make an accurate determination of whether a given piece of commercial equipment will meet military radiated emissions requirements through gap analysis. From the point of view of project planning, there are two principal coupling paths that radiated emissions will take from the equipment. One is radiation directly from the enclosure, the other is radiation from cables connected to the enclosure. Therefore, areas of the design that need the most work to control these emissions will include cable screening and enclosure screening. The more critical the limit levels – and the wider the frequency range – the more important it is to actively design the enclosure for screening effectiveness; and also to ensure that cable and interface construction maintains the screening effectiveness. The two areas are complementary, one will be useless without the other. Conductive gaskets for seams and connector shells in the enclosure need to go hand in hand with selection of screened cable and termination of that screen to the mating connector. The trick lies in understanding that here we are dealing with the electrical performance of mechanical components, and so both areas of design must be evaluated.



Marine equipment

Before leaving the subject of limits, one non-military application where it is possible to apply a gap analysis is in radiated emissions of civil marine equipment. The marine standard IEC/EN 60945 uses substantially the same method as the normal CISPR tests and CISPR results can be compared, almost directly. It would be quite typical to want to use CISPR Class A-compliant equipment – such as video monitors or network switches – on board a ship. The two limits are compared below. Note that over much of the frequency range the marine requirements are quite relaxed. But there's one exception: the VHF marine band, 156-165MHz, where they are anything but relaxed. This can cause substantial headaches for marine system builders, and it's as well to be aware of this at the outset.

RF SUSCEPTIBILITY

Radiated

The coupling routes for radiated RF susceptibility issues are generally the reciprocal of those for radiated emissions, and therefore shielding design techniques will work in both directions. However, the internal circuits which are affected by high level applied RF fields may be quite different from those which create emissions. It is usual for power switching circuits and digital processing to create RF emissions while being relatively unaffected by incoming RF; in contrast, low-level analogue circuits, typically for transducer or audio processing, will not create emissions but may be affected by millivolts of RF. Therefore for many products there can be different areas which are relevant for one or other phenomenon.

Applied RF field levels, as with emissions limits, can show wide variations depending on the required standard and application. DEF STAN 59-411 DRS02 has a "Manhattan skyline" of levels versus frequency, ranging from typically 10V/m at low frequency to 1000V/m, pulse modulated, in the microwave region, if equipment will be sited potentially in the main beam of a radar transmitter (2000V/m for aircraft). MIL-STD-461 RS103 has a rather more uniform set of requirements, ranging from 10V/m for ships below decks to 200V/m for aircraft. RTCA DO-160, which is widely applied for civil aircraft equipment and often for military ones too, has a massive table (rather than a Manhattan skyline graph, but to the same effect) which defines susceptibility levels versus frequency for 12 different categories of equipment, with the least severe being 1V/m and the most severe being 7200V/m. Frequency ranges are tailored to the application as well, but can extend from 10kHz to 40GHz.

Compare this to the majority of commercial standard requirements, which are generally fixed at 3V/m for residential and 10V/m for industrial and marine applications; railways push the boundary to 20V/m, and the basic standard IEC 61000-4-3 proposes a maximum of 30V/m. And the frequency range for these radiated requirements starts at 80MHz and goes up to 2.7GHz at the most, with much lower levels being the norm above 1GHz; it may be fair comment that most commercial products aren't expected to find themselves in the main beam of a surveillance radar. (It's noteworthy that the commercial tests refer to immunity, whereas the military/aerospace ones refer to the same phenomena as susceptibility.)

Relating these levels means that the more stringent specifications will demand a high degree of extra shielding, which has to be allowed for in the initial design choices. Trying to add or improve shielding later in the mechanical design is always going to create serious headaches.

Test method

As with radiated emissions, there are differences in the susceptibility test procedure too. The military test layout stays constant between emissions and susceptibility. The CISPR/IEC layouts are different, much to the chagrin of test labs who have to re-position equipment between tests and sometimes use different chambers in order to maintain compliance with the specifications. But for the radiated susceptibility test, the biggest issue lies in how the field strength is controlled. For the tests in MIL-STD-461 and DEF STAN 59-411 (but not DO-160) the applied field strength at a probe near to the EUT is monitored and controlled during the test. For DO-160 and the commercial test to IEC 61000-4-3, the field is pre-calibrated in the absence of the EUT and the same recorded forward power is replayed during the test. These two methods can produce fundamentally different results, for the same specification level in volts per metre, depending on the nature of the EUT.

In addition to this, there are differences in the modulation that is applied to the RF stress. The military and aerospace tests prefer 1kHz square wave modulation, but also pulse modulation where it is relevant (at radar frequencies), along with other more specific types of modulation in some cases. The IEC 61000-4-3 test uses only 1kHz sinusoidal modulation; but it does require 80% modulation depth, which effectively raises the peak applied stress level to 1.8 times the specification level. In this narrow sense, the commercial test is more stressful than the military, for a given spec level.

But when you are looking at a test report for a COTS product, for any immunity test one of the most important questions is: how was the product monitored during the test, and what criteria were applied to distinguish a pass from a fail? In many test reports, this information is so vague as to be of no help whatsoever, yet it is actually what determines the suitability of that equipment for the application. No test standard will specify the performance criteria in detail; that is the job of the test plan for that product. The report should reference the test plan and where necessary reproduce its detail. Few commercial test reports do this – often, one suspects, because there never was a test plan in the first place.

Conducted RF

Similar issues apply to the specifications for conducted RF susceptibility. Direct comparisons are harder because commercial standards, based around IEC 61000-4-6, apply a voltage level to the cable from a source impedance of 150Ω; virtually all other standards use the method of "bulk current injection" which applies a current level via a clip-on current transformer. Relating the two is only possible if you know the common mode input impedance of the interface you are testing. It would be fair to say that even the designers most familiar with their product will be guessing – it's not a feature which is necessary to know for the functioning of the equipment, even though it has a direct impact on EMC performance.

Beyond this, as with radiated RF susceptibility, the military and aerospace requirements have a smörgåsbord of levels versus frequency for different applications. DO160 has a maximum of 300mA, MIL-STD-461 CS114 has 280mA and DEF-STAN 59-411 DCS has 560mA for their most severe applications. If we take the power into the 50Ω calibration jig, this is between 4 and 15 watts. Compare this with the typical 10V emf from 150Ω which gives 5Vrms into a 150Ω calibration, as required by IEC 61000-4-6, which is only 166mW.

Design mitigation measures for this test are limited to two principal approaches: effective screening of cables, and effective filtering of interfaces. One can possibly substitute for the other, but a combination of both is the best method. Any weakness in cable screen termination will allow interference through to the screened circuit within, which can be mopped up by a moderate degree of filtering. The overall protection, though, must work across the frequency range of 10kHz to 400MHz (200MHz for MIL-STD-461). Designing a filter which will deal with this spectrum, even for power supplies, is not trivial and usually the most cost-effective approach is the combination.

LIGHTNING AND TRANSIENT SUSCEPTIBILITY

The US MIL-STD-461 doesn't have an explicit lightning surge test, at least up to issue F. One is under discussion for issue G. The UK DEF STAN 59-411 does have some serious surges, including one for lightning (DCS09), but the most comprehensive is that in section 22 of DO-160. This has been uprated in every re-issue of the standard and is now one to challenge any aircraft equipment designer – if, that is, you can decode the arcane instructions for how to select the various levels and waveforms.

This author was privileged to visit the lightning surge test facility of a major Chinese telecomms supplier a few years ago (the capacitor bank alone filled most of the room – "Please, Mr Tim, make sure to stand well back when I press this button") – there are regions of the world where thunderstorms are the norm rather than the exception, and telecom towers are natural attractors for the strike. So some parts of the facility had to be tested with the full whack. Aircraft, naturally, can't be trusted not to fly near to or even under (not into) a thunderstorm occasionally. But practically, the test levels need to be tailored more to the currents that would be expected on the wiring interfaces, which in turn depends on the unit's location in or outside the aircraft, the level of hardening required and the type of construction of the aircraft's structure.

DO-160 version G has two methods in its section 22: pin injection, and cable bundle tests. The first is a "damage tolerance" test; the second evaluates "functional upset tolerance" and has a variety of waveforms including single and multiple stroke and multiple bursts. The best commercial equipment may be specified to cope with the IEC 61000-4-5 lightning surge test, but this does not include pin injection, and its surge waveform does not reflect the variety of waveforms required by DO-160. Extra interface protection will be needed if you are trying to use such equipment in this application.

Pin injection

For this type of test, the EUT needs to be powered up and operating, but its connectors (except for the power supply) are disconnected and the specified transient pulse is applied, ten times in each polarity, between each designated connector pin and the ground reference. Thus cable screening is of no relevance for this test. If the power input is to be tested, the transient is applied in series with the supply voltage, with the external supply source properly protected.

Three different waveforms are specified, with five possible levels. The most stressful in energy terms is waveform 5A, which is a 40/120µs surge with a 1Ω source impedance and a peak voltage from 50V (Level 1) to 1600V (Level 5 – this one is fairly rare, but level 4 at 750V is not uncommon). The other waveforms (labelled 3 and 4) are a 1MHz damped sinusoid and a faster unipolar transient, from higher source impedances.

Cable bundle

These tests are intended to check for both damage and upset, and work by injecting transients into each cable interface as a whole, either via a current probe or by a connection between the unit enclosure and the ground reference of the test. In this case, cable screening effectiveness is crucial. In a well-screened system the surge will pass harmlessly down the cable screen and around the EUT enclosure without impinging on the inner circuits. Successfully beating this test then means ensuring that both the cable assembly and the enclosure have a low transfer impedance, to prevent common mode currents developing internal voltages. To put a sample figure on this, a transfer impedance of 50mΩ/m, typical of a good quality single-braided screen at 10MHz, when faced with a 1000A surge down the screen, will create a 50V pulse in common mode on the cable's internal circuits per metre length. A double-braided screen could drop this to 1mΩ/m and hence 1V. But that demands extreme care in assembling the connector screening shell.

Alternatively, if a cable is unscreened, the interface has to absorb or resist the injected surge in the same way as for pin injection. And in addition, the unit has to continue operating without upset, so any pulse propagating into the circuit must not affect its operation.

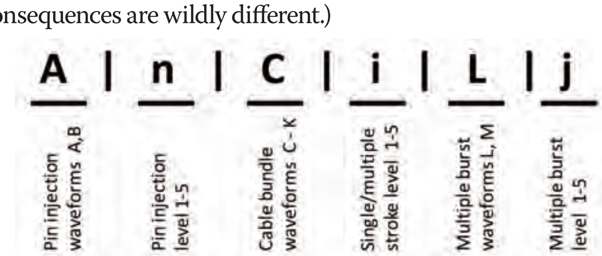
The cable bundle tests use the same waveforms (3, 4 and 5) as before, with possibly two more, waveform 1 being the current equivalent of waveform 4 (6.4/69µs) and waveform 2 being a faster one with 0.1µs risetime. Single stroke, multiple stroke (one large plus thirteen smaller transients) and multiple burst (three bursts of 20 damped sinusoid transients, every 3 seconds, for at least 5 minutes) application are specified. Waveform 6 applies to low impedance cable bundles in place of waveform 3 for multiple burst tests. The levels vary from 50V/100A for the mildest to 1600V/3200A for the most severe, and that's just for waveform 1.

Transient protection

Given that your specification, once it has been decoded, will be quite explicit as to the levels and pins to be tested, you can design in protection with a good knowledge of what it will be protecting against. There are two main techniques. The first is isolation: if all interfaces are isolated from ground, and the isolation barrier can withstand the full surge voltage, this is a good start. But remember that there is a dv/dt associated with the surges and therefore capacitance from each circuit to ground and/or through the isolation barrier is also important, since the edge of the stress waveform will be coupled through this capacitance to the circuits. If you are relying only on isolation, it is necessary to identify parasitic and intentional capacitances to the ground reference (usually the enclosure) and make sure that the paths these provide are innocuous.

The second method is clamping the surge voltage with transient suppressors to ground. Since energy will be deposited in the suppressor on each test, you need to size it appropriately for the specification level to be sure it is not over-stressed. You also need to be sure that the downstream circuits can withstand the peak voltage that the suppressor will clamp to. Whilst they can be effective, suppressors aren't suitable for all types of circuit, particularly wideband interfaces. And complementary to the comment above on capacitance, when a suppressor clamps a transient, it passes a di/dt current pulse; any inductance in series will create a secondary transient voltage, from V = -L·di/dt, which may be at damaging levels. Short leads and tracks, going directly to the right places (perhaps the enclosure, perhaps local circuit nodes) are critical.

Another more sophisticated approach is to block the surge path but only during its actual occurrence, using a series-connected high voltage MOSFET and control circuitry. Given the relatively slow risetime of the waveforms this is feasible, but it is complex, and has to take into account both surge polarities. It may well be necessary in high-reliability applications when you simply cannot use a transient suppressor, because if a suppressor is destroyed open-circuit this will not be apparent – the equipment will carry on operating normally – but you will have lost surge protection without knowing it. (A related question is, is it better for a transient suppressor to fail open circuit or short circuit? It could fail either way, but the consequences are wildly different.)



Equipment categories

The actual tests and levels applied depend on the application and need to be clearly specified in the procurement documentation. This should be "consistent with its expected use and aircraft installation". The specification should consist of six alphanumeric characters as shown below. The first, third and fifth letters are "waveform set designators", determining which tests are to be done with which waveforms – decided by the type of aircraft and whether or not the cables are screened – and the other numbers n, i and j apply levels for each set of tests, depending on where in the aircraft the equipment will be mounted.

X in the specification means no tests are to be performed, Z means that the test is performed at levels or with methods different from the standardized set.

As a very, very approximate first pass judgement, the higher the numbers and the further into the alphabet go the letters, the more severe is the test. But you can see that the complexity is daunting and every case has to be analysed in its own right.

Other transient tests

By comparison with DO-160 section 22, other military transient tests are fairly straightforward, although not necessarily lenient. In most cases the transients are applied by current probe on cable bundles; this is the case for MIL-STD-461 CS115 and 116, and for DEF STAN 59-411 DCS04, 05, and 08. DCS06 is applied on power supply lines individually, as is also DCS08. The nearest test to the DO160 lightning tests is DEF STAN 59-411 DCS09, which applies similar and in some cases identical waveforms. A wry note at the beginning of DCS09 says

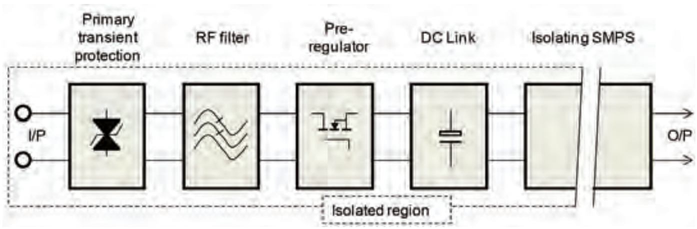
> *When testing with the Long Waveform, in particular, it is advisable for personnel in the vicinity of the EUT to wear eye protection. Some components have been known to explode and project debris over distances of several metres. Some types of pulse generators can produce a high intensity burst of noise when they are fired. Operators, trials engineers and observers should be made aware of this and advised to wear ear protection.*

Transient suppressors, where they are used, should be sized appropriately.

SUPPLY VOLTAGE RATINGS

As a final piece of light relief, don't forget that some equipment specifications make substantial demands on the power supply's robustness. We've already mentioned harmonic current limits at the beginning of this article, but there are other power input issues which do, strictly speaking, fall under the umbrella of EMC. They don't appear in MIL-STD-461 or DEF STAN 59-411, but there are other military requirements which are relevant, for instance MIL-STDs 704 and 1399, or DEF STAN 61-5, or STANAG 1008. RTCA DO-160 for aerospace has section 16 (which does include harmonic current limits); and in another industry, railway rolling stock equipment has to meet EN 50155. Mostly, these specify the degree to which input voltage dips and dropouts can be expected, along with the levels of under- and over-voltage in normal and abnormal operation. The last of these is often the most stressful.

DO-160 section 16's abnormal over-voltage requirement for Category Z (the most severe) on 28V DC supplies demands that the power input withstand 80V (+185%) for 0.1 second and 48V (+71%) for 1 second. Even the least severe, Category A, requires +65% for 0.1 second and +35% for 1 second. For EN 50155, a voltage surge on a battery supply of +40% for 0.1 second should cause no deviation of function, and for 1 second should not cause damage. Overvoltages for such durations can't be clamped by a transient suppressor; suppressors, if used, need to be rated above the peak voltage that will occur for these conditions. But at the same time, it can be difficult to design power supplies for such levels using conventional SMPS integrated circuits. Instead, a discrete pre-regulator – which might also implement other functions such as soft start and reverse polarity protection – is a common solution. So the complete power supply input scheme for a DC supply is likely to look like that shown below, and the early components need to be substantially over-rated compared to the normal operating voltage.



CONCLUSION

With all the above requirements, limits and levels in mind, if you are expecting to use any commercially-produced apparatus within a system that needs to comply with military/aerospace requirements, or others for which it wasn't designed, it should by now be obvious that right at the beginning of the design process, you must start with a detailed review of the procurement contract's EMC specification before you get involved in any negotiations on contract price. EMC requirements have the potential to make or break a project – they must be respected and their implications for schematic, PCB and mechanical practices understood.

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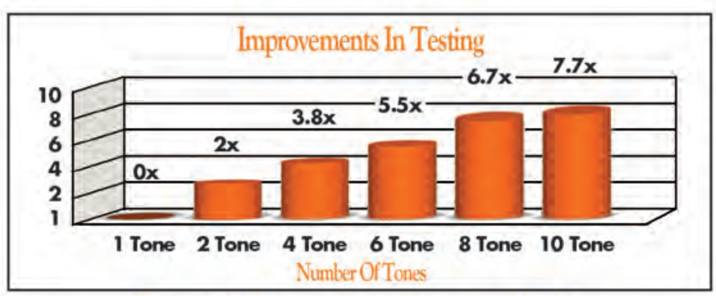

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Ist Die Heutige EMV Ausreichend Für Das Internet Der Dinge?

GUNTER LANGER
Beratender Ingenieur
Langer EMV-Technik GmbH

OVERVIEW

The number of mobile devices such as smart phones, tablets and wearables has risen significantly over the past years. At the same time, wireless communication has increased due to higher data rates. Will the growing number of wireless devices multiply the EMC problems? Is today's industry able to cope with the EMC requirements that the Internet of Things has in store for us? This article answers those questions. To read this article in English, go to our website www.interferencetechnology.com.

EINBRINGEN

DIE ANZAHL DER MOBILEN Geräte wie Smartphones, Tablets und Wearables ist in den letzten Jahren stark gestiegen. Gleichzeitig hat durch höhere Datenraten die drahtlose Kommunikation deutlich zugenommen. Wird es durch immer mehr Wireless-Geräte zu vermehrten EMV-Problemen kommen? Ist die heutige Industrie den EMV-Anforderungen, die mit dem Internet der Dinge auf uns zukommen, gewachsen?

Wenn mehr Gräte miteinander funktionieren müssen und die EMV-Qualität der Geräte auf dem heutigen Stand bleibt, werden statistisch gesehen auch mehr EMV-Probleme auftreten. Darüber hinaus kann ein Gerät trotz bestandener EMV-Prüfung in der Praxis unverträglich reagieren. Zum Beispiel besteht ein elektronisches Gerät die Störaussendungsprüfung (IEC 61000-6-3, IEC 61000-6-4). In der Praxis kann im Gegensatz zur Prüfung das elektronische Gerät an ein metallisches Objekt wie ein Gehäuse gelegt werden. Dadurch kann eine Feldkopplung entstehen. Die Feldkopplung führt zur Erhöhung der Störaussendung gegenüber dem geprüften Fall. Dabei ist es wesentlich, welche Abmessungen das metallische Objekt hat. Durch die Feldanregung können stehende Wellen entstehen, die auf die Abmessungen des metallischen Objekts passen. Die stehenden Wellen erzeugen zusätzliche Störaussendung.

In der Zukunft werden also nicht nur die drahtlose Übertragung ein Problem sein, sondern auch die Störabstrahlung der Geräte.

Eine Verschärfung der bestehenden Normen für Geräte muss nicht unbedingt zum Ziel führen.

An dem oben genannten Beispiel kann man erkennen, dass der Wirkmechanismus der Feldkopplung in der jetzigen

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Prüfung nach Norm meist nicht erfasst wird. Auf die Wirkmechanismen der Feldkopplung aufbauend kann man sich überlegen, wie man das Problem löst.

Es ist abzuwarten, ob die momentanen Messprinzipien der Normen ausreichend sind oder neue Messprinzipien entwickelt werden müssen.

Darüber hinaus zeichnen sich im Bereich der EMV-Normen für ICs (IEC 61967 und IEC 62132) neue Anforderungen ab. In Zukunft benötigen EMV-Entwicklungstools / Simulationspro-gramme für Flachbaugruppen konkrete EMV-Parameter von ICs als Eingabewerte. Es ist sinnvoll diese EMV-Parameter als Messergebnis der Messungen nach IC-EMV Norm zu gewinnen. Momentan sind die Messergebnisse von Normmessungen für derartige Vorhaben nicht ausreichend verwendbar.

Des Weiteren wird dieses Vorgehen für die IC-Entwicklung Bedeutung erlangen.

Aus diesen Gründen sollte man darüber nachdenken, inwieweit man die Prüfmethoden der Normmessung an eine solche Aufgabe anpasst. Im Folgenden wird dies am Beispiel der lei-tungsgebundenen Störaussendung für ICs dargestellt.

Die heutigen Entstörstrategien in der Elektronikentwicklung stoßen an ihre Leistungsgrenzen. IC´s als potentielle Quellen von Störaussendung machen sich erst nach dem Aufbau des ersten Entwicklungsmusters bemerkbar. Der Entwickler findet sie bei der Entstörung des Gerätes / der Flachbaugruppe. Mit Nahfeldsonden wird nach HF-Quellen in der Elektronik gesucht. Meist wird der IC als Störquelle nicht selbst entdeckt, sondern die von ihm mit Störstrom und Störspannung gespeisten Leitungsnetze. Die Elektronik wird dann mit zusätzlichen Bauteilen, Kupferfolie oder anderen Mitteln modifiziert. Schließlich soll nach dem Redesign der Flachbaugruppe mit einer EMV-Messung die erfolgreiche Entstörung bestätigt werden.

Diese Vorgehensweise ist sehr langwierig und teuer. Ein großes Problem ist, dass erst nach Fertigstellung des ersten funktionstüchtigen Entwicklungsmusters die EMV-Arbeit zielführend begonnen werden kann. Weichenstellende Erkenntnisse zur EMV des Gerätes werden zu spät gewonnen. Wichtige Entscheidungen im Entwicklungsprozess werden ohne Einbe-ziehung der EMV-Prüferkenntnisse gefällt. Durch die relativ spät gewonnenen EMV-Prüferkenntnisse sind Probleme bei der Geräteentwicklung vorprogrammiert.

Die Industrie verlangt aber nach schnelleren und effizienteren EMV-gerechten Entwicklungen. Diese können nur erreicht werden, wenn generell ein neuer Weg beschritten wird. Dieser Weg muss weit vorn im Entwicklungsprozess beginnen und tief in die Wirkungsketten der Störaussendung eingreifen. Dafür ist verwendbares Wissen über die Störquellen erforderlich. Wenn man ICs als potentielle Störquellen genauer beschreiben kann, können entsprechende Maßnahmen für eine stabile EMV des gesamten Gerätes zeitiger und effizienter ein-gesetzt werden.

Notwendig sind geeignete EMV-Parameter für ICs. An diese Parameter sind hohe Anforde-rungen gestellt. Sie müssen die EMV-Problembereiche“ der ICs für die Industriepraxis beschreiben, d.h. sie müssen sich für eine EMV-gerechte Flachbaugruppenentwicklung eignen. Weiterhin müssen an die IC-EMV-Parameter für die Praxis Maßnahmen und Verfahrensstra-tegien gekoppelt sein.

Diese Arbeitsweise sollte die heutige EMV-Elektronikentwicklung bestimmen. Heute wird im Bereich der Geräteentwicklung bedingt durch die Miniaturisierung eine höhere Empfindlichkeit der Geräte festgestellt. Die Gerätehersteller gehen mit immer größerem Aufwand gegen die Probleme vor, um die Geräte zu entstören und die entsprechenden Normen einzuhalten. Für die Gerätehersteller sind die aktuellen Normen verbindlich.

Die im obigen Beispiel dargestellte Problematik verschärft die Situation zusätzlich. Besonders für das Internet der Dinge ist es Voraussetzung, dass die Geräte in ihrem Umfeld normal und zuverlässig arbeiten.

Inwieweit die Gerätehersteller die durch die Miniaturisierung entstehende Verschärfung der EMV-Situation weiterhin beherrschen und mit steigendem Aufwand die Geräte entstören können, ist abzuwarten. Die EMV-Entwicklung wird einen immer höheren Kostenanteil bei der Geräteentwicklung ausmachen. Vor allem bei Geräten im niedrigen Preissegment ist es in Zukunft fraglich, ob weltweit die nötigen EMV-Ziele überhaupt eingehalten werden können. Dieses Problem wiederum kann damit entschärft werden, dass in Zukunft im Bereich der IC-Forschung und IC-Entwicklung bessere EMV-Parameter erreicht werden. Das bedeutet, dass auch hier mehr Aufwand nötig ist. Das betrifft natürlich die Wireless-Geräte. Die deutsche Industrie reagiert bereits auf diese verschärfte Situation.

Das zeigt sich daran, dass schon heute Unternehmen die EMV-Entwicklung zum Beginn der Entwicklung von Geräten und komplexen Systemen durch neue EMV-Technologien in Zusammenarbeit mit EMV-Fachberatern lösen.

HAUPTTEIL:

ICs erzeugen auf Grund ihrer funktionsbedingten inneren Schaltvorgänge HF-Spannungen, -Ströme und -Felder. Diese gelangen über verschiedene Wirkmechanismen als Störaussendung in Kabelbäume oder als Störstrahlung in den Raum. Folgende Wirkungen der ICs sind möglich:

1. Leitungsgebunden: HF-Strom- und -Spannungsabgabe über die IC Pins in die Leitungsnetze der Flachbaugruppe.
2. Nahfeldgebunden: E- und H-Nahfeldabgabe der ICs aus dem Die oder den IC-Anschlüssen.
3. Strahlungsgebunden: Direktaussendung von elektromagnetischen Wellen. Die Direktaussendung kann in der Praxis meist nur im Gigaherzbereich bei ICs mit sehr hohen Taktraten eine Rolle spielen.

STÖRFESTIGKEIT UNTERHALB 150 kHz

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Neue Anforderungen für EMV-Störfestigkeitsprüfungen im Niederfrequenzbereich können ab sofort mit einer Generatorlösung geprüft werden. Auf Basis der Grundnormen IEC 61000-4-16 und IEC 61000-4-19 werden eine Vielzahl von aktuellen Produktnormen wie EN 61326-3-1, IEC 61850-3, IEC 60255-26, IEC 60533 und IEC 60945 unterstützt. Kern der Lösung ist ein Generator mit einzigartiger Benutzeroberfläche und intuitivem Menükonzept, dessen Ausgangssignal und -impedanz über die Auswahl der Koppeleinrichtung erfolgt. Zeitsparende Auswertemöglichkeiten zur Prüflingsüberwachung werden durch umfangreiche Schnittstellen realisiert.

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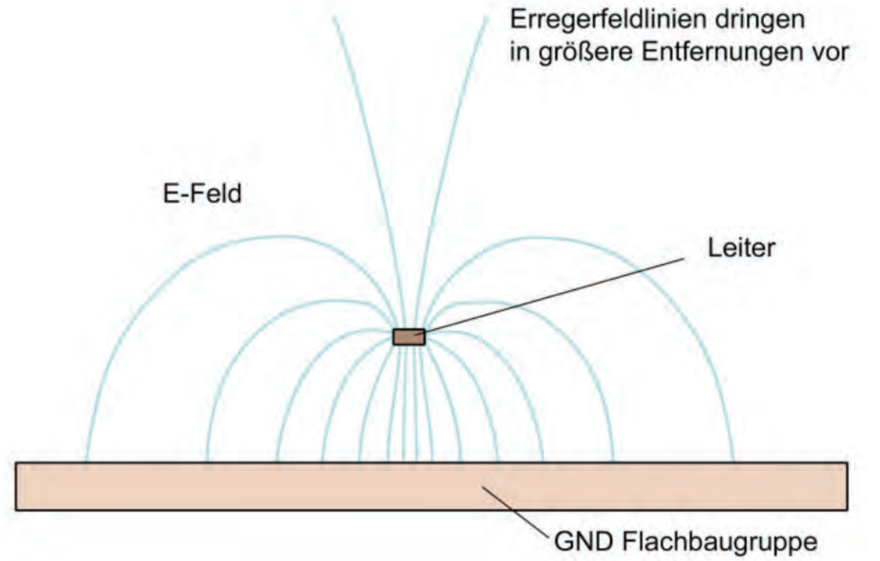

Abbildung 1 - Elektrisches Feld eines Leiterzuges

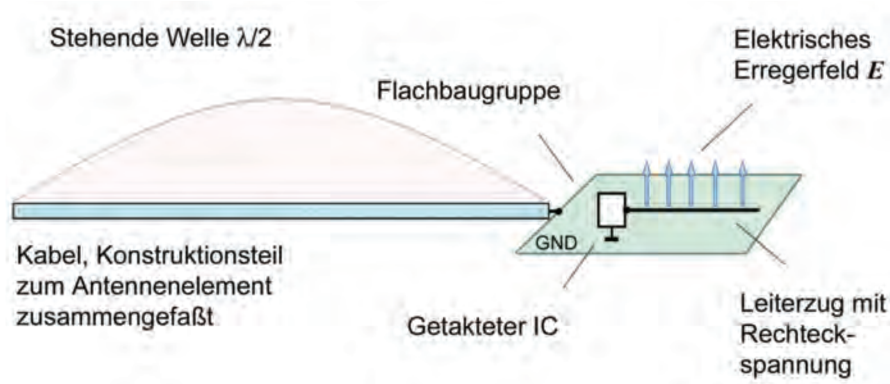

Abbildung 2 - Anregung der Abstrahlung über die elektrischen Erregerfeldlinien.

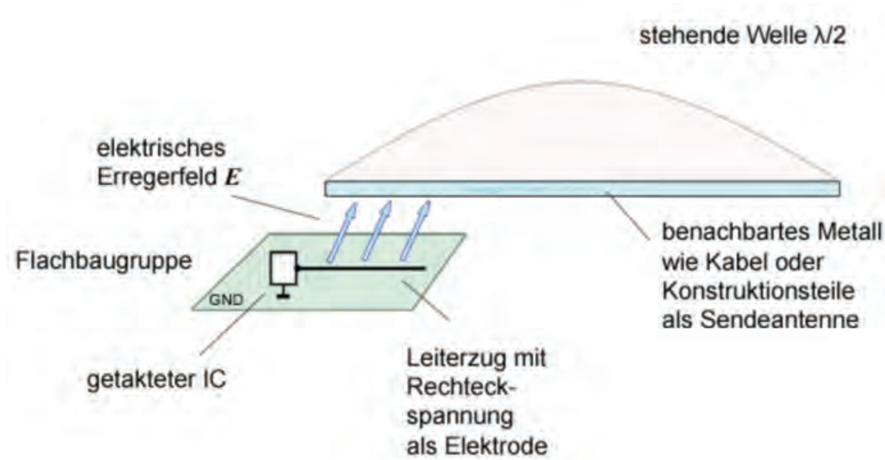

Abbildung 3 - Überkoppeln der Erregerfeldlinien auf benachbarte Metallteile.

Im folgenden Abschnitt wird **Punkt 1**: Leitungsgebundene Wirkung in der Flachbaugruppe beschrieben.

Für die Störaussendung gibt es einen geschlossenen Wirkungsweg. Im IC-Inneren sitzen die treibenden HF-Strom- und -Spannungsquellen. Diese treiben HF über Bonddraht, Leadframe und Pin in das Leitungsnetz der Flachbaugruppe. Dort entstehen aus Strom magnetisches Nahfeld und aus Spannung elektrisches Nahfeld. Diese Nahfelder führen über Wechselwirkung mit Metallteilen (Antennen) zur Störaussendung.

Zusammenhang zwischen IC-Pinspannung und Störaussendung

Die am Leiterzug der Flachbaugruppe anliegende Pinspannung des ICs baut um den Leiterzug ein elektrisches Feld auf (**Abbildung 1**). Die meisten Feldlinien führen auf die GND-Fläche der Baugruppe, wenige Feldlinien treten nach oben senkrecht aus und dringen weit in den Raum vor. Je weiter der Leiterzug am Rand des GND-Systems liegt, desto mehr Feldlinien treten in den Raum aus.

Die austretenden Feldlinien (Erregerfeldlinien) verlassen das GND-System der Baugruppe und tragen Verschiebestrom in den Raum, der das gesamte Metallsystem (Flachbaugruppe mit Kabeln und metallischen Konstruktionsteilen) zum Schwingen anregt (**Abbildung 2**).

Die auf dem Metallsystem stehenden Wellen können zur Störaussendung führen.

Der Flachbaugruppe gegenüberliegende Metallteile (Kabel, Konstruktionsteile, Schirmplatten, **Abbildung 3**) können vom elektrischen Erregerfeld erreicht und durch den übertragenen Verschiebestrom erregt werden.

Zusammenhang zwischen IC-Pinstrom und Störaussendung

Der in den Leiterzug der Flachbaugruppe einfließende Pinstrom baut ein magnetisches Feld H2 (**Abbildung 4**) auf. Ebenso erzeugt der Rückstrom im GND ein Magnetfeld H1 (**Abbildung 5**). Das Feld H1 des Rückstromes induziert im GND der Flachbaugruppe

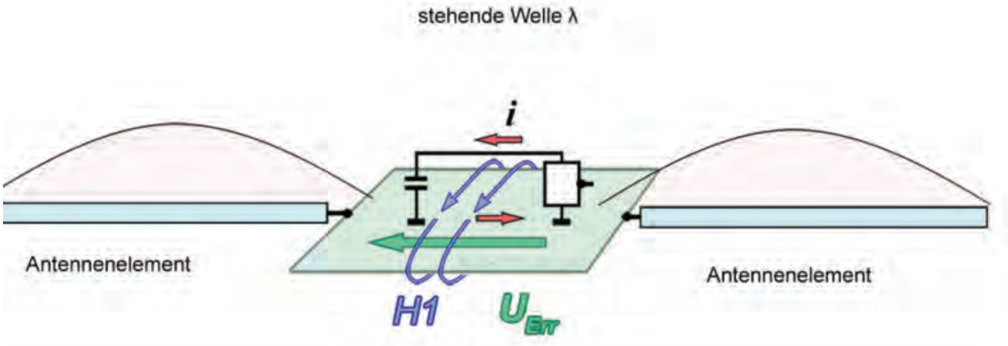

Abbildung 4 - Anregung der Abstrahlung über Gegeninduktion.

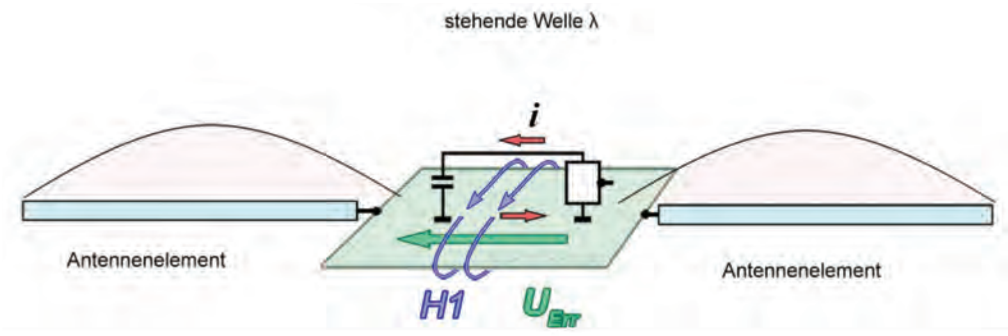

Abbildung 5 - Anregung der Abstrahlung über Gegeninduktion.

eine Selbstinduktionsspannung UErr. Diese Spannung treibt angeschlossene Kabel und Konstruktionsteile wie eine Antenne an. Die Kabel und Konstruktionsteile senden elektromagnetische Wellen aus.

Das Magnetfeld H2 (**Abbildung 4**) des Leiterzuges kann im freien Raum keine Aussendung erzeugen. Erst wenn das Magnetfeld ein Metallteil umfasst, wird in ihm durch Gegeninduktion eine Erregerspannung induziert. Die Erregerspannung erregt das Metallteil als Antenne. Das Metallteil sendet elektromagnetische Wellen aus.

Zu Punkt 2: E- und H-Nahfeldabgabe der ICs aus dem Die oder den IC-Anschlüssen.

Zusammenhang zwischen IC-Spannung und Störaussendung

Die an einem Leitungsnetz des ICs anliegende Spannung baut um das Leitungsnetze in elektrisches Feld auf (**Abbildung 1**). Die meisten Feldlinien führen auf die GND-Fläche der Baugruppe, wenige Feldlinien treten nach oben senkrecht aus dem IC aus und dringen weit in den Raum vor.

Die nach oben austretenden Feldlinien (Erregerfeldlinien) verlassen das GND-System der Baugruppe und tragen Verschiebestrom in den Raum, der das gesamte Metallsystem (Flachbaugruppe mit Kabeln und metallischen Konstruktionsteile) zum Schwingen anregt (**Abbildung 2**). Das Leitungsnetz des ICs kann sich im Inneren auf dem Die befinden. Die Leitungsnetze, die über Bonddraht, Leadframe und Pin mit dem Die verbunden sind, erzeugen aufgrund ihrer größeren Abmessung wesentlich mehr elektrisches Erregerfeld und damit mehr Störaussendung.

Der Flachbaugruppe gegenüberliegende Metallteile (Kabel, Konstruktionsteile, Schirmplatten, Abbildung 3) können vom elektrischen Erregerfeld des ICs erreicht und durch den übertragenen Verschiebestrom erregt werden.

Zusammenhang zwischen IC-Strom und Störaussendung

Die Stromschleifen des ICs können sich einmal im Inneren auf dem Die befinden. Zum anderen können Schleifen durch die Pins des ICs gebildet werden. Diese Schleifen laufen über das Groundsystem der Flachbaugruppe, Pin, Leadframe, Bonddraht und den Die. Derartige Schleifen können z.B. über Vdd oder Vss Pins gebildet werden. Die nach außen führenden Vdd / Vss Schleifen sind wesentlich größer als die im Inneren des Dies befindlichen Schleifen. Die größeren äußeren Schleifen können mehr Magnetfeld erzeugen und bewirken meist die höchste Störaussendung. Der IC-Strom baut ein magnetisches Feld H2 (**Abbildung 4**) um die Schleife auf. Ebenso erzeugt der Vdd / Vss -Rückstrom im GND der Baugruppe ein Magnetfeld H1 (**Abbildung 5**). Das Feld H1 des Rückstromes induziert im GND eine Selbstinduktionsspannung UErr. Diese Spannung treibt angeschlossene Kabel und Konstruktionsteile wie eine Antenne an.

Das Magnetfeld H2 der IC-Schleife kann im freien Raum keine Aussendung erzeugen. Erst wenn das Magnetfeld H2 ein Metallteil umfasst, wird in ihm durch Gegeninduktion


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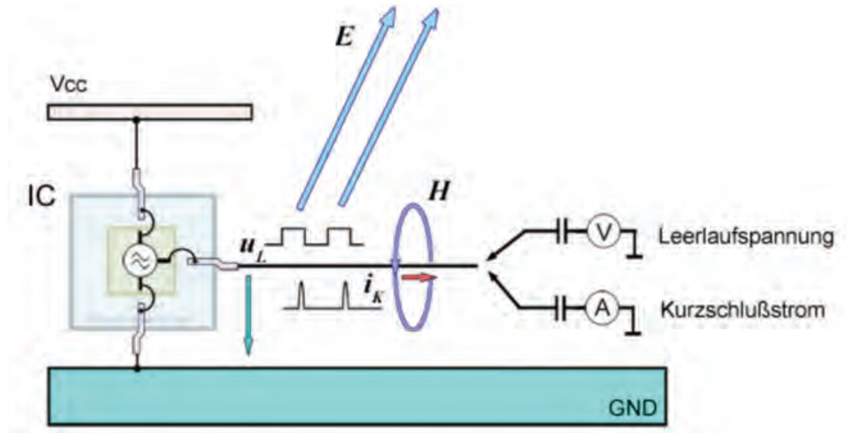


Abbildung 6 - Kurzschluss- und leerlaufnahe Messung der Pingrößen

eine Erregerspannung induziert.

In der Entstörpraxis verteilen sich die EMV-Probleme zu ungefähr gleichen Teilen auf elektrische und magnetische Felderregung.

EMV-PARAMETER FÜR IC-PINS

Der IC-Pinstrom und die IC-Pinspannung sind die pinbezogenen EMV-Parameter des ICs. Das elektrische Nahfeld und das magnetische Nahfeld des ICs sind die feldbezogenen EMV-Parameter des ICs. Alle vier Größen (u, i, E, H) des ICs müssen durch geeignete Messeinrich-tungen erfasst werden.

Das elektrische Nahfeld der Leiterzüge der Flachbaugruppe ist proportional der Pinspannung, das magnetische Nahfeld der Leiterschleifen der Flachbaugruppe ist proportional dem Pinstrom des ICs. Pinstrom und Pinspannung sind abhängig von der Belastung des Pins durch den an ihn angeschlossenen Leiterzug der Flachbaugruppe.

Für die IC-Parameter sind die Werte der Fälle zu verwenden, bei denen die höchste Pinspannung und der höchste Pinstrom erzeugt werden.

Strom und Spannung der Leiterzüge sind abhängig von der treibenden Spannung im IC und von der Impedanz der Last am Leitungsnetz der Baugruppe. Im Spezialfall kann im Leitungsnetz Leerlauf vorliegen, dann sind die Spannung und damit das elektrische Nahfeld am höchsten. Die potentielle Erregung der Aussendung ist dann am größten.

Der beschreibende EMV-Parameter für den IC ist seine Leelaufspannung $U_l(f)$.

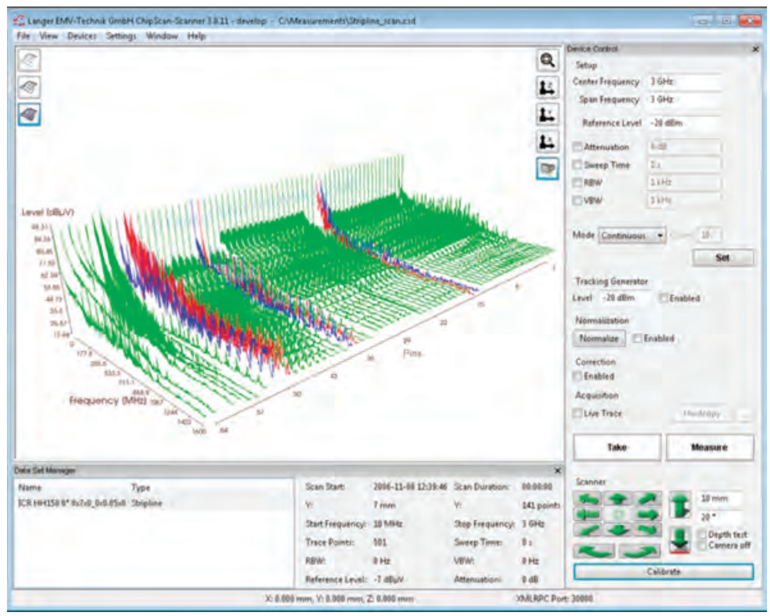


Abbildung 7 - Leerlaufspannung eines Test IC 01.

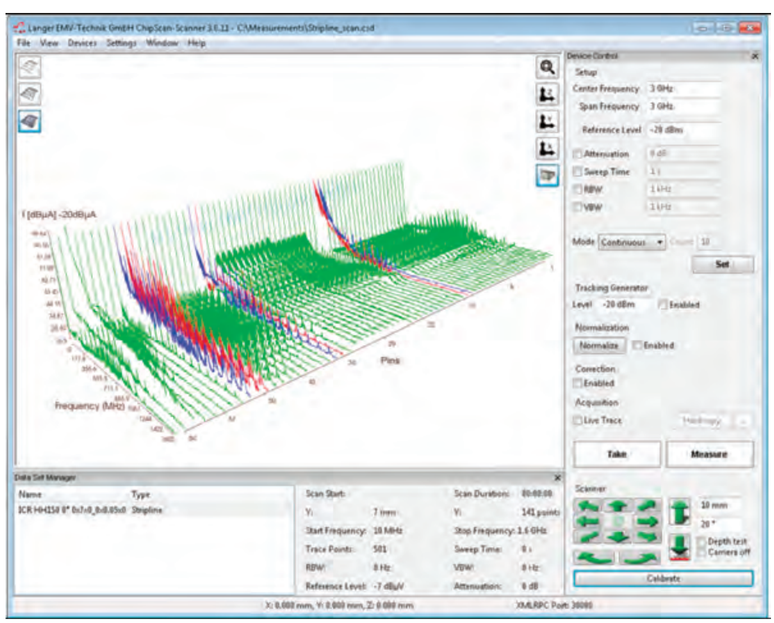


Abbildung 8 - Kurzschlußstrom eines Test IC 01.

Das magnetische Nahfeld ist proportional dem Strom im Leiterzug. Der Strom ist abhängig von der treibenden Spannung des ICs und von der Last der Leitung. Im Spezialfall kann Kurzschluss vorliegen. Dann sind der Strom, das Magnetfeld und damit die Aussendung am größ-ten.

Der beschreibende EMV-Parameter für den IC ist sein Kurzschlussstrom $I_k(f)$.

Die maximalen Werte ($U_l(f)$, $I_k(f)$) für Pinstrom und Pinspannung entsthen bei Pin-Kurzschluss oder bei Pin-Leerlauf. In diesen Fällen wird über die oben genannten Koppelmechanismen die höchste Störaussendung generiert.

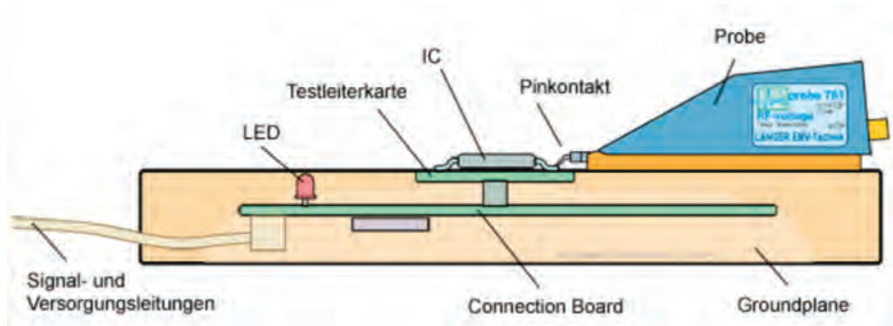
Daraus folgt, dass jeder Pin eines ICs seinen eigenen EMV-Parameter für die leitungsgebundene Störaussendung hat. Die EMV-Parameter eines IC-Pins sind seine Leerlaufspannung und sein Kurzschlussstrom.

Die Leerlaufspannungen und Kurzschlussströme können für alle Pins des ICs durch leerlauf und kurzschlussnahe Messungen erfasst werden. Zwei Spektren für jeden Pin ergeben für einen 64-Pin IC bereits 128 Spektren. Weiterhin kann der Pin unterschiedliche Schaltzustände einnehmen (Eingang, Ausgang H, L, und hochohmig). Die interne Funktion kann ebenfalls unterschiedliche Zustände einnehmen (Clk-PLL aus/ein).

Große Datenmengen können entstehen, die sich schwer überblicken lassen. Eine übersichtliche Darstellung der Ergebnisse erfolgt in 3D (**Abbildung 7**). Durch einen speziell entwickelten Messplatz mit einer entsprechenden Software (ChipScan-ESA) lassen sich die Pinspektren halbautomatisch erfassen. Die Visualisierung erfolgt in 3D, die für ausgewählte Pins auf eine 2D Darstellungen umgeschaltet werden kann (**Abbildung 11**).

VERWENDUNG DER IC-PARAMETER

Aus den 3D Spektren lassen sich leicht die Problempins für praktische Anwendungen erkennen. Leerlaufspannungen im Bereich 80 dBμV kön-



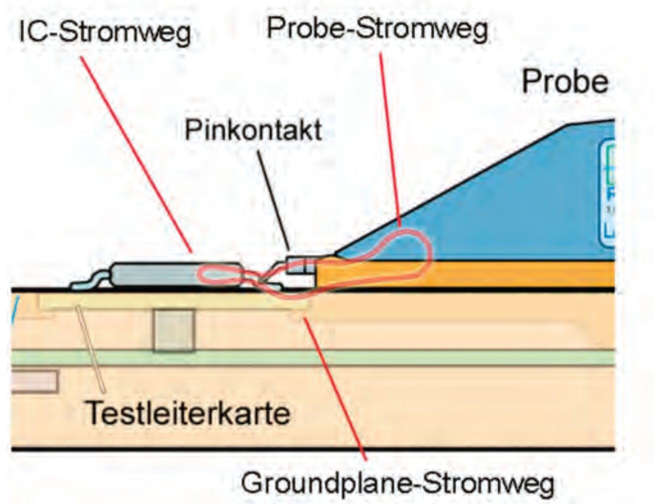


Abbildung 9 - Meßsystem für Pinstrom und -Spannung.

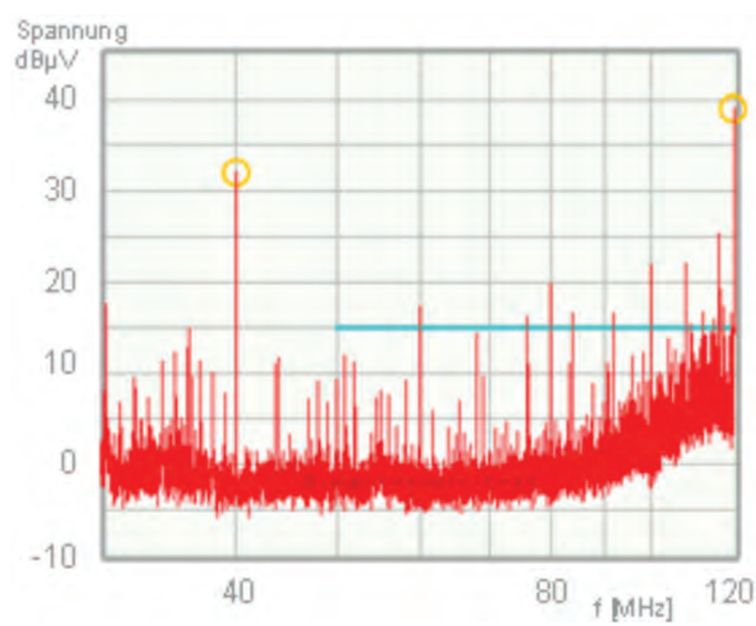


Abbildung 10 - Messung einer IC 02 Anwendung an der Boardnetznachbildung. Grenzwertüberschreitung von 24 dB bei 120 MHz. Ursache: E-Feldauskopplung aus einem am IC 02 angeschlossenem Leiterzug.

nen bereits über Leiterzuglängen von ca. 10 mm grenzwertüberschreitende Störaussendung anregen (besonders problematisch im Automobil). Auf Basis der EMV-Parameter der IC-Pins können Layout und Konstruktion rechtzeitig und kostensparend in die entsprechende Richtung gelenkt werden. Es wird ICs geben, bei denen einzelne Pins hohe Werte für die leitungsgebundenen EMV-Parameter der Störaussendung aufweisen. Diese Werte liefern die Anleitung zur verträglichen Verwendung des ICs auf der Flachbaugruppe. Damit sind diese ICs trotzdem für eine Entwicklung zu ver-wenden. Für IC-Anwender ist eine Bestimmung der EMV IC Parameter vor einer Baugruppenentwicklung sinnvoll.

Wenn ICs ohne dieses Wissen verbaut werden (wie im Allgemeinen heute noch üblich), kann erst nachdem das erste Entwicklungsmuster ausgemessen wurde, das Problem überhaupt entdeckt werden. Hoher Entstöraufwand entsteht (Layoutänderungen, Konstruktionsänderungen).

Mit den IC-EMV-Parametern lassen sich zwei neue Arbeitsmittel für die Elektronikentwick-lung erzeugen:

1. Pin parameter bezogene Leerlaufspannungs- und Kurzschlußstromspektren (3D / 2D)
2. Layout und Konstruktionshinweise gekoppelt an die EMV-Parameter der IC-Pins

Die Konstruktionshinweise (Gegenmaßnahmen) sind für den EMV-Fachmann aus den Pinspektren, den Wirkzusammenhängen (**Punkt 1** und **2**) und dem Charakter der speziellen Anwendung ableitbar. Für die Praxis ist es besser, sie als Information den Pins zuzuordnen. Die EMV-Parameter der IC-Pins $U_l(f)$, $I_k(f)$ lassen sich frequenzabhängig in Pegelbereiche mit un-terschiedlichem Gefahrenpotential einteilen. Je nach Gefahrenpotential wird eine bestimmte Barriere an konstruktiven Maßnahmen benötigt. Diese Strategie wird das Fundament der EMV-Arbeit der nächste Jahre bilden.

Beispiele für pinselektive Gegenmaßnahmen zur Leerlaufspannung:

Die statisch stehenden Portpins 16 bis 35 (**Abbildung 7**) zeigen hohe Leerlaufspannungen. Wenn viele Portleiterzüge angeschlossen werden, führt das zur Störaussendung über das elektrische Feld. Zur Abhilfe sollten die Leiterzüge gut mit GND umschlossen sein und nicht am Baugruppenrand liegen.

Beispiele für pinselektive Gegenmaßnahmen zum Kurzschlussstrom.

Die Portpins 16 bis 35 liefern auch relativ hohe Kurzschlusswerte (**Abbil-**

dung 8). Entfernt liegende Filterkondensatoren (Steckverbinder, Analog in) können kritische Stromschleifen erzeugen. Zur Abhilfe sollten die Filterkondensatoren in die Nähe des ICs gelegt werden oder Serienwiderstände eingefügt werden. Serienwiderstände an den Analogeingängen reduzieren den austretenden Strom.

Die Versorgung Pin 12, 13 liefert im unteren Frequenzbereich (< 100 MHz) und Pin 50, 51, 52 im mittleren Frequenzbereich (um 500 MHz) hohe Werte. Als Gegenmaßnahme kann für niedrige Stromaufnahmen die über den Stützkondensator führende Stromschleife mit einem Widerstand (< 10 Ohm) oder einem Chipferrit bedämpft werden. Die Abblockkondensatoren und der IC sollten nicht zu weit am Baugruppenrand liegen (> 20 mm). Der IC sollte so platziert werden, dass die Orientierung der IC-Stromschleife in Richtung Baugruppenquerachse liegt. Das gilt besonders für Baugruppen, die nicht breiter als 50 mm sind. Die Orientierung der IC-Stromschleifen können mit Feldsonden für HF-Feldmessung an ICs ausgemessen und als IC-EMV-Feldparameter zur Verfügung gestellt werden.

MESSSYSTEME FÜR IC-EMV-PARAMETER VON IC-PINS

In **Abbildung 9** ist die Messanordnung zur Pinstrom- und Pinspannungsmessung dargestellt.

Der Test IC (DUT) ist auf eine Testleiterkarte aufgebracht, die in eine Groundplane eingebettet ist. Es entsteht eine durchgehende GND-Fläche. Das ist die Voraussetzung für Messungen bis in den GHz Bereich.

Auf die Groundplane wird eine Messprobe (für Spannung oder Strom) aufgesetzt deren Messspitze jeden einzelnen Pin kontaktieren kann. Der Messpfad (IC - Pinkontakt - Probe) ist nur wenige mm lang, so dass elektrisch kurz gemessen werden kann. Die Versorgung und Steuerung des ICs erfolgt über Filter vom Connection Board (**Abbildung 9**). Das Connection Board ist in die Groundplane eingesetzt.

PRAXISBEISPIEL

Die Ergebnisse einer Messung von Fahrzeugkomponenten sind in **Abbildung 10** zusammengefasst. Bei 120 MHz kommt es auf Grund einer E-Feldanregung zur Grenzwertüberschreitung von 24 dB. Dieses Problem wurde erst bei der Prüfung eines Entwicklungsmusters entdeckt. Die Ursache wird durch die Messung des IC-EMV Parameters Leelaufspannung $U_l(f)$ der IC-Pins geklärt.

An den IC-Pins für den Quarz könnten außergewöhnlich hohe Spannun-

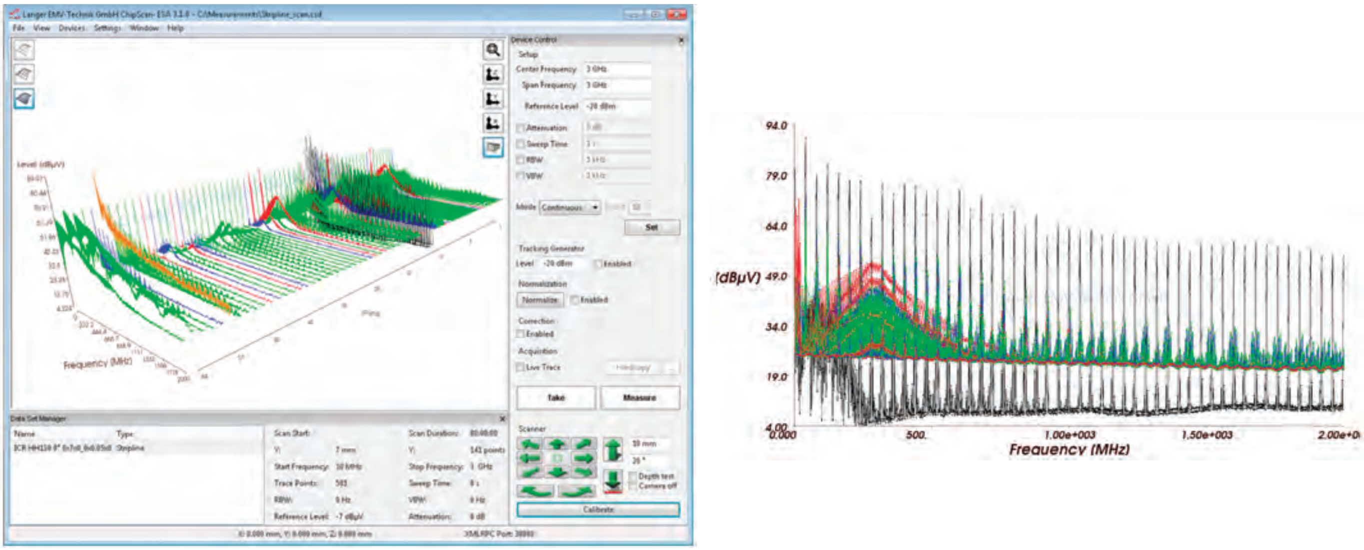


Abbildung 11 - Leerlaufspannungsmessung an IC 02 in 3D und 2D

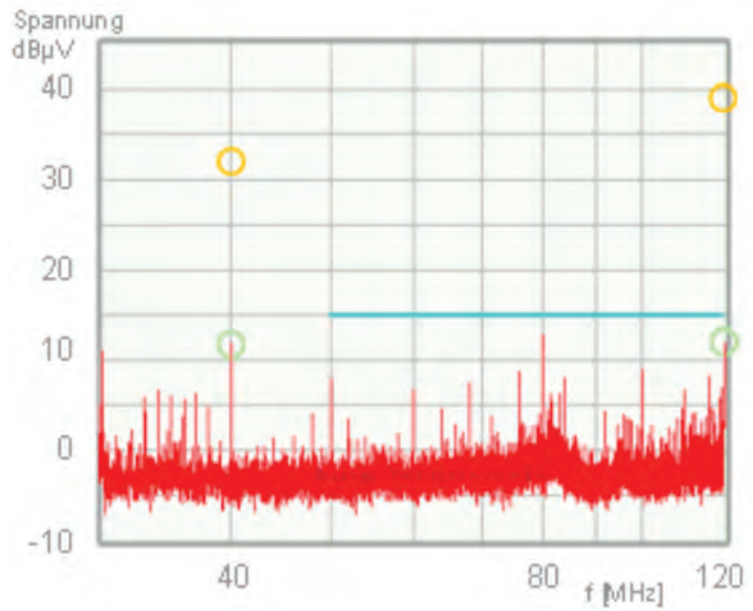


Abbildung 12 - Nachmessung mit Gegenmaßnahme: Die Schirmung des IC 02 verhindert die E-Feldauskopplung.

gen (ca. 80 dBµV bei 120 MHz) im 40 MHz Raster festgestellt werden (in **Abbildung 11** schwarz dargestellt)

Alle an diese Pins angeschlossenen Leitungen und metallischen Teile geben elektrisches Feld ab wie oben unter **Punkt 1** der Wirkmechanismen beschrieben ist. Das elektrische Feld ist außergewöhnlich hoch und erregt entsprechend die Baugruppe und den Kabelbaum.

Das heißt die Auskopplung des Feldes erfolgt über:

- Bonddraht und Leadframe der IC-Pins, die zum Quarz führen
- 15 mm Leitung zum Quarz,
- Quarzgehäuse und der Quarzbeschaltung 3 x 0603 SMD-Bauteile

Die Oberflächenreduktion dieser metallischen Teile bringt Abhilfe. Also Leitungsverkürzung und Einbettung in GND, Verwendung kleinerer Quarzgehäuse. Das ist in unserem Beispiel jedoch noch nicht ausreichend. Die Leerlaufspannung $U_1(f)$ des Pins ist so hoch, dass bereits die Metallfläche von Bonddraht und Leadframe genügte, eine Grenzwertüberschreitung bei der Komponentenmessung zu bewirken. Die Verwendung von entsprechenden Filterkondensatoren zur Spannungsreduktion schließen sich am Quarz aus. Als letztes Mittel bleibt die Anwendung eines E-Feldschirmes direkt über dem IC. Die positiven Ergebnisse dieser Maßnahmen sind in **Abbildung 12** dargestellt, die Grenzwerte wurden eingehalten.

Die praktische Umsetzung eines E-Feldschirmes bedeutet hohen Zusatzaufwand - für Automobilanwendungen schwer zu tragen. Eine einfache Lösung liegt in der Verschiebung der problematischen Pins in die Baugruppenmitte und der Benutzung großer vorhandener metallischer Bauteile als Schirm. Große metallische Bauteile, wie z.B. Elektrolytkondensatoren können als E-Feldschirm genutzt werden. Dadurch eventuell ausgelöste Resonanzen, würden bei der nächsten EMV-Prüfung bemerkt. Die Elektrolytkondensatoren müssen in der Nähe der kritischen Leitungsnetze platziert werden. Sie ragen weit über die Leitungsnetze hinaus und fangen die Erregerfeldlinien auf. Der Erfolg im Praxisbeispiel war analog **Abbildung 12**.

Der Entwicklungsablauf des im oberen Beispiel beschriebenen Produktes war aber schon so weit vorangeschritten, dass eine entsprechende Umplatzierung von Bauteilen nicht umgesetzt werden konnte. Der Bauraum für die Kondensatoren war an der notwendigen Stelle nicht vorhanden.

Eine Neukonstruktion des Gehäuses und neue Werkzeuge wären notwendig gewesen, ebenso eine Neuentflechtung der Leiterkarte. Dazu kommt, dass alle schon vorliegenden Freigaben hätten wiederholt werden müssen.

Da keine Möglichkeit bestand, die auf der Baugruppe vorhandenen Elektrolytkondensatoren umzuplatzieren, musste zwangsläufig ein extra Metallteil als Schirm über dem IC eingefügt werden. Wenn zu Beginn der Entwicklung die entsprechenden Informationen über die au-ßergewöhnlich hohe Leerlaufspannung $U_1(f)$ vorgelegen hätten und die Baugruppe hinsichtlich der Problempins des ICs entwickelt worden wäre, wäre kein Problem entstanden. Die Elektrolytkondensatoren wären von vornherein ohne weiteres an entsprechender Stelle platzierbar gewesen.

Schon heute ist es möglich, die EMV-Eigenschaften von ICs zu ermitteln. Eine Übernahme der ermittelten Werte in Produktdatenblätter ist sinnvoll. Erforderliche EMV-Maßnahmen für die Flachbaugruppe können schon während dem Entwicklungsprozess eingeplant werden. Damit kann jeder IC prinzipiell verwendet werden.

Mit Hilfe der Prüfmethoden zur Ermittlung der IC-EMV-Parameter wird der IC-Hersteller in die Lage versetzt, die Entwicklung von ICs effizienter durchzuführen.

Besonders durch voranschreitende Miniaturisierung von Baugruppen und die immer größere Anzahl von elektronischen sehr komplexen Geräten ist die EMV-Bewertung von ICs eine unerlässliche Voraussetzung für die zukünftige Entwicklung von elektronischen Geräten.

Diese Verwendung von IC-EMV-Parametern wird sich auch positiv auf die Entwicklung des Internet der Dinge auswirken.

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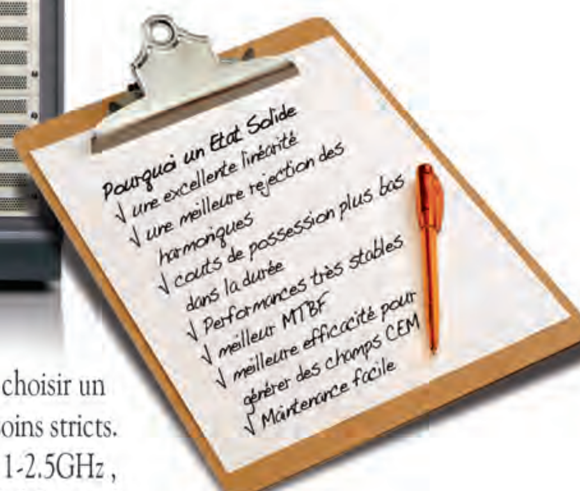

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De Quoi S'agit-il, Pourquoi Cette Norme a-t-elle été Rédigée et Quel est son Avenir?

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OVERVIEW

This article discusses CISPR 32, "Electromagnetic compatibility of multimedia equipment – Emission requirements" which was was first published in 2012. This standard came about due to a major development in consumer electronics, the digital television receiver. The CISPR is a special committee of the IEC. CISPR stands for the French words for the Special Committee on Radio Interference. CISPR publishes a number of EMC standards used for a variety of product families. This article will discuss only a very small portion of the standards published by CISPR. To read this article in English, go to our website www.interferencetechnology.com.

PRÉSENTATION

LA NORME CISPR 32, Compatibilité électromagnétique des équipements multimédia - Exigences d'émission, a été publiée pour la première fois en 2012. Cette norme est intervenue en raison d'un développement majeur dans le secteur des produits électroniques grand public : le téléviseur numérique.

Le CISPR est un comité spécial de la Commission électronique internationale (CEI). CISPR est une abréviation française qui signifie Comité international spécial des perturbations radioélectriques. Le CISPR publie un certain nombre de normes relatives à la compatibilité électromagnétique (CEM) utilisées dans une variété de familles de produits. Cet article ne présente qu'une toute petite partie des normes publiées par le CISPR.

Au niveau du CISPR et avant le développement et l'utilisation à grande échelle des téléviseurs numériques, les fabricants de téléviseurs n'avaient à se conformer qu'à une seule norme portant sur les émissions : La norme CISPR 13, qui définit les limites et les méthodes de mesure des émissions provenant des récepteurs de radiodiffusion. De même, les fabricants d'ordinateurs n'avaient à se conformer qu'à une seule norme portant sur les émissions : la norme CISPR 22, qui définit les limites et les méthodes de mesure des émissions provenant des appareils de traitement de l'information (ATI), c'est-à-dire les ordinateurs et leurs appareils périphériques. Ces deux normes sont indépendantes l'une de l'autre, et définissent différentes limites et méthodes de mesure et différentes configurations pour les équipements soumis aux essais. L'une des différences majeures constatées par les fab-

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ricants de télévisions en termes de configuration concernait l'exigence, dans la norme CISPR 22, d'examiner l'impact des câbles raccordés à plusieurs ports E/S qui ne figure pas dans la norme CISPR 13.

Lorsque les téléviseurs numériques ont été développés, les fabricants se sont alors vus soumis à deux normes relatives aux émissions. Sachant qu'un boîtier de téléviseur numérique contient un récepteur de radiodiffusion et un ordinateur, les normes CISPR 13 et CISPR 22 s'appliquaient donc toutes deux au produit. Comme les limites et les méthodes de tests n'étaient pas les mêmes dans les deux normes, il fallait suivre des procédures distinctes pour se conformer à chacune d'elles. Cela va sans dire que le temps et les coûts impliqués dans le processus de qualification ont tous les deux augmenté. Les gestionnaires ont tendance à voir d'un mauvais œil tout ce qui augmente le temps et les coûts impliqués dans le processus de développement, particulièrement lorsqu'ils n'y voient aucun avantage. Par conséquent, le CISPR s'est lancé dans la résolution de cette question.

Pour ce qui est des normes relatives aux émissions des téléviseurs numériques, cette démarche était compliquée par le fait que la norme CISPR 13 était maintenue par le sous-comité E du CISPR (récepteurs de radiodiffusion) et la norme CISPR 22 par le sous-comité G du CISPR (EIT). Lorsqu'on doit trouver un moyen de coordonner deux normes ou d'en écrire une nouvelle, le fait d'avoir deux sous-comités distincts n'est pas la méthode la plus efficace pour y parvenir. En fin de compte, CISPR/E et CISPR/G ont été fusionnés en 2001 pour former le nouveau sous-comité I du CISPR (compatibilité électromagnétique des matériels de traitement de l'information, multimédia et récepteurs). CISPR/E et CISPR/G n'existent plus depuis la création de CISPR/I. Au départ, CISPR/I comportait 4 groupes de travail. Le groupe de travail 1 était chargé du maintien et de la mise à jour de la norme CISPR 13 (émissions) et de la norme CISPR 20 (immunité) relatives aux récepteurs de radiodiffusion. Le groupe de travail 3 était chargé du maintien et de la mise à jour de la norme CISPR 22 (émissions) et de la norme CISPR 24 (immunité) relatives aux ATI. Le groupe de travail 2 était chargé de créer la nouvelle norme relative aux émissions des équipements multimédia (CISPR 32), et le groupe de travail 4 était chargé de créer la nouvelle norme relative aux exigences d'immunité des équipements multimédia (CISPR 35). Fin 2012, les groupes de travail 1 et 3 ont été dissous, et tout le travail en cours concernant les anciennes normes a été intégré dans le groupe de travail 2 pour les émissions et dans le groupe de travail 4 pour l'immunité.

La rédaction des nouvelles normes ne consistait pas simplement à fusionner deux documents existants. Au fil des années de travail sur la création de la norme CISPR 32, diverses idées ont été proposées et abordées, à la fois dans le groupe de travail 2 et par les comités nationaux. Plusieurs projets de comité ont été soumis pour commentaires aux comités nationaux avant l'émergence de la forme définitive de la norme. Un projet de comité pour adoption a été soumis et adopté en 2010. Les votes des comités nationaux étaient accompagnés d'un grand nombre de commentaires. Ces commentaires ont été examinés dans le groupe de travail 2 et le projet final de norme internationale (FDIS) a été soumis et adopté au cours du 4e trimestre de 2011. Ce FDIS a été mené à bien, et l'édition 1.0 de la norme CISPR 32 a été publiée en janvier 2012.

LA NORME CISPR 32:2012 (1ÈRE ÉDITION)

Bien que sa structure soit différente, la norme CISPR 32 ressemble davantage à la norme CISPR 22 (EIT) que la norme CISPR 13 (récepteurs de radiodiffusion). La plupart des limites sont celles qui figurent dans la norme CISPR 22. Les limites des émissions par conduction provenant de lignes électriques et de l'accès aux télécommunications sont spécifiées dans la même plage de fréquences de 150 kHz à 30 MHz, et les émissions sont mesurées à l'aide des mêmes techniques et équipements que dans la norme CISPR 22 et avec les même les limites. De même, les limites des émissions rayonnées sont spécifiées dans la même plage de fréquences de 30 MHz à 6 GHz, à l'aide des mêmes techniques de mesure que dans la norme CISPR 22 et, encore une fois, avec les mêmes limites. La norme CISPR 32 ajoute également les limites des émissions rayonnées provenant de récepteurs FM à la fréquence fondamentale et harmonique de l'oscillateur local. La première édition a encore été modifiée, passant d'une norme qui stipule les exigences spécifiques relatives aux émissions par conduction provenant de l'accès aux télécommunications comme dans la norme CISPR 22, à une norme qui définit les limites des « émissions conduites en mode asymétrique » s'appliquant aux accès aux réseaux câblés, aux accès à fibre optique munis d'un blindage métallique ou aux éléments de tension et ports d'antenne. Des limites supplémentaires sont définies pour les « émissions conduites de tension différentielle » sur des accès de syntonisateur de récepteur de radiodiffusion TV avec un connecteur accessible, des accès de sortie de modulateur RF et des accès de syntonisateur de récepteur de radiodiffusion FM avec un connecteur accessible. Cet ensemble final de limites n'est fourni qu'aux niveaux de classe B.

En vertu des règles de la CEI, une norme ne peut être modifiée que deux fois avant la publication d'une nouvelle édition. De plus, les correctifs publiés pour rectifier des erreurs dans les normes publiées sont considérés comme des amendements. Les membres du CISPR/I ont rapidement constaté que le bureau central de la CEI avait procédé à des modifications apparemment anodines entre le FDIS qui avait été adopté par les comités nationaux et la forme publiée de la norme CISPR 32:2012, qui n'étaient finalement pas si anodines que cela. En réalité, du fait des modifications ou des suppressions dans les notes, trois tableaux critiques contenus dans la norme étaient devenus inutilisables.

Les premiers correctifs publiés pour la norme CISPR 32 dans la version française étaient d'ordre éditorial. Les deuxièmes correctifs rectifiaient les erreurs qui avaient été introduites par le Bureau central de la CEI lorsqu'il a créé la forme publiée de la norme CISPR 32:2012. Par conséquent, en août 2012, deux modifications avaient déjà été apportées

à la norme CISPR 32. Les nouveaux ajouts proposés pour la norme CISPR 32 ont donné lieu à la 2e édition de la norme, plutôt qu'à un amendement.

La 1ère édition de la norme CISPR 32 portait sur la réalisation d'essais relatifs aux émissions rayonnées dans un site d'essai en espace libre (OATS), avec ou sans couverture de protection contre les intempéries, dans une chambre semi-anéchoïque à RF ou dans un OATS en espace ouvert (FSOATS). Contrairement à la norme CISPR 22, qui fournit des indications sur les essais relatifs aux émissions rayonnées inférieures à 1 000 MHz à des distances autres que 10 mètres pour certains appareils de classe B, la norme CISPR 32 définit explicitement les limites à 3 mètres, ainsi que celles qui portent sur l'adéquation des sites d'essai choisis pour ces différentes distances de mesure. Elle limite également l'utilisation d'un FSOATS à des essais à des fréquences de plus de 1 GHz.

LA NORME CISPR 32:2015 (2E ÉDITION)

Qu'est-ce qui a changé avec la publication de la 2e édition de la norme CISPR 32 en mars 2015 ? La 2e édition de la norme CISPR 32 contient un certain nombre de clarifications, de nouvelles méthodes d'essai et des directives pour des essais sur d'autres types de produits.

La 2e édition de la norme CISPR 32 ajoute des limites et d'autres directives pour mener des essais sur des émissions rayonnées inférieures à 1 GHz dans une chambre entièrement anéchoïque (FAR). Les restrictions et les clarifications concernant l'utilisation d'une FAR pour des essais relatifs aux émissions rayonnées inférieures à 1 GHz sont présentées au tableau A1.4 et comprennent la restriction selon laquelle cette installation ne peut être utilisée que pour tester du matériel à l'essai (EUT) de table. Les tableaux qui présentent les limites relatives aux émissions rayonnées ont tous été modifiés pour couvrir les différents types d'installations de mesure. Les limites sont maintenant présentées pour un OATS/une chambre semi-anéchoïque (SAC) à 10 ou 3 mètres et pour une FAR à 10 ou 3 mètres, tant pour du matériel de classe A que de classe B.

Un nouveau tableau (A.7) a été ajouté pour présenter les exigences relatives aux systèmes extérieurs de réception satellite domestiques. Ce tableau comprend les limites relatives aux émissions rayonnées dans une plage de fréquences de 30 MHz à 18 GHz, les seules limites supérieures à 6 GHz dans la norme CISPR 32. Une nouvelle annexe (Annexe H) a été ajoutée pour fournir des renseignements complémentaires sur les mesures de systèmes extérieurs de réception satellite domestiques.

L'Annexe I a été ajoutée pour fournir des renseignements sur d'autres méthodes d'essai, comme la cellule électromagnétique transverse en gigahertz (GTEM) et une chambre réverbérante (RVC). L'Annexe I précise que les informations sur ces deux équipements d'essai sont fournies à titre indicatif et que le respect des limites indiquées à l'Annexe I ne constitue par une conformité à la norme CISPR 32.

Par ailleurs, lorsque la 2e édition de la norme CISPR 32 a été publiée, un certain nombre des références datées qui figurent dans la section 2 de la norme ont également été mises à jour. De nouvelles figures ont été ajoutées, des définitions ont été mises à jour et d'autres modifications ont été apportées dans l'ensemble de la norme. Ces modifications sont beaucoup trop nombreuses pour les décrire dans le présent article.

COMMENT SAVOIR CE QUI A ÉTÉ MODIFIÉ ?

La CEI permet de voir facilement ce qui a été modifié lors de la publication de la nouvelle édition d'une norme. Moyennant des frais supplémentaires, vous pouvez acheter la version de la norme, qui indique toutes les modifications et tous les ajouts en rouge. Un déni de responsabilité dans le préambule stipule que la version n'est pas une norme officielle de la CEI et qu'elle ne vise à vous présenter que ce qui a été modifié. Le déni de responsabilité stipule que « Seule la version courante de cette norme doit être considérée comme le document officiel ». Une personne cynique ferait observer que, pris au pied de la lettre, ce déni de responsabilité a également pour effet d'augmenter les ventes de la norme. Dans le cas d'une société qui aurait besoin de plusieurs exemplaires de la norme, l'auteur recommande de n'acheter qu'un petit nombre de versions et d'acheter en volume la version de la norme dont la société a besoin. Et la CEI permet effectivement d'acheter plusieurs exemplaires en offrant des remises au volume sur les versions électroniques. Par exemple, il est possible d'acheter une licence pour 20 exemplaires au prix de 4 exemplaires individuels. Planifiez vos achats en conséquence.

QUE RÉSERVE L'AVENIR ?

Le groupe de travail 2 du CISPR/I envisage d'apporter un certain nombre de mises à jour et de changements potentiels à la norme CISPR 32 au cours des prochaines années. Le document pour observations 510 du CISPR/I (CISPR/I/510/DC) a été publié le 26 juin 2015 en fonction des problèmes qui ont fait l'objet de discussions lors de la réunion du groupe de travail 2 du CISPR/I en mai 2015, et comprend un certain nombre d'éléments à prendre en compte pour le travail futur sur la norme CISPR 32. Les commentaires du Comité national sur ce document pour observations devaient être soumis au plus tard le 28 août 2015, et le travail a démarré lors de la réunion du groupe de travail 2 du CISPR/I à Stresa en Italie, le 1er octobre 2015. Du fait que le présent article a été rédigé avant l'échéance du 28 août, on ne peut pas préciser ici comment ces éléments seront traités. Une description de certains des éléments est présentée pour donner au lecteur une idée de ce qui pourrait se produire ou non à l'avenir.

La première partie dresse une liste de 8 éléments dont l'intégration dans un correctif devrait être envisagée pour apporter des modifications d'ordre éditorial à la norme. Les propositions permettraient de clarifier certains points qui ont suscité des questions, et aucune ne changerait la signification de la norme.

La deuxième partie du document pour observations présente une liste détaillée de 10 problèmes à étudier et à prendre en compte dans le cadre d'un travail à court terme. Tout ou une partie de ces éléments pourrait figurer dans une modification future de la norme CISPR 32:2015. Certains de ces éléments comprennent les possibilités suivantes : modifier les exigences relatives aux accès aux réseaux câblés pour n'exiger que les mesures courantes lorsqu'une interface de télécommunications est dotée d'un gabarit spectral défini ; envisager d'utiliser le détecteur de valeur quadratique moyenne (RMS) en option ou en annexe d'information ; clarifier la nécessité ou l'absence d'une isolation supplémentaire au-dessus du plan de sol lorsque les câbles d'interconnexion sont déjà isolés ; envisager d'améliorer la terminaison des câbles qui partent d'une FAR ; envisager de modifier la méthodologie de mesure et les limites à plus de 1 GHz ; et envisager de clarifier la manière d'évaluer le couplage d'un signal radio souhaité (et son harmonique) à la ligne soumise à l'essai lors des mesures des émissions par conduction.

La troisième partie de ce document pour observations présente 11 éléments à prendre en compte dans le cadre d'un travail à long terme. Bien que tous les éléments ne soient pas énumérés ici, les principaux éléments susceptibles de présenter un intérêt comprennent la terminaison des câbles qui partent de la zone de mesure ; l'utilisation éventuelle de la méthode de répartition de probabilité des amplitudes (RPA) comme alternative à plus de 1 GHz ; la détermination de l'image d'essai appropriée pour les nouvelles technologies d'affichage ; la détermination de la nécessité éventuelle de déplacer l'Annexe I (RVC et GTEM) dans le corps principal du document ; et l'inclusion éventuelle de l'approche complète de la norme CISPR 16-4-2 sur l'incertitude des instruments de mesure.

Veuillez noter qu'aucun de ces éléments figurant dans le document pour observations 510 du CISPR/I ne constitue des modifications définitives de la norme CISPR 32. Il ne s'agit que d'éléments à envisager et qui doivent faire l'objet de discussions, initialement dans le groupe 2 du CISPR/I, puis à l'échelle du CISPR/I tout entier. Des éléments simples pourraient figurer dans la norme CISPR 32 dans quelques années, et l'intégration des éléments plus significatifs et/ou sujets à controverse pourrait nécessiter encore plus de temps. Songez qu'il a fallu onze ans entre la formation du CISPR/I et la première publication de la norme CISPR 32. La modification des documents du CISPR peut demander beaucoup de temps. Pour illustrer un cas extrême, songez que les travaux sur la création de la norme CISPR 35 (complément à la norme CISPR 32 concernant l'immunité) ont démarré en même temps et que CISPR 35 n'a pas encore été acceptée. Il est à espérer que la norme CISPR 35 finira par être publiée au cours de la première moitié de 2016, mais cela reste à voir.

SYNTHÈSE

J'ai parlé, à un haut niveau, du contenu de la norme CISPR 32, à la fois dans la 1ère édition et dans la 2e édition. N'oubliez pas que, comme tous les documents du CISPR (d'ailleurs, tous les documents de la CEI), la norme CISPR 32 n'est qu'une suite de mots couchés sur papier. À moins que, et jusqu'à ce qu'un régulateur l'adopte dans ses réglementations nationales, elle n'a aucune signification. Par exemple, la norme CISPR 32:2012 a été adoptée dans l'Union européenne en tant que norme EN 55032:2012, et elle doit être utilisée en remplacement de EN 55013 et/ou EN 55022 pour tous les produits mis sur le marché de l'Union européenne (quelle que soit la date à laquelle elle a été déclarée conforme à la directive CEM pour la première fois) au plus tard le 5 mars 2017. Au moment de la rédaction du présent article, rien n'a été dit dans la liste des normes harmonisées concernant la norme EN 55032:2015, et nous devons donc attendre la nouvelle édition.

La norme CISPR 32 est importante pour les fabricants d'équipements multimédia (y compris de téléviseurs numériques) et propose une approche unifiée pour démontrer un niveau raisonnable de contrôle des émissions provenant de ces produits vers les produits d'autres utilisateurs du spectre des radiofréquences. La conception des produits déjà conformes aux exigences de la norme.

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OVERVIEW

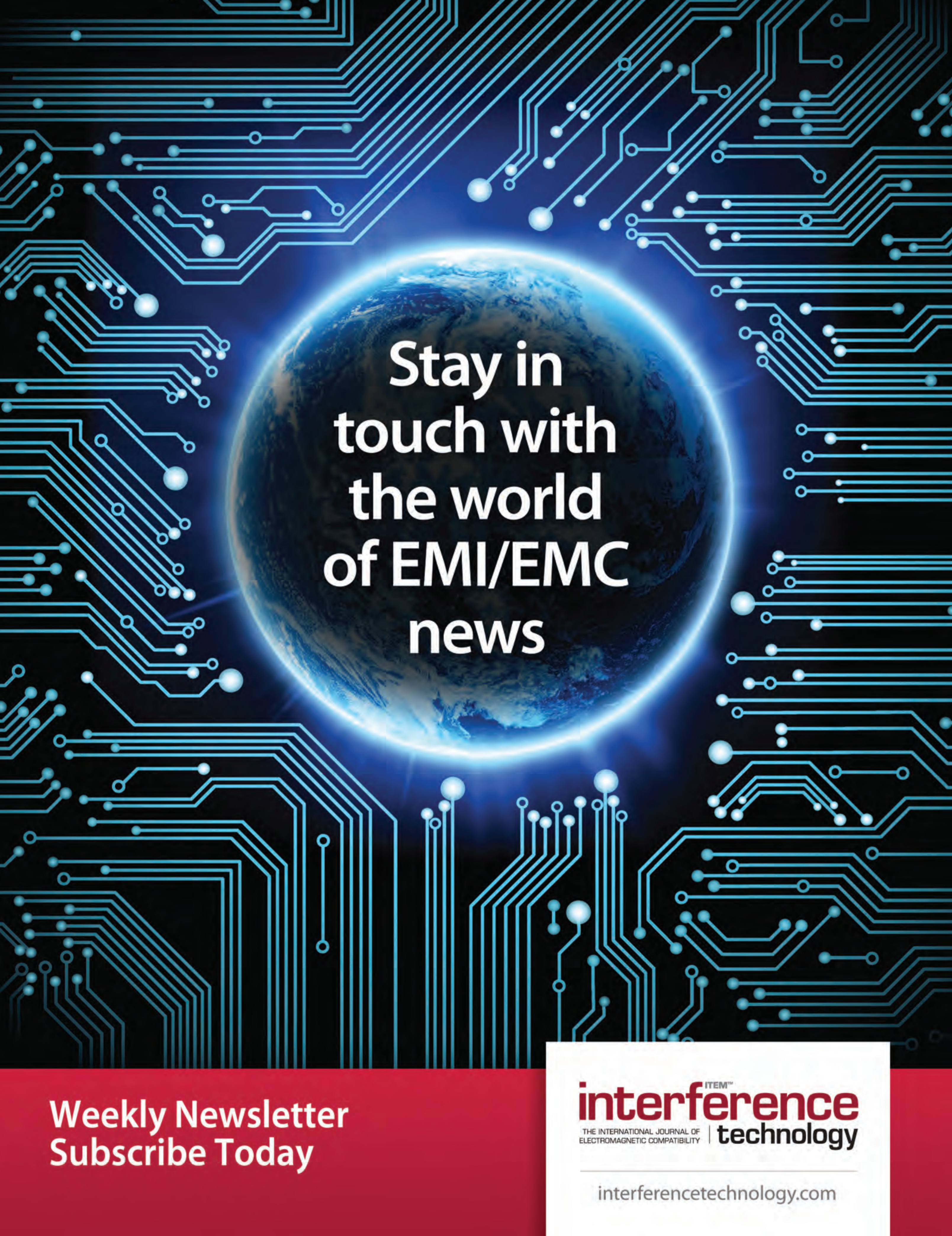
This article discusses how filters are not all the same. It point how to consider what we are asking the filter to do. It's quite important at this time, because EMC requirements are being extended both upwards from the 40th harmonic of the power frequency and downwards from the historic 150 kHz lower limit of 'high frequency emissions'. For some products, requirements already exist down to 9 kHz and there is no low-frequency limit now in the standard, CISPR 11/EN 55011, for 'industrial, scientific and medical' equipment, or in the new Radio Equipment Directive. To read this article in English, go to our website www.interferencetechnology.com.

INTRODUCTION

OGGI È PRASSI NORMALE acquistare i filtri di ingresso per la rete elettrica sotto forma di scatole di metallo con quattro o cinque terminali. È possibile consultare gli elenchi dei fornitori e chiedere consiglio, ma spesso viene indicato lo stesso filtro utilizzato per un prodotto precedente senza prestare molta attenzione. Un filtro è sempre un filtro, dopo tutto.

Però i filtri non sono tutti uguali. Per prima cosa pensiamo a quello che il filtro dovrà fare. È una considerazione importante in questa fase, perché i requisiti EMC vengono estesi sia in alto, dalla quarantesima armonica della frequenza della corrente, sia in basso, dallo storico limite inferiore a 150 kHz per le "emissioni ad alta frequenza". Per alcuni prodotti, i requisiti sono già scesi fino a 9 kHz e ora non esiste un limite inferiore della frequenza nello standard CISPR 11/EN 55011 per le apparecchiature "industriali, scientifiche e medicali" né nella nuova Direttiva per le apparecchiature radio.

Che ci piaccia o no (ma ci deve piacere), il filtro agisce sia sull'energia che arriva dall'impianto elettrico (problema di immunità), sia sull'energia che esce dal prodotto ed entra nell'impianto elettrico (problema di emissione). Per entrambi i flussi abbiamo due modalità: differenziale, in cui appare una tensione tra i due conduttori di corrente, e comune, in cui entrambi i conduttori hanno la stessa tensione in relazione alla terra locale. In caso di alimentazione trifase a tre fili, la configurazione del filtro è più complicata, ma nell'alimentazione trifase a quattro fili, ogni fase viene trattata come se fosse una singola fase. A questo indirizzo sono disponibili alcuni esempi: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Il modo in cui possiamo attenuare i flussi dipende dalle impedenze della relativa sorgente. Ovviamente non è molto utile collegare un condensatore in una sorgente a bassa impedenza per deviare la corrente, poiché rimane comunque disponibile una grande quantità di corrente, ed è altrettanto inutile collegare un induttore in serie con una sorgente ad alta impedenza. In effetti questo è un esempio di un concetto molto più generale.

È utile pensare in termini di energia, anziché di tensione o corrente. L'energia è il prodotto della potenza e del tempo ed è l'"elettricità" che paghiamo. Un filtro può funzionare in due modi: può assorbire l'energia indesiderata in ingresso o può rifiutare di accettarla. Esistono filtri ad assorbimento o dissipazione (quelli che utilizzano induttori con nucleo ferromagnetico, ad esempio), ma l'energia si trasforma in calore e la quantità spesso è troppo elevata per essere accettata. Quindi la maggior parte dei filtri è "riflettente": rifiutano di accettare l'energia in ingresso e la respingono alla sorgente.

Sono in grado di farlo poiché hanno un'impedenza di ingresso molto diversa dall'impedenza della sorgente. Il "Teorema della massima potenza" dice che il trasferimento ottimale di energia avviene quando le resistenze di sorgente e carico (resistenza di ingresso del filtro) sono uguali e le loro reattanze sono uguali e opposte (ad esempio, una induttiva e l'altra capacitiva). Ma il nostro filtro riflettente vuole il peggiore trasferimento di potenza possibile, quindi le resistenze devono essere molto diverse e, se possibile, le reattanze devono avere lo stesso segno.

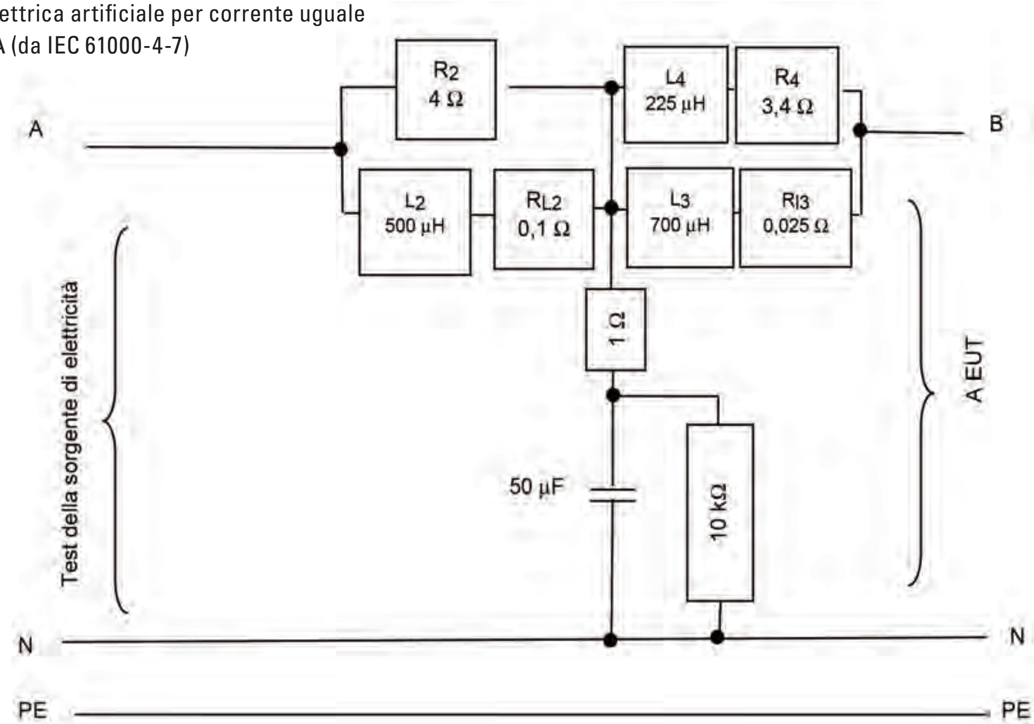
Quindi, che cos'è l'impedenza della rete elettrica? I comitati per gli standard EMC hanno dedicato molto lavoro a questo soggetto complesso. Sappiamo che, alla frequenza della potenza, per le normali prese a muro l'impedenza deve essere compresa tra 0,1 Ω e 1 Ω in base alle considerazioni sulle cadute di tensione, ma viene presa in considerazione solo la resistenza del conduttore. La rete inoltre ha ciò che può essere rappresentato come un induttore con perdita in serie e questo modello funziona in modo soddisfacente fino a circa 9 kHz. In Europa, il valore "medio" è vicino a 800 μH, benché si avvicini alla media di zero e infinito se consideriamo tutte le eccezioni, inclusi i lunghi cavi elettrici sospesi nelle aree rurali. I valori "medi" per gli altri impianti elettrici sono reperibili in IEC TR 60725.

Una rete che rappresenta l'impedenza dei circuiti a 230 V 50 Hz 16 A in Europa da 2 kHz a 9 kHz è fornita in IEC 61000-4-7 e indicata qui sotto nella Figura 1, ma è in fase di sviluppo una rete nuova e più accurata.

Per le frequenze superiori a 9 kHz, disponiamo di informazioni su "reti stabilizzatrici d'impedenza di linea" (LISN) o "reti elettriche artificiali" (AMN) in CISPR 16-1-2/EN 55016-1-2. Per valori tra 9 kHz e 150 kHz, viene fornita un'impedenza di 5 Ω in serie con 50 μH, con una resistenza in parallelo di 50 Ω, mentre per l'intervallo da 150 kHz a 30 MHz viene fornita un'impedenza di 50 Ω in parallelo con 50 μH. Esiste una terza rete, per valori da 150 kHz a 100 MHz, che è 50 Ω in parallelo con 5 μH in serie con 1 Ω. Tuttavia, alcuni di questi valori sono "tradizionali" e tendono di nuovo ad essere la media di zero e infinito. Ciò nonostante, l'uso di questi valori non ha portato alla proposta di cambiarli basandosi sul presupposto che esistono altri valori palesemente migliori.

Tuttavia, l'impedenza in una particolare presa a muro è indeterminata e può addirittura variare, in base ad altri carichi che si trovano sullo stesso circuito e al modo in cui la rete di alimentazione è configurata in una data ora del giorno. Vogliamo quindi che il nostro filtro sia molto tollerante rispetto all'impedenza della

Figura 1. Rete elettrica artificiale per corrente uguale e inferiore a 16 A (da IEC 61000-4-7)



sorgente e non presenti, ad esempio, comportamenti risonanti in concomitanza con possibili reattanze di linea.

L'impedenza del carico può essere molto problematica. Molto spesso è un raddrizzatore a onda completa, quindi estremamente non lineare. Dall'esperienza dei problemi di EMC riscontrati sul campo sappiamo che il circuito è trasparente dal condensatore del filtro all'uscita del filtro della rete elettrica, poiché se il condensatore si asciuga in modo tale che la sua capacità scende fino a un valore molto più basso, le emissioni ad alta frequenza provenienti dai processi interni ai circuiti del prodotto aumentano notevolmente in ampiezza, di solito di oltre 20 dB.

Nota per i progettisti: considerare l'uso di un componente ad alta temperatura (105 °c o addirittura 135 °c), con valore abbondante della corrente ondulata, per contrastare questo effetto. Anche un condensatore da 100 nf in parallelo può essere utile.

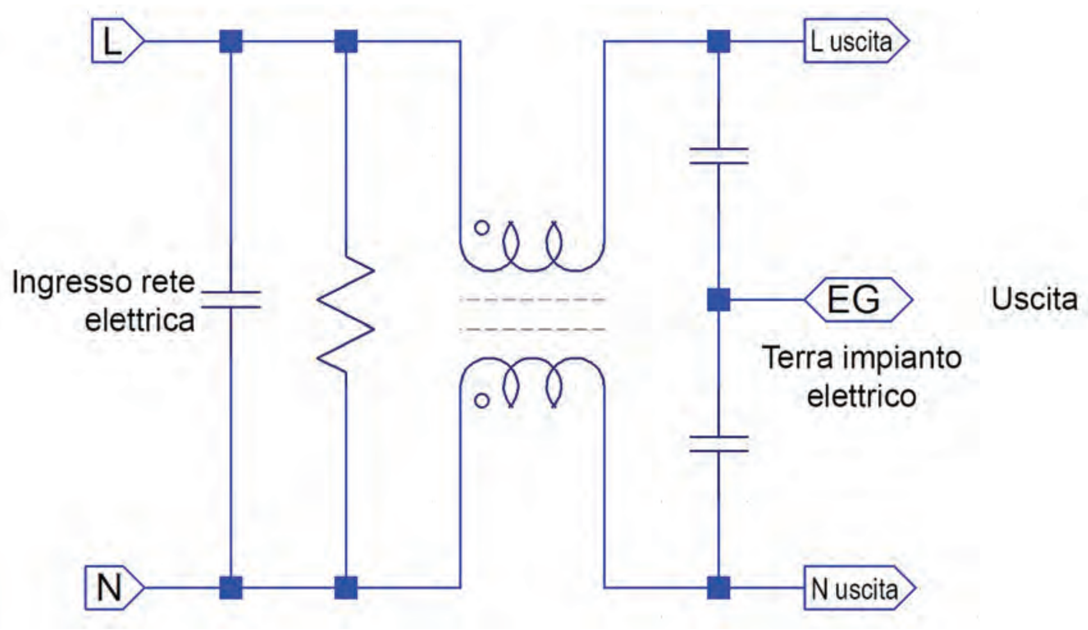
Esistono due sorgenti di energia ad alta frequenza che si propagano dal prodotto all'impianto elettrico: picchi da commutazione dai diodi del raddrizzatore e tutte le frequenze elevate generate dai circuiti nel prodotto che possono essere modellate come tensione in serie con l'effettiva resistenza al carico del raddrizzatore. Può inoltre essere presente un circuito di correzione del fattore di potenza attivo che precede il lato CA del raddrizzatore.

Per l'intervallo di frequenza "tradizionale" da 150 kHz in su, si presume che le sorgenti (rete elettrica e raddrizzatore o qualsiasi elemento nel prodotto) abbiano valori di impedenza elevati (e vengano quindi gestite nel filtro dai condensatori) tra i conduttori attivi per presentare una bassa impedenza all'energia in modalità differenziale, e valori uguali da ogni conduttore alla terra per la effettuare la stessa operazione con energia in modalità comune.

I filtri semplici per i prodotti a bassa potenza hanno quindi una configurazione π modificata (rigorosamente una configurazione a O, perché ha induttori in entrambe le "gambe"), come mostra la Figura 2. Gli induttori sono piuttosto speciali e sono detti "strozzamento in modalità comune". Le due bobine, come indicato, sono su un singolo nucleo, normalmente di ferrite, e le due bobine sono nella stessa direzione, come indicano i "punti di messa in fase". Quindi, per le correnti in modalità comune che scorrono nella stessa direzione delle due bobine, l'induttanza è alta, ma per le correnti in modalità differenziale, inclusa la corrente di alimentazione, l'induttanza è bassa, ma è previsto che non sia molto piccola, in modo tale che, in combinazione con i condensatori, attenui anche le correnti ad alta frequenza in modalità differenziale. Il condensatore all'ingresso consente di attenuare ulteriormente le correnti in modalità differenziale, indipendentemente dalla direzione in cui scorrono. Il resistore parallelo ha il compito di scaricare il condensatore, in modo da non lasciare attive le punte della spina se il cavo di alimentazione viene scollegato dalla presa a muro. Come mostrano i circuiti del filtro trifase accessibili tramite il link riportato sopra, il conduttore di terra può essere applicato al filtro utilizzando un induttore separato.

Le correnti in modalità comune (emissioni indesiderate o interferenze in ingresso) scorrono nella stessa direzione delle due bobine, quindi l'impedenza effettiva è molto superiore. I condensatori in uscita tentano di attenuare le tensioni in modalità comune preservando allo stesso tempo l'equilibrio dell'impedenza per la modalità differenziale. "Tentano" perché i relativi valori devono essere limitati in modo da non causare

Figura 2. Filtro di ingresso semplice rete elettrica



una quantità inaccettabile di corrente nella connessione di terra. Questo problema è piuttosto serio quando un numero elevato di prodotti, che contribuiscono tutti più o meno con un solo milliampere, viene collegato alla stessa rete di terra. Nel continente americano, i prodotti collegati a 240 V passano correnti di terra uguali e contrarie dai due conduttori attivi, quindi non contribuiscono con corrente di terra netta (ciò avviene perché il sistema di distribuzione è 120 V-0-120 V, con la tensione in un conduttore attivo invertita rispetto all'altro, in modo tale che tra i conduttori attivi la tensione sia 240 V).

Questa configurazione in realtà è adatta alle frequenze in cui l'alimentazione elettrica e le impedenze di carico sono relativamente alte, poiché i condensatori tendono a mettere in cortocircuito le sorgenti; non funziona bene, invece, per le sorgenti a bassa impedenza e, con frequenze molto inferiori a 150 kHz, che iniziano ora ad essere interessate da questioni di EMC, l'alimentazione elettrica e le impedenze di carico non sono per niente alte.

Quindi si rende necessario qualcosa di più, almeno in ingresso, quando l'energia con frequenza inferiore in modalità differenziale deve essere controllata e l'impedenza della sorgente è più bassa.

La soluzione è aggiungere singoli induttori in ogni "gamba" del filtro, a monte del condensatore parallelo. Ora la bassa impedenza di sorgente dell'alimentazione elettrica incontra l'alta impedenza degli induttori e il flusso di energia viene limitato. Questa soluzione probabilmente risulterà più utile in futuro, poiché i requisiti di immunità a bassa frequenza, che sono già negli standard EMC di base ma non ampiamente applicati negli standard di prodotto, e i futuri standard sulle emissioni diventeranno requisiti di legge.

La stessa soluzione con gli induttori in serie sarà probabilmente necessaria all'estremità di uscita del filtro se il carico è qualcosa, ad esempio un invertitore, che produce emissioni nell'intervallo da 2 kHz a 150 kHz, come avviene in molti casi. Quindi le dimensioni delle piccole scatole di metallo che utilizziamo oggi sono destinate ad aumentare (e con esse i costi, ovviamente) nei prossimi anni.

È necessario essere molto cauti riguardo alle specifiche pubblicate sull'attenuazione dei filtri. Spesso le misurazioni vengono effettuate con sorgente e carico resistivi di 50 Ω, procedura facile ma tutt'altro che realistica. Molti produttori inoltre pubblicano risultati in altre condizioni, ad esempio una sorgente di 0,1 Ω e un carico di 100 Ω e viceversa, come descritto nell'Allegato C dello standard internazionale CISPR 17/EN 55017 (che include procedure di test non solo per i filtri completi ma anche per i singoli componenti), il che non è necessariamente più realistico. E non spiega del tutto come eseguire i test. Specifica che le caratteristiche del filtro probabilmente variano in base al flusso di corrente con frequenza della rete elettrica, ma non elabora il fatto che l'attenuazione in modalità differenziale (la tensione tra L e N in uscita divisa per la tensione corrispondente in ingresso) in realtà deve essere misurata con segnali a radiofrequenza bilanciati, mentre l'attenuazione in modalità comune deve essere misurata con segnali non bilanciati (ovvero un solo lato messo a terra). Ma le reti LISN standard hanno solo uscite L e N, da cui esce la tensione in modalità comune più o meno metà della tensione in modalità differenziale.

La Figura 3 mostra la disposizione per la misura dell'attenuazione in modalità differenziale in una configurazione bilanciata. Le disposizioni per l'applicazione della tensione della rete elettrica e un carico non sono mostrate.

Se si utilizza correttamente questa configurazione, sono evidenti gli effetti delle capacità parassite all'interno del gruppo filtri.

La Figura 4 mostra la disposizione per la misura dell'attenuazione in modalità comune. Anche in questo caso, le disposizioni per l'applicazione della tensione della rete elettrica e di un carico non sono mostrate.

Nessuna di queste disposizioni mostra i trasformatori necessari per eseguire i test 0,1 Ω/100 Ω.

È assolutamente necessario misurare le prestazioni del filtro nel prodotto in cui deve essere utilizzato, anche se è abbastanza ingenuo pensare di poter ottenere misure realistiche. Deve essere presa una decisione riguardo al fatto di includere o meno una rete stabilizzatrice d'impedenza di linea (LISN), che presume che l'alimentazione della rete elettrica "sembri" 50 Ω con frequenze elevate o utilizzare un'alimentazione che si spera possa essere rappresentativa senza una rete.

Figura 3. Misura dell'attenuazione in modalità differenziale in una configurazione bilanciata

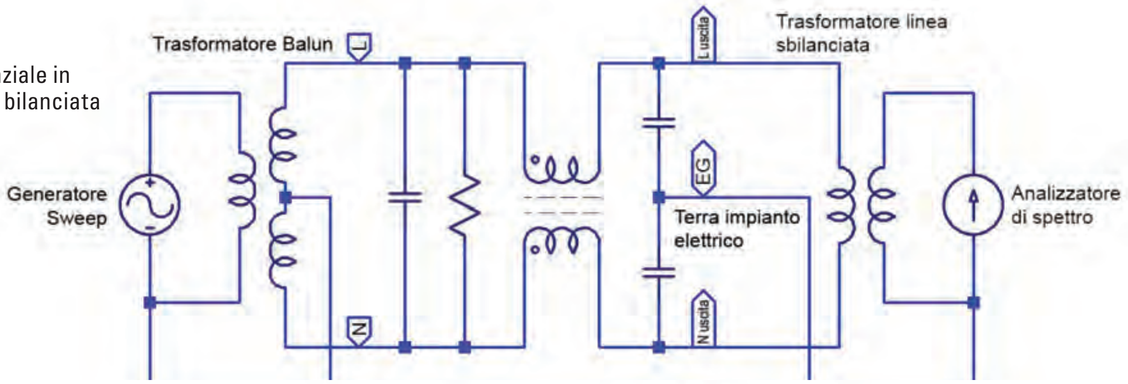
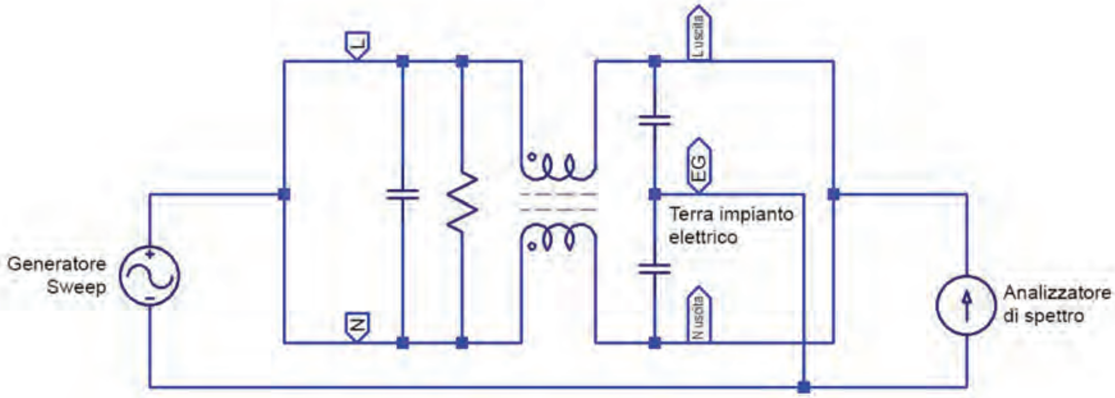


Figura 4. Misura dell'attenuazione in modalità comune



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Interferencias electromagnéticas entre pistas múltiples distribuidas aleatoriamente en el PCB de una estructura de Audio/Multimedia: Comportamiento diafónico (crosstalk) en Dispositivos Inteligentes Portátiles

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OVERVIEW

The scope of this paper is to devise a method to evaluate the performance integrity of a smart handheld device having a printed-circuit board (PCB) at its baseband section, infested with a random cluster of traces [1-17]. The associated transport of high-speed signals (audio and/or multimedia) on a specific trace (called, "the aggressor") and the corresponding high-speed digital signal-processing (DSP) would invariably culminate in causing unwanted crosstalk across nearby traces (dubbed as "victims") commensurate with the associated electromagnetic (EM) coupling between the lines. To read this article in English, go to our website www.interferencetechnology.com.

RESUMEN

En los dispositivos inalámbricos de última generación, es inevitable tener que dar cabida a un denso layout de pistas de cobre en los circuitos impresos asociados (de una capa o multicapa). Es relevante destacar que, considerando los niveles de banda base de las secciones de audio y/o multimedia en dispositivos portátiles inteligentes, vemos que a menudo en los circuitos impresos (PCB) prevalecen los trazados de pistas en zigzag; por lo tanto, es necesaria una estrategia específica para abordar la magnitud de la diafonía en pistas (víctimas) cercanas a caminos de señales agresivas. El presente estudio se ha concebido por tanto para abordar y evaluar la integridad de un dispositivo inteligente, con un PCB en la sección de banda base infestado de manojos de pistas aleatorios, asumiendo que una pista asociada de transporte de señales digitales de alta velocidad (llamada agresora) induce diafonía indeseada en las pistas víctimas cercanas. Se han considerado en este estudio los atributos probabilísticos relevantes de los patrones de pistas distribuidos aleatoriamente en el PCB, que propician valores de diafonía no determinísticos y se han estimado los correspondientes valores de paradiafonía y telediafonía (near-

and far- end crosstalk, NEXT and FEXT). Estos aspectos nos pueden permitir dar sugerencias para mitigar la diafonía de forma adecuada en secciones de banda base que tienen que convivir con el transporte digital de alta velocidad. Se presentan resultados de estudios experimentales y se validan las correspondientes estimaciones teóricas de paradiafonía y telediafonía

INTRODUCCIÓN

EL OBJETIVO DE este artículo es concebir un método para evaluar la integridad de un dispositivo inteligente portátil, con una placa de circuito impreso (PCB) en la sección de banda base, infestada con un manojo aleatorio de pistas[1-17]. El transporte asociado de señales de alta velocidad (audio y/o multimedia) en una pista específica (llamada "agresora") y el correspondiente procesado de señal digital (DSP) de alta velocidad, acabará invariablemente causando una diafonía indeseada en las pistas cercanas (llamadas "víctimas"), proporcional al acoplamiento electromagnético (EM) entre las líneas.

Los atributos probabilísticos de estos patrones de pistas distribuidos aleatoriamente en el PCB propician valores de paradiafonía y telediafonía no determinísticos en las pistas víctima [2] [4] [7-9]. El conocimiento de estos parámetros nos llevaría a poder poder proponer sugerencias y posibles revisiones de diseño en cuanto a la mitigación en secciones de banda base de dispositivos portátiles inteligentes.

En el presente trabajo se han realizado estudios experimentales en un PCB de ensayo y se han obtenido las estimaciones teóricas de paradiafonía y telediafonía, validadas con valores medidos. Se presentan de forma conjunta la heurística teórica propuesta, los cálculos realizados y los resultados experimentales obtenidos, para ilustrar la eficacia del estudio y su utilidad. El artículo está organizado de la siguiente manera: En la sección siguiente (SECCIÓN II), se proporcionan detalles básicos necesarios en cuanto a la relación entre los dispositivos portátiles inteligentes modernos y las características de transporte de señales digitales en sus secciones de banda base mediante grupos de pistas de circuito impreso. En la SECCIÓN III se da un repaso a las interferencias electromagnéticas (EMI) en un grupo aleatorio de pistas de circuito impreso. En la SECCIÓN IV se hace una exposición de la heurística teórica, acompañada de descripciones de la estimación de diafonía en discusión. En la SECCIÓN V se define el factor de acoplamiento interpista (F) y se evalúa mediante consideraciones de campo EM. Para el análisis y el estudio de cálculo (y eventualmente prácticas experimentales), se describe un layout de PCB de ensayo en la SECCIÓN VI. Se presenta en la SECCIÓN VII el marco analítico pretendido; y, finalmente, se presentan los datos medidos y calculados, junto con deducciones y sugerencias de mitigación de diafonía en el contexto de las configuraciones del PCB de ensayo.

II. TRANSPORTE DIGITAL DE SEÑALES EN LA SECCIÓN DE BANDA BASE DE DISPOSITIVOS PORTÁTILES INALÁMBRICOS

En el contexto moderno, la gama de dispositivos inalámbricos modernos soportan una gran variedad de aplicaciones de datos diversos (diverse data applications, DDA) con salidas en forma de audio, video y pantallas alfanuméricas. De forma específica, considerando los dispositivos portátiles inteligentes actuales, la fase final de la información remite invariablemente a un esquema de pantalla-visualizador y/o salida de audio [17]. Estos visualizadores/salidas son normalmente el resultado de un sinfín de señales de banda base procesadas y conducidas a través de un conjunto de pistas de cobre densamente empaquetadas y trazadas sobre PCBs (de capa única o multicapa) hacia las secciones finales de una pantalla táctil, altavoz o micrófono. Existen, por lo tanto, entre la electrónica de procesado de la señal y las secciones finales de visualización de los dispositivos inalámbricos portátiles, multitud de líneas de transmisión en forma de pistas de cobre que conectan los nodos fuente y los puntos terminales, que serpentean a menudo aleatoriamente (hacia y desde los extremos de envío y recepción). Están además normalmente empaquetadas muy juntas en formato de fan-outs paralelos y/o no paralelos vistos normalmente como patrones de trazado bidimensional (2D). Dichas pistas pueden aparecer en un PCB de una capa y/o apiladas en múltiples capas según convenga.

Considerando el plan de layout y topología de pistas en un PCB tal y como descrito anteriormente, se pueden clasificar en dos tipos: (i) pueden representar un patrón simple con pistas paralelas pero muy próximas entre ellas o, (ii) alternativamente, pistas que aunque no se crucen pueden presentar un patrón complejo, con dichas pistas trazadas en zigzag sin una regla determinística, mediante decisiones ad hoc basadas en la conectividad necesaria para el recorrido de las señales. (En caso de ser necesario que algunas pistas se crucen entre sí, se opta por separarlas a nivel de capa mediante el uso de PCBs multicapa).

Aunque exclusivamente en las secciones banda base de dispositivos portátiles, los tipos de pistas de PCB descritas anteriormente deben también transportar señales digitales a tasas de bits muy altas. Por ejemplo, si tomamos como ejemplo los teléfonos inteligentes y otros dispositivos portátiles/móviles modernos, las tasas de bits de datos usadas en niveles de banda base pueden ser significativamente altas (~ 500 Mbps); además, estos flujos de bits de alta velocidad se transfieren a menudo entre chips y/o varios nodos circuitales durante el procesado de señal de banda base, por ejemplo, entre un sensor de imagen y un ISP (image sensor processor) [17]. Para negociar tales transferencias, se prevé una gran cantidad de pistas de cobre a nivel de placa (en una única superficie o en múltiples, apiladas en placas o superficies flexibles). Además, estas pistas pueden ser de distintas longitudes para posibilitar los tránsitos digitales necesarios entre los pines de cualquier par de dispositivos situados en diferentes posiciones en la placa.

La señal de banda base transmitida físicamente representa, en esencia, una transmisión de trenes de pulsos "digital-sobre-digital". En el contexto moderno de 3G,considerando 4G y las implicaciones LTE asociadas, los datos de banda base gestionados en las estructuras de los teléfonos inteligentes (así como en dispositivos similares) son relevantes para versiones específicas de procesadores con diseños de chip y/o SoCs (system-on-chips) que concentran generosos programas de procesado digital de la señal (DSP) de audio y video. Estos procesadores son necesarios para conseguir la integración de múltiples estándares, reducir la disipación de potencia y facilitar nuevas funciones clave para la siguiente generación de dispositivos portátiles inteligentes. Es importante recalcar quelos procesadores de banda base asociados proporcionan operaciones eficientes, con una buena relación de coste, mediante un procesado específico para aplicaciones multimedia para el nivel de entrada 3G así como para la siguiente generación/evolución de sistemas 4G.

En tal complejidad de estructuras banda base y operaciones a nivel de chip específicas, las aplicaciones que corren por debajo van a requerir inevitablemente el uso de tasas de bit de alta velocidad, colocadas en pistas próximas, amontonadas y trazadas casi aleatoriamente según convenga. Por ejemplo, si consideramos el soporte de procesado de video necesario para imágenes de 10/12 Mpixels y reproducción de video de 720p con aceleración de gráficos 2D/3D, las necesidades operacionales hacen subir las velocidades de los procesadores hasta 1 GHz o incluso más. Las transmisiones eléctricas de datos relacionadas recuerdan de formarecurrente la gravedad de los transportes múltiples de alta velocidad en el espacio tan limitado de los layouts en las placas de circuitos (y/o placas flexibles). El tema subyacente que se nos plantea, por lo tanto, puede resumirse como sigue: junto con los diseños de empaquetado de los componentes y los chips colocados en la placa, las interconexiones que soportan los transportes digitales mencionados estarán, inevitablemente, en yuxtaposición de forma muy cercana; es más, se van a trazar de forma impredecible según convenga. Además, las líneas de transmisión (pistas) desplegadas van a ocupar una alta densidad (por unidad de área) del PCB y en distintas longitudes.

Las transmisiones digitales, en los contextos de PCB con estructuras de banda base descritos anteriormente, acaban a menudo presentando problemas de diafonía específicos que requieren mitigaciones efectivas [4,9,12,14- 16]. En concreto, si consideramos el layout de un PCB con dos o más líneas adyacentes muy juntas, su proximidad acarreará un fuerte acoplamiento EM entre ellas, como se ha indicado anteriormente. Efectivamente, las fuerzas EM causadas por el transporte en las pistas de señales variables en el tiempo interactuarán con las líneas adyacentes causando interferencias electromagnéticas (EMI). Esto significa diafonía, entendida como la transferencia inintencionada de señales de una línea (llamada anteriormente agresora) a las líneas vecinas (designadas anteriormente como víctimas). Tales efectos de diafonía dependen fundamentalmente de la magnitud de las fuerzas electromagnéticas inducidas transportadas en las pistas, en función de la tensión, v(t) y corriente, i(t) relativas de la señal. Es más, las pistas representan un conjunto de líneas de transmisión con sus características de resistencia, capacidad e inductancia distribuidas; y las características de pérdidas dieléctricas del material del PCB que contiene las pistas también jugara su rol en cuanto a las características de propagación EM de la transmisión de señal, produciendo atenuación, así como efectos de capacidad e inductancia distribuida en la señal transportada.

III. EMI EN LOS GRUPOS DE PISTAS DE PCB: UNA MIRADA GENERAL

A nivel de sistema, una «pista» en un PCB es un segmento, línea de transmisión, de una interconexión más general formada normalmente por un driver, los encapsulados asociados, uno o dos conectores más vías, etc. En la Fig. 1 se ilustra una placa típica de conexión a cables con todas las pistas de salida.

Predecir la proliferación de EMI en el PCB y el comportamiento del acoplamiento entre pistas asociado, con el objetivo de evaluar la diafonía resultante, es bastante tedioso, especialmente cuando las pistas están situadas de forma arbitraria, no paralelas y espaciadas aleatoriamente entre sí. No es fácil, y normalmente poco práctico, encontrar soluciones analíticas exactas. No obstante, sí se han obtenido en el pasado modelos aproximados y deducciones de resultados simulados relativos a topologías simples de pistas paralelas [10, 11].

Evaluar la influencia de la diafonía cuantitativamente es todavía más difícil cuando las señales en las pistas cor-

FIGURA 1: Grupos de pistas saliendo de un PCB: por ejemplo, en la estructura de banda base de un dispositivo portátil.

responden a formas de ondas digitales de alta velocidad con características bruscas de tiempo de subida. El correspondiente acoplamiento EM interpista y diafonía pueden introducir errores de intervalo de tiempo (TIA, *time-interval-error*), en formas de onda pulsadas, debido a la dispersión espúrea de la energía EM, como indicado por los autores en [17].

IV. ESTIMACIÓN DE LA DIAFONÍA: PRESENTACIÓN DEL PROBLEMA Y DESCRIPCIÓN

En vistas a los aspectos modernos de la diafonía frente a PCBs exclusivos de los dispositivos inalámbricos portátiles modernos, el presente estudio aborda dichos problemas relativos a las pistas de PCB densamente empaquetadas, tanto en el caso que la líneas sean paralelas como en el caso de patrones en zigzag siendo aleatorias las longitudes de los segmentos de línea; además, se asume que todas las líneas se han diseñado para soportar formas de onda pulsadas de alta velocidad con tiempos de subida bruscos, susceptibles de causar dispersiones de energía EM significativas [12, 17] en la estructura compuesta del PCB con pistas metálicas sobre una placa dieléctrica; y que la correspondiente interferencia electromagnética (EMI) que penetra en la placa se manifestará en forma de diafonía en las pistas víctima. El layout genérico, de un par de pistas en un PCB con problemas de diafonía, adecuado para este estudio, se ilustra en la Fig. 2. El par víctima-agresor no tiene porqué implicar pistas paralelas. En general estos pares pueden ser no paralelos, como se ilustra en la Fig. 3.

En la Fig. 4 se ilustran de manera más completa, pistas víctima múltiples $\{V_T\}$ infectadas por una agresora, A_T. En general, estas pistas pueden presentar caminos ondulantes, y como tales,cada pista se puede caracterizar mediante un valor eficaz (RMS) de geometría ondulatoria observada en el plano 2D del PCB. En la Fig.4 se muestra un valor X_A de dicho valor RMS para laagresora, A_T; mientras el conjunto $\{X_V\}$ denota los correspondientes valores para el conjunto de víctimas$\{V_T\}$v = 1, 2, …. (Nota: las víctimas de identifican con el índice, v= 1, 2, 3,..)

En línea con el alcance del presente estudio expuesto anteriormente, los objetivos subyacentes pretenden deducir un índice de acoplamiento que mida de forma implícita las componentes inducidas del campo eléctrico (E) y magnético (H) en las pistas víctima como resultado de una señal de alta velocidad transportada en una línea agresora expresada en términos de sus funciones de tensión v(t) y corriente i(t) variables en el tiempo.Es posible estimar los valores de las componentes de campo E y H, se propone que ello podría implícitamente permitir estimar la EMI asociada y por tanto deducir el coeficiente de acoplamiento diafónico de interés.

El modelado tradicional de EMI y diafonía en tales ambientes implicaría determinar los efectos inductivos (L) y capacitivos (C) percibidos en las pistas en base a consideraciones deimpedancia reactiva (mutua) [6]. No obstante, en este tipo de evaluación EMI(y en estimación dediafonía) basada en C y L, las estimaciones subyacentes pueden resultar intensivas en cálculo, puesto que los efectos capacitivos e inductivos asociados deben ser determinados (principalmente de forma numérica) a través de una cuadrícula en la que se colocan las pistas víctimas y agresora. En otras palabras, cuando consideramos el acoplamiento interpista subyacente en términos capacitivos e inductivos clásicos, implica influencia reactiva (es decir, fenómenos de relación corriente-tensión en el sentido de Kirchoff) experimentada a lo largo de un gran nombre de conjuntos de nodos y espirales distribuidos, modelados en una cuadrícula bidimensional representando el patrón 2D de las mallas, cada una con características de línea de transmisión específicas, de las pistas involucradas.

No obstante, como se ha comentado anteriormente, lo que se propone es que el índice de acoplamiento (F) de interés se puede definir alternativamente (en lugar de a partir de las perspectivas C y L), a través de evaluaciones de las componentes E y H, a través del entramado de pistas víctima, debidas a entidades de tensión y corriente de señales variables en el tiempo. El índice de acoplamiento correspondiente (F) puede expresarse de la siguiente manera [18]:

$$F = \sum_{k=1}^{K} |J(k)| \Delta A(k) \qquad (1)$$

Donde |J(k)| denota la magnitud de la densidad de corriente de desplazamiento (en A/m^2) en el centro de la k-ésima malla de la matriz K: [I × J] ilustrando el layout completo de pistas víctima en el PCB. Esto es, se divide el área en la que residen las pistas víctimas en el PCB en K mallas, como se muestra en la Fig.5; y, ΔA(k) es elárea (en m2) de la k-ésima malla con las coordenadas (i, j) en cuestión. Por tanto, F en la ecuación (1) representa la influencia total de todas las corrientes de desplazamiento recibidas como resultado de las fuerzas de campo E y H en el PCB, sumadas sobre todo el layout de la pista víctima.

Se puede ver en [18] que abordar la deducción de los efectos EMI mediante la ecuación (1) es igual de eficaz, en un 98%, que los resultados obtenidos mediante el método tradicional de estimación por capacidad-inductancia. Pero las ventajas de abordarlo mediante la ecuación (1) son:

- Es independiente de la posición de las pistas víctima en la superficie del layout
- Es menos complejo a nivel de cálculo, y pueden usarse métodos tradicionales de diferencias finitas, de elementos finitos, de los momentos (métodos MDF, MEF y MM) para determinar numéricamente las componentes E y H asociadas a la interferencia, que nos llevan a la estimación del coeficiente, F
- Encaja muy bien con el patrón aleatorio de las líneas víctima frente a las agresoras; y no se requieren, per se, detalles en cuanto a las posiciones exactas de los nodos y bucles de Kirchhoff para decidir [L] y [C] [19-21].

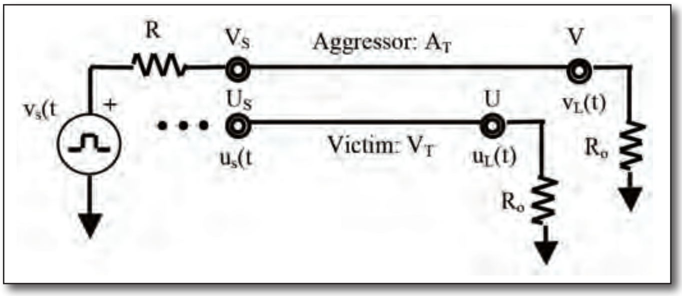

FIGURA 2: Un conjunto de hipotéticas pistas víctima paralelas $\{V_T\}_{v = 1, 2, \ldots}$ y la pista agresora (A_T) en un PCB. Se muestran los nodos terminales de la agresora y la víctima, con sus tensiones asociadas $\{v_s, u_s\}$ y $\{v_L, u_L\}$, que corresponden respectivamente a los puntos extremos de fuente y carga.

En vistas de lo anterior, el presente estudio está focalizado en la deducción del coeficiente (F) a partir de las componentes E y H para especificar las implicaciones de la telediafonía (FEXT) y la paradiafonía (NEXT) experimentadas en un patrón de pistas complejo típico, como por ejemplo el ilustrado en la Fig. 5. Se usan las nociones de [18] y la ecuación (1), pero con modificaciones importantes en este estudio específicamente enfocado a layouts de PCB de dispositivos inalámbricos portátiles.

Las corrientes acopladas inducidas por diafonía en las líneas víctima se manifiestan en forma de telediafonía y paradiafonía. En un par simple de pistas paralelas (con terminaciones adaptadas), la línea (activa) agresora (1) se acoplará electromagnéticamente con la línea (no activa) víctima (2) a través de dos consideraciones EM, (i) el campo de fuerza de Coulomb debido a las cargas en las líneas (tradicionalmente considerados efectos capacitivos, C); y (ii) el campo de fuerza de inducción de Faraday debido al acoplamiento magnético variable en el tiempo entre las líneas, comúnmente considerados efectos inductivos (L). Para analizar la EMI subyacente se usan normalmente un par de matrices de inductancias y capacitancias (m × n). Por ejemplo, en el caso de un par de líneas agresora-víctima (1 y 2), las matrices relevantes L-C se pueden escribir de la siguiente manera [19-21]:

$$\frac{\Delta F}{F} = \frac{\frac{\partial}{\partial t}[\Delta H(t)]}{\frac{\partial}{\partial t}[H(t)]} + \frac{\Delta E(t)}{E(t)} \qquad (2)$$

donde L11 o L22 representan la autoinductancia (henry por unidad de longitud) de las líneas 1 o 2; y, L12 o L21 denotan la inductancia mutua (henry por unidad de longitud) entre las líneas 1 y 2. De forma similar, C11 o C22 representan la autocapacitancia (faradios por unidad de longitud) de las líneas 1 o 2 (medidas respecto a tierra) y C12 o C21 , la capacidad mutua (faradios por unidad de longitud) entre las líneas 1 y 2, por unidad de longitud. En consecuencia, las tensiones de telediafonía y paradiafonía inducidas pueden escribirse como:

$$^{V}\mathrm{NEXT} = \frac{v_s}{4}\left[\frac{L_{12}}{L_{11}} + \frac{C_{12}}{C_{11}}\right] \qquad (3)$$

$$^{V}\mathrm{FEXT} = \frac{v_s}{4}\left[\frac{L_{12}}{L_{11}} + \frac{C_{12}}{C_{11}}\right] \mathrm{x} \left(\frac{l\,(L_{11}C_{11})^{1/2}}{2t_r}\right)$$

donde vs es la tensión fuente en la línea agresora (Fig. 2); y, ℓ es la longitud (en m) de las pistas-líneas; tres el tiempo de subida (en s) de la señal de entrada, vs(t); y, ℓ(L11C11)$^{(1/2)}$ denota el retardo de propagación producido a lo largo de la línea de longitud ℓ metros.

V. ESTIMACIÓN DEL FACTOR DE ACOPLAMIENTO INTERPISTA (F) A PARTIR DE CONSIDERACIONES DE CAMPO EM

En vez de la manera tradicional de estimar el coeficiente de acoplamiento interpista a partir de consideraciones L y C, este estudio está concebido, como mencionado anteriormente, para formular una manera alternativa de abordar el problema basada en parámetros de campo EM para deducir la diafonía asociada acoplada a través de las pistas. Se presupone que el método propuesto es más apropiado para pistas con patrones aleatorios. La heurística relevante subyacente es la siguiente: considérese un layout de PCB con una pista víctima (V_T) y una pista (agresora) ruidosa (A_T) como se ilustraba anteriormente en la Fig.2. La diafonía entre V_T y A_T depende de un mapa de emisiones EM superpuesto a V_T y A_T a través de todo el dominio del layout en un plano bidimensional. En la práctica, las pistas (V_T y A_T) en el PCB se pueden representar por segmentos unidos por un conjunto de puntos de giro (Figs. 3 y 4). El número de puntos de giro (N) y su posición

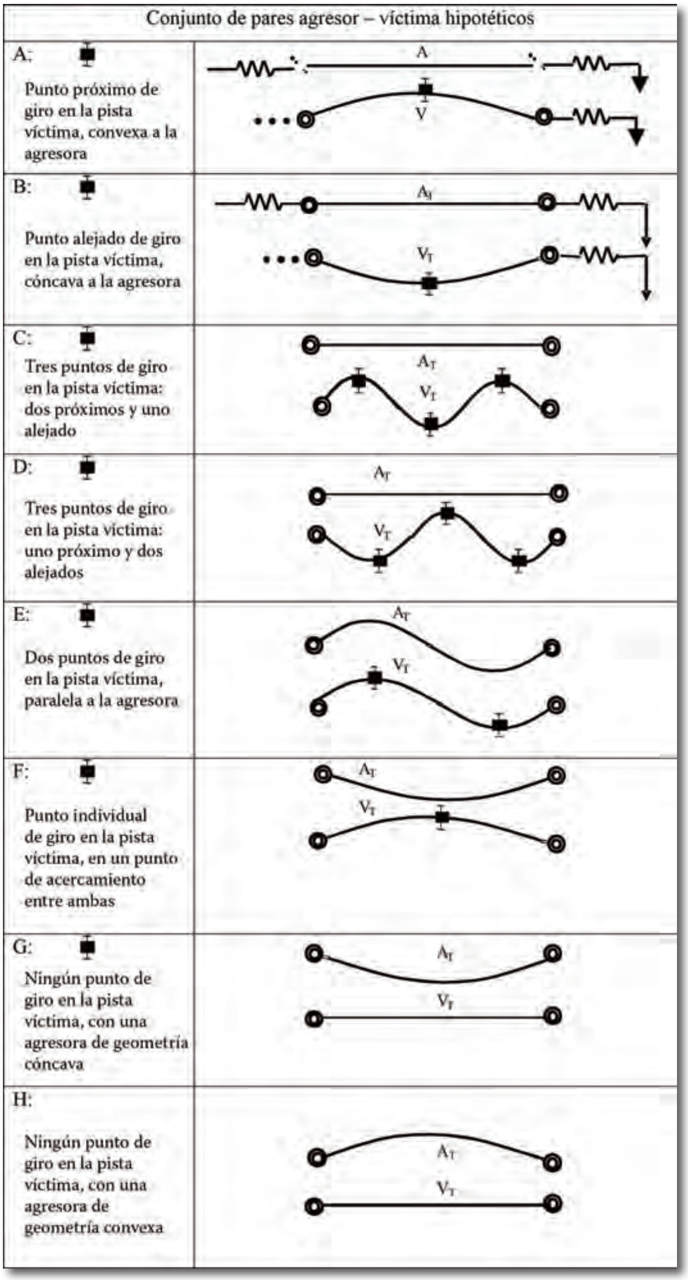

FIGURA 3: Conjunto de posibles *layouts* de pistas agresora (A_T) y víctima (V_T) donde se muestra su disposición geométrica no paralela relativa en el PCB, con uno, más o cero puntos de giro en las pistas víctima.

en el PCB dependerán de las interconexiones electrónicas necesarias según convenga. Las coordenadas de estos puntos de giro son, no obstante, conocidas a priori y, por lo tanto, determinísticas. Es decir, representan puntos locales con coordenadas definidas en la geometría 2D del layout del PCB diseñado. Además, los puntos terminales de las pistas (dos para VT y dos para AT) están también determinísticamente especificados en coordenadas conocidas (predefinidas); y, en general, todas las pistas se suponen de la misma anchura (w metros). Dados los anteriores detalles, el estudio en marcha tiene las siguientes motivaciones:

a) Determinar las componentes de campo E y H de la EMI en los dominios de pista de interés, y conocer dichas componentes en las posiciones definidas de los puntos de giro

b) Calcular el índice de acoplamiento resultante total, F para cualquier pista víctima especificada, respecto de una pista agresora

c) Evaluar los niveles correspondientes de telediafonía y paradiafonía en los nodos terminales

d) Verificar experimentalmente la heurística teórica propuesta y las evaluaciones computacionales realizadas

e) Buscar y sugerir métodos para la mitigación (reducción) del acoplamiento diafónico relacionado

VI. LAYOUT DE PCB DE ENSAYO PARA EL ESTUDIO ANALÍTICO, COMPUTACIONAL Y EXPERIMENTAL

Para ilustrar el método de evaluación de paradiafonía y telediafonía en un layout de pistas de distribución aleatoria, se considera el PCB de ensayo y las pistas que se muestran en la Fig. 5. Supongamos que las pistas mostradas son tales que las pistas víctima se presentan unidas a terminales fijos {P1}, {P2} y que se suponen confinadas en una determinada área rectangular. vs(t) alimenta la pista agresora, normalmente una tensión pulsada de alta velocidad, que produce componentes de campo EM que se extienden por las inmediaciones y que invaden completamente el dominio de las pistas víctima. El objetivo del estudio es el siguiente: (i) analizar el electromagnetismo asociado y deducir las componentes de campo E y H especialmente en los puntos de giro de interés; (ii) evaluar en consecuencia la paradiafonía y telediafonía en cualquier pista víctima dada; y (iii) de ahí, obtener eventualmente un layout de pistas víctima con niveles de paradiafonía y telediafonía minimizados, como una alternativa al diseño PCB original, compatible a nivel EM. Para complementar el típico acoplamiento EM nodo a nodo en un par agresora-víctima como el ilustrado en la Fig. 6, se muestran en la Fig. 7 posibles ejemplos de pistas víctima situadas entre nodos de inicio y final, P1-P2 con un número variable (N) de puntos de giro.

El layout (a) en la Fig. 7, con la víctima (P1 - P2) sin puntos de giro se toma como referencia, y asumiendo el caso estándar de pistas paralelas, se puede deducir la paradiafonía y telediafonía determinísticamente mediante las relaciones de las matrices de acoplamiento de las ecuaciones (2) y (3). Es decir, en términos de [L] y [C] de la ecuación (2), las siguientes relaciones de campo EM se pueden escribir como influencias de acoplamiento inductivo (IC) y acoplamiento capacitivo (CC):

$$V(t)_{IC} = - L \times \frac{d[i(t)]_{IC}}{dt} \qquad (4a)$$

$$V(t)_{CC} = \frac{I}{C} \times \int [i(t)]_{CC}\, dt \qquad (4b)$$

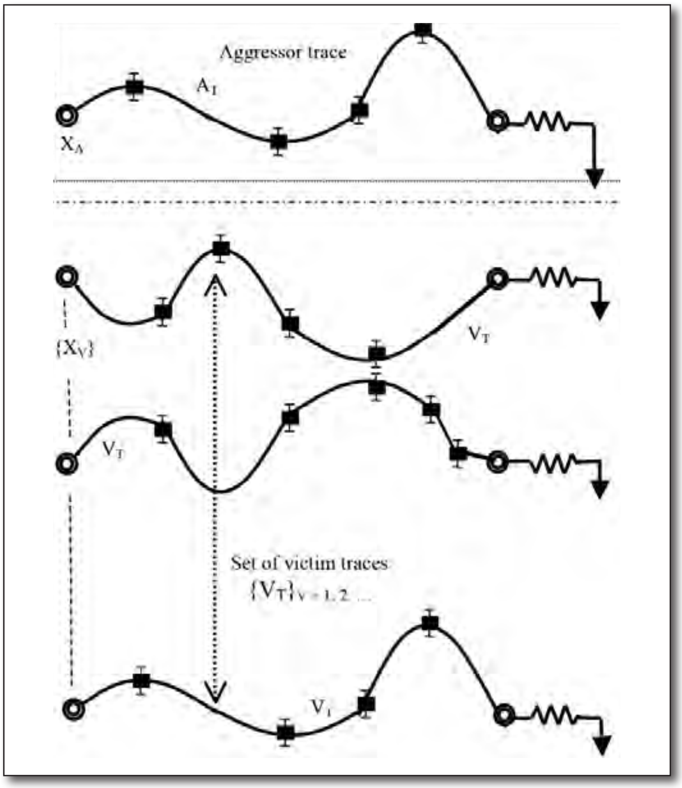

FIGURA 4: Conjunto de pistas víctima distribuidas aleatoriamente $\{V_T\}_{v = 1, 2,...}$ dispuestas respecto de una pista agresora (A_T) en el PCB.X_A y $\{X_V\}$ denotan, respectivamente, los valores eficaces (RMS) de las ondulaciones geométricasaleatorias de las pistas en el plano 2D del PCB.

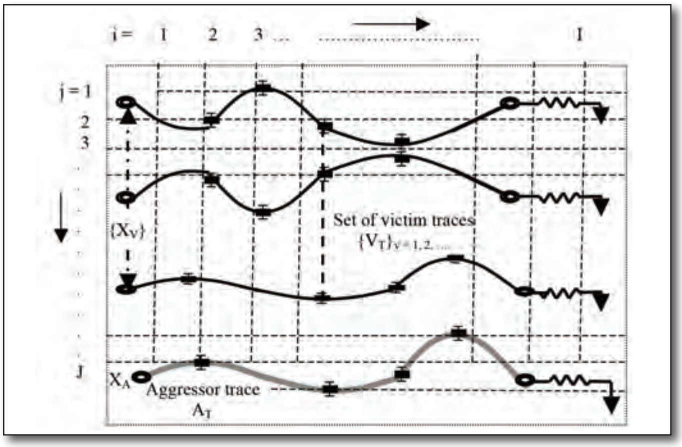

FIGURA 5: Una matriz K: [I × J] de una malla concebida en el plano 2D del *layout* del PCB infestado de pistas víctima.

donde v_{IC} y v_{CC} son tensiones inducidas por unidad de longitud de la víctima debidas a efectos inductivos y capacitivos respectivamente.

Las relaciones correspondientes en términos de campos magnéticos (H)y eléctricos (E) se escriben mediante:

$$v_{IC}(t) = -\mu[L]x\frac{d[H(t)]_{IC}}{dt} \qquad (5a)$$

$$v_{CC}(t) = \frac{\varepsilon}{[C]}\int\left[\frac{d[E(t)]_{CC}}{dt}\right]dt = \frac{\varepsilon}{[C]}E_{CC}(t) \qquad (5b)$$

Y, por tanto, la relación de campo EM acoplado superpuesto neto viene dada por:

$$v\text{[redacted]}C + v_{IC} = \text{[redacted]}\mu\ l\text{[redacted]}x\text{[redacted]}\frac{d[\mathbf{H}(t)]_{IC}}{dt}\Big]_{HC} + \left[\frac{\varepsilon}{[C]}\mathbf{E}_{CC}E_{CC}(t)\right]_{CC} \qquad (6)$$

Supóngase que los puntos de giro (nodos) en la pista víctima aparecen localizados aleatoriamente respecto de la pista agresora, para un conjunto dado de [L] y [C]. Se pueden entonces especificar las componentes E y H correspondientes como entidades perturbadas a lo largo de las pistas de ensayo. El mínimo cambio en la influencia del acoplamiento se puede escribir entonces como:

$$\frac{\Delta F}{F} = \frac{\frac{\partial}{\partial t}\text{[redacted]}H(t)\text{[redacted]}}{\frac{\partial}{\partial t}\text{[redacted]}(t)\text{[redacted]}} + \frac{\Delta E(t)}{E(t)} \qquad (7)$$

VII. ANÁLISIS

Consideremos el espacio total (Ω) de layout del PCB en el que, como comentado anteriormente, pueden existir un número de pistas trazadas aleatoriamente según convenga, pero dispuestas de forma próxima entre ellas. Por ejemplo, se ilustra en la Fig. 8 un hipotético layout en una capa única dada (en el que se asume que no existen cruces físicos).

Supongamos que AA' denota el agresor (infectante o pista activa) conduciendo un tren temporal de información binaria de alta velocidad. Sea YY' una línea vertical de separación en el PCB que asumimos separa el dominioΩ en dos regiones, Ω1 y Ω2 re-presentando los extremos iniciales y finales respectivamente. En referencia a los espacios Ω1 y Ω2, y en términos de heurística de acoplamiento reactivo clásica, cada espacio tiene sus propias matrices de acoplamiento capacitivo [C] e inductivo [L]. Estas matrices pueden ser vistas alternativamente como componentes de campo eléctrico (E) y magnético (H) que emanan de la línea agresora común AA' y que interfieren (o generan diafonía) en el conjunto de líneas víctima bb', cc', dd' ,etc. Es decir, en cuanto a Ω1 y Ω2, los acoplamientos capacitivo e inductivo se pueden especificar implícitamente en términos de las respectivas componentes de campo E y H asociadas mediante el siguiente conjunto de

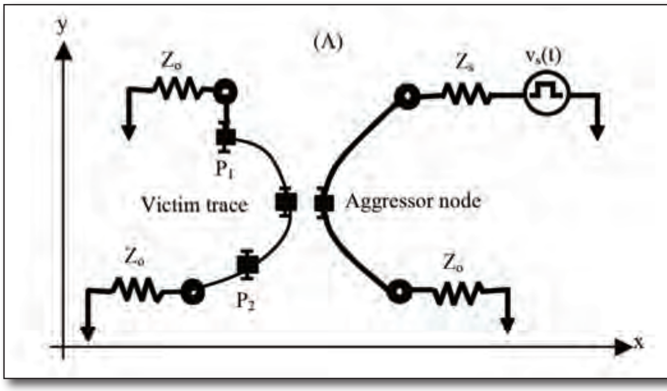

FIGURA 6: Pistas agresora y víctima: nodos terminales y puntos de giro.

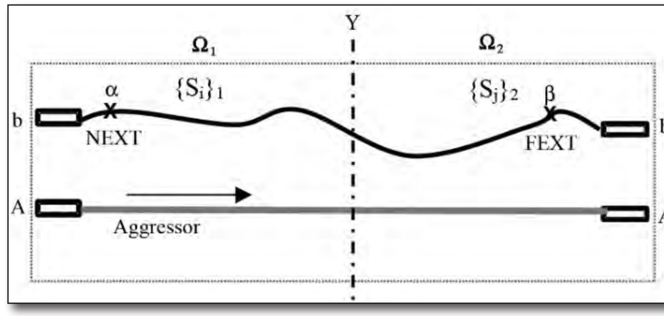

FIGURA 9: Representación de los dominios Ω_1 y Ω_2 con el conjunto de índices de susceptibilidad $\{S_i\}$ 1 y $\{S_j\}$ 2 respectivamente; indicando α y β los niveles de paradiafonía y telediafonía respectivamente en la pista víctima.

matrices: Ω1 [E] y [H] y Ω2 [E]2 y [H]2.

De forma análoga, se pueden atribuir, a cada Ω1 y Ω2, ciertos niveles de susceptibilidad, S1 y S2 respectivamente, a la diafonía en víctimas, como resultado de la excitación EM proveniente de la pista agresora, AA'.

En otras palabras, el campo EM inducido debido al flujo de señal en AA' (agresor), causará un camino de susceptibilidad punto a punto en las víctimas; y, los valores pertinentes se pueden expresar como {Si}1 y {Sj}2 respectivamente en Ω1 y Ω2 como se puede ver, por ejemplo, en la Fig. 9, asumiendo un escenario exclusivo de víctima bb' frente a agresor AA'. Para proceder al análisis, los dominios Ω1 y Ω2 en la Fig. 9 se han dividido de nuevo en cuadrículas (mallas) tal y como se ilustra en las Figs. 10 y 11.

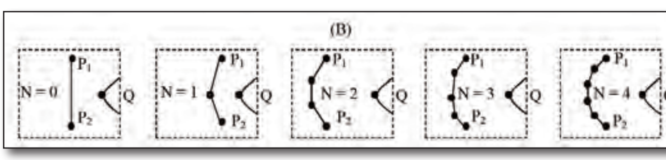

FIGURA 7: Conjunto de layouts de pistas víctima (P 1 - P 2) y agresora (Q), cada una de ellas con un número variable de puntos de giro (N).

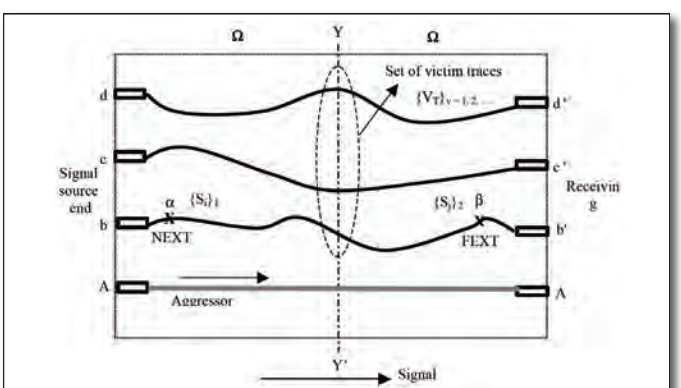

FIGURA 8: Un *layout* de PCB hipotético, con una agresora (AA') y un conjunto de pistas víctima $\{V_T\}_{v = 1, 2,...}$ (Se asume que no hay cruce de pistas). Las regiones Ω_1 y Ω_2 representan los dominios inicial y final, definidos respecto de los extremos fuente y receptor.

Las coordenadas de una malla específica del dominio Ω1 son $(X_{m = 1, 2, ..., M}, Y_{v = 1, 2, ...})$. De la misma forma, las coordenadas de una malla para el dominio Ω2 son $(X_{n = 1, 2, ..., N}, Y_{v = 1, 2, ...})$. Los vectores de campo interferentesE y H, por su parte, se suponen variables malla a malla, a lo largo de las direcciones x e y, punto a punto. Por lo tanto, considerando los nodos de las cuadrículas en las matrices de Ω1 y Ω2, se le puede asignar a cada uno de ellos un valor de susceptibilidad a la diafonía $(S_m)_1$ y $(S_n)_2$ en Ω1 y Ω2 respectivamente. Además, la presencia de $\{S_m\}_1$ y $\{S_n\}_2$ denota, por ejemplo, valores punto por punto en la pista víctima bb' de la Fig. 10 respecto del agresor AA'.

Por lo tanto, considerando los nodos en las extremidades de la víctima bb', cuando m = 1 (en Ω1), {Sm = 1}1 denota la paradiafonía; y, cuando n = N (en Ω2), {Sn = N}2 se refiere a la telediafonía. Además, los elementos de {Sm} y {Sn} se toman como valores normalizados (entre 0 y 1); y, la normalización se hace con respecto al nivel de señal (o campo EM) forzado (por la señal) en el extremo de partida de la línea agresora.Al movernos a lo largo de la línea víctima (llámese bb'), el progreso espacial unidimensional paso a paso de la influencia de la diafonía (de malla a malla) se puede especificar mediante la relacionada aleatoriedad de la influencia del campo EM (interferente) en la víctima. La heurística relevante es como sigue:

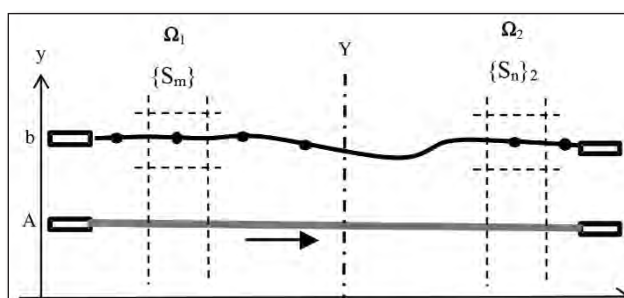

FIGURA 10: Representación punto a punto de los índices de susceptibilidad en los nodos especificados dentro de cada malla de la matriz dibujada en el plano 2D del *layout* de la víctima.

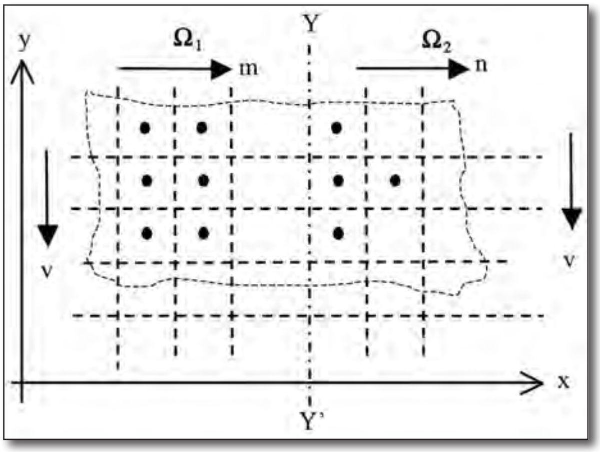

FIGURA 11: Representación de unos conjuntos de mallas hipotéticas {m × v} y {n × v} prescritas para Ω_1 y Ω_2 respectivamente. (Las pistas víctima se indican con el índice v tanto en Ω_1 como en Ω_2, tal y como se hace en el texto).

Considerando el marco 2D de pistas víctima en el PCB, como se ha indicado anteriormente, la línea central YY' divide el dominio 2D en dos secciones, Ω1 y Ω2 correspondientes a las regiones de paradiafonía y telediafonía respectivamente. Además, estas secciones se dividen en conjuntos de {m × v} y {n × v} mallas como se puede ver en la Fig. 11. Cada nodo corresponde a una malla, donde los campos inducidos interferentes E y H representan los nodos susceptibles de sufrir diafonía. La influencia del acoplamiento EMI a través de las pistas y la susceptibilidad a la diafonía resultante en cada nodo es especificada por (Sm, v)1 y (Sn, v)2 para los dominios Ω1 y Ω2 respectivamente. Considerando un modo m-ésimo en Ω1 y uno n-ésimo en Ω2, la influencia del acoplamiento EMI proliferante (a lo largo de los nodos de la fila) concuerda con un proceso de Poisson (o ley de los sucesos raros); y como tal, la dinámica de los valores de susceptibilidad en los modos (m + 1)-ésimo y (n + 1)-ésimo puede representarse en términos de los correspondientes valores en los modos m-ésimo y n-ésimo, que pueden expresarse como una proliferación paso a paso de esta manera:

$$\left(S_{m+1,v}\right)_1 = \left[1 - \exp(-\lambda t)\right]\left(S_{m,v}\right)_1 \quad (8a)$$

$$\left(S_{n+1,v}\right)_1 = \left[1 - \exp(-\lambda t)\right]\left(S_{n,v}\right)_2 \quad (8b)$$

donde λ es una constante de caída del campo a lo largo de la fila (o sea, en la dirección x) y t es el instante en el que tiene lugar la interferencia. De forma similar, el progreso del acoplamiento EMI a lo largo de la columna de mallas (en la dirección y, es decir, a lo largo de las mallas en las posiciones v = 1, 2, ...) puede también escribirse en términos de dinámica de proceso de Poisson. No obstante, los eventos de acoplamiento dirigidos hacia x e y pueden verse como dos procesos espacio-temporales independientes sobre el entorno 2D en cuestión. De ahí que la dinámica del índice de susceptibilidad (S), asumido como una variable aleatoria, pueda escribirse en términos de las dos ecuaciones diferenciales parciales estocásticas independientes siguientes. Siendo las coordenadas de los nodos (x_m, y_v) y (x_n, y_v)para Ω1 y Ω2 respectivamente, las ecuaciones pertinentes son:

A lo largo de la dirección x:

$$\frac{\partial S(t, x_m, y_v)}{\partial t} = S(t\,; x_m, y_v)\left[G - hS(t; x_{m+1}, y_v)\right] \quad (9a)$$

$$\frac{\partial S(t, x_n, y_v)}{\partial t} = S(t\,; x_m, y_v)\left[G - hS(t; x_{n+1}, y_v)\right] \quad (9b)$$

Y un par similar de ecuaciones diferenciales parciales se pueden establecer también para la dirección y. En la ecuación (9) G denota la tasa de proliferación espacial de EMI y h es un coeficiente local que pondera el nuevo acoplamiento EMI percibido del nodo (m + 1)-ésimo o (n + 1)-ésimo debido a la dinámica de proliferación. Dichas ecuaciones diferenciales se refieren a modelos de crecimiento logístico para la evolución espacio-temporal de los niveles de susceptibilidad de las EMI inducidas en los nodos considerados. Las soluciones pertinentes toman un formato sigmoideo. Esto es, los niveles de susceptibilidad denotan implícitamente las probabilidades correspondientes de EMI predominante en los nodos a lo largo de la cuadrícula; y, pueden describirse como soluciones sigmoideas de la ecuación (9) como sigue [17][22, 23].

$$p\left(x_m, y_v\right)_{\Omega_1} = \frac{1}{2}\left[1 + \tanh\left(\frac{S_m^0 + S_n^{(1-0)}}{2}\right)\right] \quad (10a)$$

$$p\left(x_n, y_v\right)_{\Omega_2} = \frac{1}{2}\left[1 + \tanh\left(\frac{S_n^{(1-0)} + S_m^0}{2}\right)\right] \quad (10b)$$

donde θ es la fracción igual al cociente de la población de nodos parcial en Ω1 respecto del total de nodos en el marco entero de Ω1 y Ω2; es decir, θ = (Número de nodos en Ω1/ Número total de nodos en Ω1 y Ω2). Puede llegarse a estas nociones y resultados siguiendo la teoría probabilística de incertidumbre aplicada a la invasión aleatoria de la proliferación de diafonía en los dominios de interés.

La idea general es la siguiente: la proporción de las influencias de la EMI inducida neta en las regiones Ω1 y Ω2 puede deducirse en base a la incertidumbre estadística del acoplamiento EM en las pistas víctima debido al tránsito de señales de la pista agresora. Dado que el número total finito de nodos en el marco completo de Ω1 y Ω2 es μT y las víctimas son (μ1, μ 2, μ3 ... etc.) con distintos niveles de susceptibilidad 1, 2, 3,... etc., el grado estadístico resultante de incertidumbre (θ) de acoplamiento EM en Ω1 y Ω2 puede expresarse en términos de las consideraciones de entropía asociada (ζ) expresadas en forma de Bernoulli de esta forma [24]:

En cuanto a Ω1, la correspondiente ζ1 a lo largo de la dirección x puede especificarse mediante entropía funcional como sigue:

Para la región Ω1,

$$5_1 = \frac{1}{\mu_T} \ln\left[\frac{\mu_T!}{\mu_1!\mu_2!\ldots\mu_M!}\right] \qquad (11a)$$

Igualmente, para la región Ω2,

$$5_2 = \frac{1}{\mu_T} \ln\left[\frac{\mu_T!}{\mu_1!\mu_2!\ldots\mu_N!}\right] \qquad (11b)$$

Por lo tanto, θ correspondería a la relación ζ1/ζ2 de la incertidumbre relativa (de las influencias EMI) asociada en las regiones Ω1 y Ω2; y, ζ1/ζ2 se aproxima a, θ = (Número de nodos en Ω1/Número total de nodos en Ω1 y Ω2). De la misma manera, en cuanto a la aleatoriedad del layout de pistas, se pueden atribuir los coeficientes (normalizados, 0 a 1) RN y RF a la paradiafonía y telediafonía en la v-ésima víctima de Ω1 y Ω2 respectivamente, de forma consistente con las relaciones de la ecuación (10):

$$R_N(v) = \frac{1}{2}\left[1 + \tanh\left(\frac{S^0_{m=1} + \sum_n S^{(1-0)}_n}{2}\right)\right]_{\Omega_1} \qquad (12a)$$

$$R_F(v) = \frac{1}{2}\left[1 + \tanh\left(\frac{\sum_m S^{(1-0)}_m + S^0_{n=N}}{2}\right)\right]_{\Omega_2} \qquad (12b)$$

El concepto de deducción de la paradiafonía y la telediafonía especificado por la ecuación (12) a partir de atributos probabilísticos de la susceptibilidad de diafonía en los nodos de interés, implica lo siguiente: el aspecto funcional logístico de la ecuación (12) sugiere que la penetración de la diafonía a lo largo de los nodos de una pista víctima se incrementará (o reducirá) al mismo tiempo que el nivel de susceptibilidad de acoplamiento debido a los campos E y H en la víctima (que emanan del agresor) se incremente o reduzca. Además, la influencia total de la susceptibilidad, con sus implicaciones estadísticas, en Ω1 y Ω2 resulta de lasuperposición de tales influencias en los nodos {m} y {n} de Ω1 y Ω2 respectivamente. Como se comentó anteriormente, en la perspectiva clásica de estimaciones de EMI, el alcance de la susceptibilidad EMI total viene determinada por el acoplamiento EM a través de [C] y [L] deducido a partir de un marco determinista en términos de relaciones de impedancia tensión-corriente (desde la perspectiva de Kirchhoff). En cambio, el presente estudio sigue los atributos estadísticos asociados dictados por las perturbaciones aleatorias de los valores en las matrices [ΔE] y [ΔH] correspondientes a los nodos víctima de interés. Como mencionado anteriormente, tal aleatoriedad viene en buena medida impuesta por los aspectos estocásticos del layout geométrico debido al trazado aleatorio y/o el espacio geométrico entre el agresor AA' y la víctima bb', ilustrado por ejemplo en la Fig. 3. Cuando el acoplamiento interpista es visto en términos de componentes de campo EM, puede cuantificarse mediante el factor F deducido a partir de entidades relacionadas con E y H, y sus valores perturbados relativos (causados por la aleatoriedad) a través del área de ensayo. Es decir, se supone que la invasión de componentes de campo E y H, del agresor sobre las víctimas, produce unas correspondientes perturbaciones aleatorias de acoplamiento, observadas a través de los valores diferenciales de las componentes [ΔE] y [ΔH]; y, el resultado sería los parámetros de diafonía en forma de los valores probabilísticos especificados en la ecuación (12).

Por lo tanto, considerando la transferencia de señales a través de las pistas (colaborando al acoplamiento diafónico indeseado), puede entenderse en términos de componentes de campo EM relativas (especificadas implícitamente a través de F), de línea a línea (empezando en la línea agresora), a lo largo del conjunto de pistas víctima, {v = 1, 2, …}. Es más, en términos de entidades relacionadas con E y H, se pueden prescribir valores F relevantes usando los parámetros geométricos ilustrados en la Fig. 12.

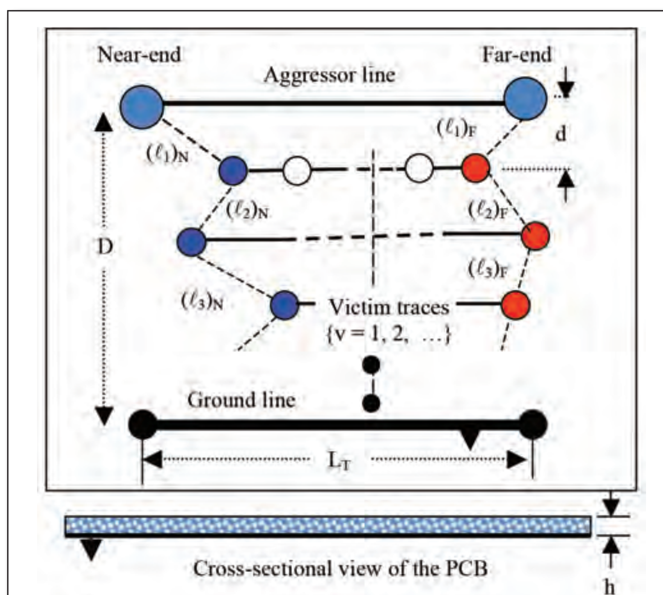

FIGURA 12: Parámetros geométricos de las pistas y valores de distancia asociados a la separación de los nodos, $(\ell_{v=1,2,\ldots})$N y $(\ell_{v=1,2,\ldots})$F relativos al conjunto de víctimas {v = 1, 2,...} experimentando paradiafonía y telediafonía respectivamente.

$$(R_N)_{v=1,2,..} = \left[[\text{illegible}]^2 / [\text{illegible}] + [\text{illegible}_N]^2 \times [\text{illegible}] \right] \left[\frac{v_s}{v_N x(t_r/2t_s)} \right]$$

(13a)

$$(R_F)_{v=1,2,..} = \left[[\text{illegible}]^2 / [\text{illegible}] + [\text{illegible}_F]^2 \times [\text{illegible}] \right] \left[\frac{v_s}{v_N x(t_r/2t_s)} \right]$$

(13b)

En referencia a las entidades geométricas de la Fig. 12, los coeficientes de campo EM inducidos (0 a 1) en la v-ésima pista víctima, dependerán de las dimensiones de las pistas y del PCB. Además, las componentes de campo penetrantes (con tres grados de libertad dimensional) se atenuarán con un aumento de la distancia de la pista víctima al agresor. Así mismo, se pueden prescribir [ ] los siguientes coeficientes, dependientes del campo EM, para evaluaciones de paradiafonía y telediafonía respectivamente (Fig. 12):
donde ts representa el tiempo de estabilización de la señal pulsada. Que es aproximadamente igual a (de 2 a 3) x (tiempo de subida del pulso, tr). Además, v_N representa una tensión de referencia igual a 1 voltio y v_S es el nivel de señal aplicado al inicio de la pista agresora.

Adicionalmente, la telediafonía se ve también influida por el retardo de propagación debido a la distancia finita desde la fuente al nodo terminal a lo largo de la línea agresora (de longitud L_T m). Los correspondientes coeficientes de ponderación para la telediafonía se pueden expresar como:

$$T_F = 1/\{1+[t_s(=3t_r)\times J\ /L_r]\} \qquad (14)$$

Además, ϑ ilustra la velocidad del tránsito de pulsos en la pista y se puede especificar, a partir de conceptos de línea de transmisión, como prácticamente igual ac/(εr)1/2, donde c (= 3 × 10^8 m/s) representa la velocidad de propagación de una onda EM en el vacío y εr es la constante dieléctrica del material del substrato del PCB. Entonces, las expresiones finales de paradiafonía y telediafonía en la v-ésima víctima son, respectivamente:

$$(NEXT)_V = (R_N) \text{ x } (F_N)_V \qquad (15a)$$

y

$$(FEXT)_V = (R_F)_V \text{ x } (F_F)_V \text{ x } T_F \qquad (15b)$$

VIII. RESULTADOS CALCULADOS, MEDIDOS Y OBSERVACIONES DEDUCTIVAS

Para verificar la eficacia del análisis presentado y las formulaciones predictivas derivadas para la paradiafonía y telediafonía del PCB de ensayo en discusión, se usa un PCB de ensayo como se ilustra en las Figs. 13a y 13b, y la línea agresora marcada se excita con una señal pulsante a dos frecuencias de ensayo, 40 MHz y 80 MHz. Tanto la agresora como las víctimas se terminan con una impedancia de Ro = 50 ohm, siendo la impedancia de la fuente (RS) también de 50 ohm. Con una señal de tensión conocida vs(t), a 40 u 80 MHz, aplicada en el nodo fuente de la agresora, se miden las tensiones (inducidas) de paradiafonía y telediafonía, llamadas (uN)v y (uF)v respectivamente, con un osciloscopio de banda ancha. Los valores correspondientes de paradiafonía y telediafonía en las víctimas v = 1, 2, ..., 8 se determinan respectivamente como: $(u_N)v/v_S$ y $(u_F)v/v_S$.

Además, se realizan los cálculos pertinentes con los valores de paradiafonía y telediafonía dados por la ecuación (15) usando los detalles de la placa y las pistas. En la Tabla 1 se presentan datos calculados y valores medidos relevantes sobre la paradiafonía y telediafonía observadas en el conjunto de pistas víctima (indexadas como v = 1, 2,..., 8) de la Fig. 12. Estos detalles se ilustran también en las Figs. 14a y 14b con estimaciones estadísticas de límite superior (UB, upperbound) e inferior (LB, lowerbound). Estos límites se corresponden con los extremos que definen la barra de error en las entidades aleatorias estimadas (ilustrando los valores de paradiafonía y telediafonía en cuestión).

Los valores de UB y LB se obtienen de reemplazar la función tanh(.) de la ecuación (12) por Lq(.), donde Lq(.) denota la función de Langevin-Bernoulli resultante explícitamente de la siguiente expresión: Lq(z) = (1 + 1/2q) × coth[(1 + 1/2q)z] – (1/2q) × coth[(1/2q) z]. El parámetro q representa la función de desorden estadístico [22]. Es decir, cuando q = 0.5, se refiere a la condición de desorden estadístico correspondiente al límite superior en la aleatoriedad de las estimaciones; y cuando q = ∞, se refiere a un estado de total desorden que representa el límite inferior de la estimación. El concepto de estimar los valores de limite superior e inferior en cuanto a las estimaciones estadisticas es descrito en [23] por uno de los autores.

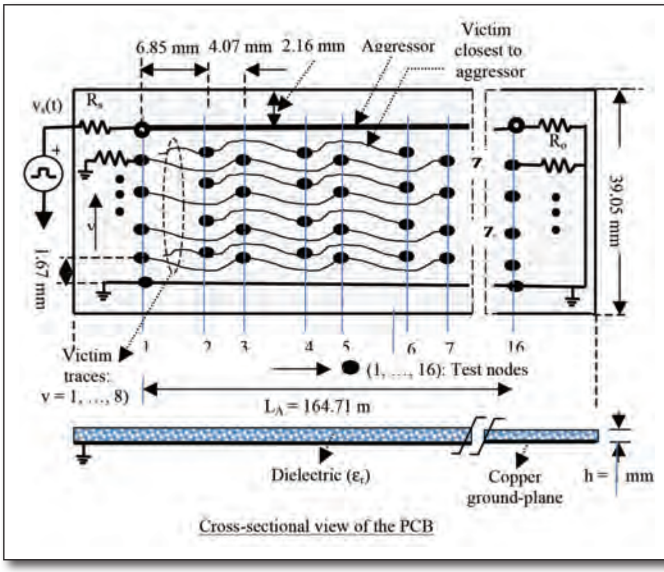

FIGURA 13a: PCB de ensayo con la agresora y un conjunto de ocho (8) pistas víctima. Las pistas están adaptadas con una impedancia R o = 50 ohm. La impedancia de la fuente R s es también de 50 ohm. Cada pista tiene 16 nodos (incluyendo los nodos de paradiafonía y telediafonía situados en las terminaciones inicial y final respecto de la fuente).

FIGURA 13b: El PCB usado en los estudios experimentales.

De los resultados obtenidos puede deducirse lo siguiente:

• En lugar del método tradicional de uso de los parámetros LC para la evaluación de la paradiafonía y telediafonía en un PCB soportando pistas multiples para el transporte de pulsos de alta velosidad, se propone aqui una técnica alternativa implícita basada en la evaluación del acoplamiento interpista causado por las componentes de campo E y H de la EMI involucrada.

• El método propuesto es extensivo incluyendo los aspectos estadísticos de la alta densidad de pistas dispuestas mediante trazados aleatorios en el PCB. Esta configuración de pistas es común en las secciones de banda base de los dispositivos inalámbricos portátiles modernos, ha($X_{m = 1, 2, \ldots, M}$, $Y_{v = 1, 2,\ldots}$).

• Considerando tres atributos atributos del fonómeno EMI asociado, en concreto, (i) el campo EM, (ii) los aspectos estadisticos de los elementos fiscios del PCB y (iii) los aspectos de retardo de tránsinto de la propagación de los pulsos de las señales en las pistas, se obsteinen un par de algoritmos en forma cerrada (ecuaciones 15(a) y 15(b)) para deducir valores aproximados de paradiafonía y telediafonía en un PCB de ensayo. Usando los detalles y datos necesarios pueden realizarse cálculos relevantes de paradiafonía y telediafonía con poco esfuerzo de cálculo. Se demuestra su viabilidad en referenciaa un PCB de ensayo.

• Se verifica la eficacia de los algoritmos desarrollados validando los resultados de los cálculos con datos medidos en un PCB de ensayo. Los resultados presentados en la Tabla 1 y en las Figs. 14(a) y 14(b) indican, por tanto, que el procedimiento de estimación de paradiafonía y telediafonía propuesto en este estudio arroja resultados favorables (especificados entre los límites vinculantes superior e inferior) cercanos a los datos medidos.

• La propuesta descrita es un motivado esfuerzo de aliviar la situación actual de falta de un método extensivo para determinar los coeficientes de paradiafonía y telediafonía relacionados con el PCB de ensayo descrito, infestado con un layout aleatorio de pistas. Es decir, con la llegada de PCBs que requieren una alta densidad de pistas con caminos de tránsito de señales aleatorios y que además tienen que soportar pulsos de alta velocidad, de categoría DDA (garantizado en los dispositivos portátiles inalámbricos modernos), tener que estimar el acoplamiento EMI interpista y la diafonía asociada es un hecho; no obstante, no parece que esté en boga ninguna estrategia teórica y/o computacional clara (que los autores sepan). Es por ello que se ofrece este estudio.

El estudio realizado proporciona también algunas observaciones concluyentes en cuanto a la infección de diafonía y EMI en la clase de PCB de ensayo descrito. Normalmente se puede tener en cuenta lo siguiente:

• Los valores de diafonía (paradiafonía y/o telediafonía) no sólo se definen por la tradicionalproximidad mutua conocida entre las víctimas (y con la agresora) sino también por el número de puntos de giro en cada pista. Tales puntos representan discontinuidades en la línea de transmisión, con las correspondientes distribuciones distorsionadas de campo E y H acoplándose en la líneas cercanas.

• La pista víctima más cercana a la agresora puede sufrir efectos de diafonía de forma intensa.

• No solo la geometría de las rutas de las pistas, sino también la disposición mutua de los nodos puntos de giro en las pistas adyacentes establecerán los niveles de paradiafonía y telediafonía (Figs. 3 y 7).

• El efecto neto de la diafonía viene dado por: (i) la penetrción de campos E y H a través de las pistas aleatorias; (ii) la aleatoriedad del *layout* géometrico de las pistas y (iii) las

v_s volts (RMS)	f MHz	v	Measured values of crosstalk at the victim trace: Index - v		Computed data: Estimated crosstalk - UB and LB values at the victim trace: Index - v			
			NEXT	FEXT	$(NEXT)_v$		$(FEXT)_v$	
					UB	LB	UB	LB
2.161	40		Measured data at the trace: v = 1		Computed data at the trace: v = 1 taking $t_s \approx 2t_r$			
			$(u_N)_1/v_s$ = 0.073	$(u_F)_1/v_s$ = 0.090	0.09	0.08	0.09	0.07
			Normalized values of NEXT and FEXT with respect to measured data at v = 1					
		1	1.00	1.00	1.00	1.00	1.00	1.00
		2	0.65	0.61	0.47	0.48	0.47	0.48
		3	0.48	0.45	0.30	0.31	0.30	0.31
		4	0.32	0.38	0.22	0.23	0.22	0.23
		5	0.35	0.34	0.17	0.18	0.17	0.18
		6	0.22	0.24	0.14	0.15	0.34	
		7	0.32	0.24	0.12	0.13	0.12	
		8	0.30	0.32	0.11	0.12	0.11	0.15
1.007	80		Measured data at v = 1		Computed data at the trace: v = 1 taking $t_s \approx 2t_r$			
			$(u_N)_1/v_s$ = 0.314	$(u_N)_1/v_s$ = 0.321	0.25	0.19	0.24	0.18
			Normalized values of NEXT and FEXT with respect to measured data at v = 1					
		1	1.00	1.00	1.00	1.00	1.00	1.00
		2	0.55	0.43	0.46	0.46	0.46	0.46
		3	0.22	0.22	0.28	0.27	0.28	0.29
		4	0.19	0.19	0.20	0.21	0.21	0.21
		5	0.12	0.07	0.15	0.16	0.15	0.17
		6	0.72	0.05	0.12	0.13	0.12	0.13
		7	0.03	0.04	0.09	0.11	0.01	0.11
		8	0.04	0.03	0.08	0.10	0.01	0.01

TABLA 1: Valores medidos y calculados de paradiafonía y telediafonía referentes al PCB de ensayo que muestra la Fig. 13.

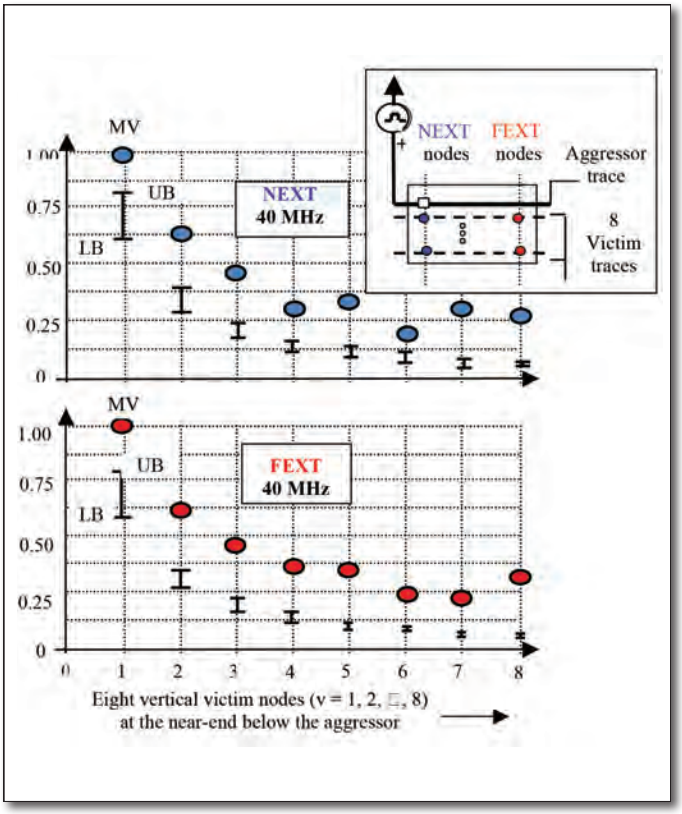

FIGURA 14a: Valores medidos y calculados de paradiafonía y telediafonía del PCB de ensayo a 40 MHz. (MV: Valores medidos; UB y LB representan los valores límite superior en inferior respectivamente de los datos calculados).

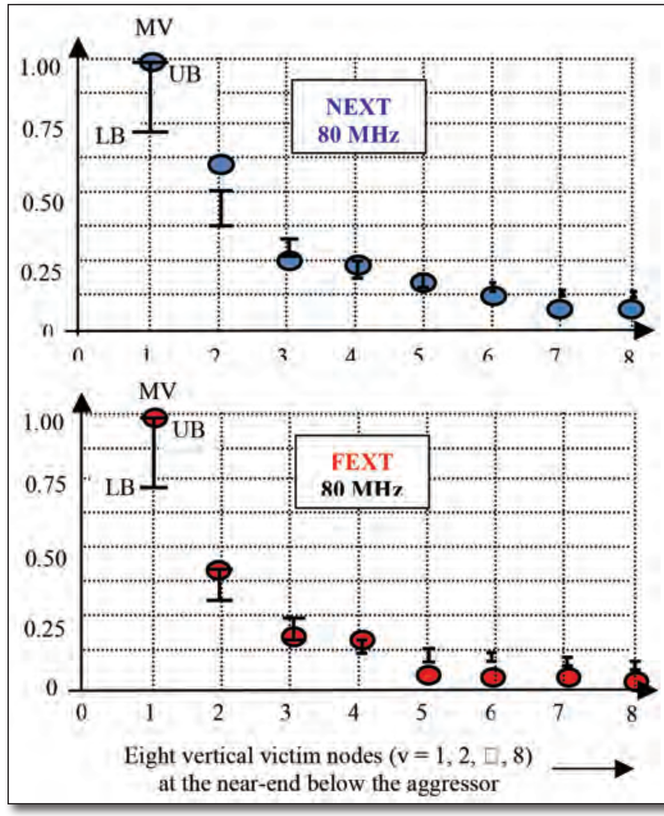

FIGURA 13a: Valores medidos y calculados de paradiafonía y telediafonía del PCB de ensayo a 80 MHz. (MV: Valores medidos; UB y LB representan los valores límite superior en inferior respectivamente de los datos calculados).

caracteristicas del pulso de las señales.

Si considereamos los estudios sobre aspectos practicos en el diseño de PCBs de alta velocidad [2, 4], los objectivos culminan en la deducción de soluciones tangibles para la supresión de EMI y en la formulación de consideraciones de compatibilidad EM (EMC) para minimizar la diafonía [6-9, 12, 15, 16, 25, 26].

Basado en las observaciones del presente estudio en relación a la diafonía percibida en el PCB de ensayo (con un grupo de pistas dispuestas aleatoriamente), se sugiere lo siguiente en vistas a posibles esfuerzos de mitigación de diafonía:

• Diseñar los PCB con pistas seperadas de forma óptima.

• Minimizar el numero de nodos puntos de giro en las pistas.

• Si una pista tiene que cambiar inevitablemente de dirección, hacerlo mediante un giro suave en vez de abrupto.

Los esfuerzo de mitigación de la diafonía deberian realizarse al mismo tiempo que la minimización del TIE elabora en [17].

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Conozca las Generaciones de los Sistemas Móviles

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La evolución tecnológica de las redes celulares nos ofrece conexiones de datos cada vez más rápidas, y el tiempo de respuesta para nuestras peticiones en relación con los servicios se está reduciendo drásticamente haciendo nuestra experiencia de usuario más veloz y eficiente. Tenemos actualmente acceso de altísima calidad para un abanico de contenidos tan variados que nunca hemos visto algo parecido antes. Además, con la evolución de los estándares internacionales, podemos testificar la apariencia de nuevas soluciones comerciales cada vez más avanzadas. Sin embargo, frecuentemente en este entorno tan dinámico, la cantidad de diferentes términos técnicos nos confunden, y ya que el significado real de los mensajes de los operadores, vendedores del equipo y proveedores de servicios se suelen perder tras la diversidad de términos. Parece que uno de los temas más confusos es la definición de las generaciones de los sistemas celulares, así que me he propuesto resolver el misterio y dar a conocer las respuestas al respecto.

OVERVIEW

The evolving mobile communications technologies provide us with vastly increasing data rates, faster response times and increasingly fluent means to access more contents than ever in the history of telecommunications. Along with the development of the standards, the commercial solutions keep appearing for our selection. Often in this highly dynamic environment, the vast amount of technical and marketing terms gives us challenges in capturing the real meaning of the messages that operators, device vendors and service providers want to give us. One of the most confusing topics in this field is the definition of the "mobile communications generations," so let's solve the mystery in this article. To read this article in English, go to our website www.interferencetechnology.com.

INTRODUCCIÓN

ANTES DE APARECER LA PRIMERA GENERACIÓN YA SE VISLUMBRABA EL POTENCIAL La fase inicial de las redes móviles en los 1980 nos ofreció completamente nuevas maneras de recibir y realizar llamadas de voz en diferentes lugares sin estar prisionero de un lugar fijo, dando un salto en la comunicación. En realidad, ya mucho antes que empezara esta época, existían algunos sistemas inalámbricos con bastante potencial pero que ya se han olvidado en la historia. Uno de ellos era el sistema automático MTA (Mobile Telephony System, versión A) que fue probado en Estocolmo y Gotemburgo, Suecia, en 1956. El equipo de usuarios era adecuado sólo para ser instalado en coche ya que era relativamente pesado y voluminoso. Al final, esta iniciativa era tan avanzada en teoría, que todavía era imposible realizarla

en la práctica debido a los componentes electrónicos aún no desarrollados en su totalidad – pero sin embargo la idea merece toda la admiración por haber demostrado tan concretamente las ventajas de los sistemas que ofrecía la telefonía móvil. Otro ejemplo fue en el año 1971, cuando la tecnología ya estaba más sólida y lista para la iniciación del sistema ARP (Auto Radio Phone) la cual empezó primeramente a comercializarse en Finlandia. Este sistema funcionó mediante la banda de frecuencia 160 MHz confiablemente hasta el año 2000, dando servicio a los clientes especialmente en áreas remotas durante 3 décadas completas. Otros sistemas aparecieron y desaparecieron especialmente en 450 MHz. Todas estas redes históricas se pueden referir como generación cero, con un número de usuarios relativamente bajo, y con limitaciones importantes en portabilidad del equipo.

LA ÉPOCA ANALÓGICA INICIABA CON COMUNICACIONES MÓVILES

La evolución analógica inició con fuerza en los años 1980 la cual fue la representante de la primera generación de las redes celulares. Estas contenían por primera vez en la historia de las telecomunicaciones métodos automatizados para establecer llamadas sin necesidad de conocer la localización del usuario. Algunos ejemplos de las redes 1G eran AMPS (Advanced Mobile Phone System) en América y TACS (Total Access Communications System) en Reino Unido. A la vez, había otros sistemas en varios rincones del mundo de los cuales uno de los más internacionales era NMT 450 (Nordic Mobile Telephone) y su versión evolucionada, NMT 900.

Las redes de 1G demostraron concretamente los beneficios de comunicaciones independientemente del lugar y tiempo. Como resultado, esta evolución ha dado el inicio al entorno actual en donde las redes inalámbricas dominan las comunicaciones. Investigando la historia, la popularidad de las llamadas móviles 1G sorprendió completamente a los operadores, vendedores del equipo y reguladores de frecuencia especialmente al final de los 1980 y en principio de los 1990. Esta incredulidad para entender el crecimiento tan drástico causó a veces demoras en el despliegue de estaciones base, problemas en la oferta de capacidad, e incluso bloqueos de llamadas. Además, la bajada de los precios de las llamadas así como el coste de los equipos móviles cada vez más accesibles generó tanta demanda que los modelos de negocio de hoy en día no se pueden comparar con el éxito de los operadores y vendedores del equipo de aquella época. Todavía el número de usuarios de telefonía móvil está creciendo, como nos demuestran las estadísticas de ITU (International Telecommunications Union) en la figura 1. Además, podemos asumir que el crecimiento de equipos relacionados con IoT (Internet of Things), es decir, la comunicación entre las máquinas, va a aumentar el número de suscripciones drásticamente en los años que vienen ya que la versatilidad de los equipos nos sorprende cada vez.

LA ÉPOCA DIGITAL ABRIÓ LAS PUERTAS PARA EL ÉXITO TOTAL

La capacidad ofertada de los sistemas 1G fue al final muy limitada en comparación con la demanda. En otro lado, las redes 1G eran muy locales, con la excepción de algunos sistemas como NMT que funcionó entre los mismos usuarios que pudieron disfrutar los servicios de telefonía móvil mientras viajaron en los países nórdicos y en Suiza. De todas formas, era visible la necesidad del uso internacional de llamadas la cual estaba todavía por venir. Estas eran algunas de las razones más importantes para desarrollar sistemas actualizados que al final fueron diseñados basándose en tecnologías digitales capaces de proveer los servicios más avanzados y de cubrir la necesidad internacional de comunicación móvil. Estos sistemas representan la segunda generación, y entre ellos se encuentra, p.ej. el sistema CDMA de IS-95 en América. Sin duda alguna, observando el número de los usuarios, el sistema GSM (Global System for Mobile Communications) es el rey de las redes 2G hasta hoy en día.

Además, GSM nos ofreció la primera vez el concepto de separación del equipo de usuario (teléfono móvil mismo) y la tarjeta inteligente (es decir tarjeta SIM, o Subscriber Identity Module) para guardar los datos de usuario, p.ej. la identificación de suscripción. SIM contiene los datos necesarios de manera segura, y se puede cambiar la tarjeta fácilmente entre los teléfonos sin necesidad de dar de baja y de alta la suscripción. Las redes 2G también ofrecen varios servicios novedosos de los cuales el que más éxito ha logrado en todos los tiempos es el servicio SMS (Short Message Service), útil hasta hoy en día a pesar de varios servicios rivales.

La transferencia de datos originales de los sistemas 2G estaba basado en la conmutación de cirquitos que ofreció una alternativa inalámbrica para los módems de redes fijas de aquella época de los 90. Los estándares de servicio de paquete de datos (GPRS, General Packet Radio Service) mejoraban aún más la experiencia del usuario ofreciendo conectividad IP para los usuarios de GSM desde inicios de los 2000. Esta fase se puede interpretar como la iniciación de la época de ¨todo-sobre-IP" a través de los sistemas de telefonía móvil. El desarrollo de los servicios IP de GSM ha sido realmente impresionante. Desde los primeros valores de paquetes de datos de apenas 10 kb/s, la conectividad de datos IP actuales es capaz de ofrecer 500 kb/s hasta 2 Mb/s con funcionalidades novedosas como DLDC (Downlink Dual Carrier) y EDGE avanzado (Enhanced Data rates for Global Evolution). Las técnicas de GSM en esta fase avanzada se ofrecen bajo el término "3GSM" que forma el sistema de multimedia específicamente basado en GSM.

3G INICIÓ LA ÉPOCA DE MULTIMEDIA MÓVIL

A pesar de todos los avances de 2G desde su primer despliegue en 1991 hasta ahora, sus limitaciones han sido bien entendidas. Como próximo paso para avanzar, las organizaciones de estandarización como ETSI, 3GPP y 3GPP2 empezaron a desarrollar la nueva generación, 3G. Este trabajo cada vez más internacional dio resultado a los sistemas como cdma2000 en América y UMTS (Universal Mobile Telecommunications System) en Europa, en los principios de los 2000. Una de las ventajas de la generación 3G es la velocidad de datos mucho más alta, p.ej. en 1x-EV-DV de cdma2000, y HSPA (High Speed Packet Access) de

UMTS. La definición del término 3G proviene de ITU (International Telecommunications Union) que ha aceptado los sistemas comerciales de 3G oficialmente bajo el abanico de tecnologías compatibles con los requisitos de IMT-2000 (International Mobile Telecommunications). UMTS con algunas variaciones así como cdma2000 cumplen estos requisitos además de otros sistemas de 3G que son EDGE, DECT y WiMAX. Desde entonces, datos aún más rápidos han sido demandados y proveídos. La razón principal para diseñar los sistemas 3G fue por la necesidad de los operadores de ofrecer servicios de multimedia cada vez más avanzados. Desde la fase inicial de las redes 3G, su velocidad original de unos cientos de kb/s ha aumentado drásticamente, promediando hoy en día en rango de 20-40 Mb/s.

LA ÉPOCA 3G AVANZADA

Aunque en teoría fuera posible desarrollar las tecnologías anteriores como CDMA y GSM, nos encontramos con limitaciones importantes en cuanto a la rentabilidad tecno-económica. Por eso, es justificado enfocarse en la modernización de la última generación 3G que es capaz de utilizar más eficientemente el espectro de frecuencias como un resultado de avances de tecnologías de telecomunicaciones y rendimiento de procesadores. Hemos visto ya en práctica sistemas 3G mejorados, de los cuales LTE (Long Term Evolution) es actualmente lo más popular a nivel mundial siendo realidad desde los años 2011-12. LTE nos ofrece una utilización eficaz del espectro, y la velocidad de datos alcanza un nivel de cientos de Mb/s. Otro tramo de 3G evolucionado se llama WiMAX, aunque aún no ha sido exitoso en el mercado comercial en comparación con LTE.

LA GENERACIÓN 4G MEJORA… Y GENERA CONFUSIÓN

Hasta la aparición de las redes 3G iniciales, la terminología relacionada ha sido entendible para distinguir las generaciones. La definición de 3G está basada en los requisitos de ITU IMT-2000 distinguiéndola de manera entendible de las generaciones anteriores. Pero, parece que el término "4G" ha generado varias interpretaciones entre operadores y vendedores del equipo, entre otras entidades. ITU nos ofrece la definición más estricta de todas ya que acepta solamente dos sistemas en la categoría 4G, y esas son las versiones evolucionadas de LTE y WiMAX. Pensando lógicamente, la versión básica de LTE que se ha definido de parte de Release 8 de 3GPP nos da rendimiento que es sin duda relativamente cerca de los requisitos de ITU 4G, pero sin embargo LTE básica no puede cumplir con los requisitos tan estrictos ni en teoría. Por eso, el termino más representativo pudiera ser, p.ej. "sistema posterior de 3G", o "pre-4G". A veces, se ve usando el término "3.9G" que también es entendible. Vale mencionar que estos términos son prácticos pero que no se usan oficialmente en entorno de estandarización. Sin embargo, aunque LTE básico definido en Release 8 y 9 no cumple con los requisitos de 4G de ITU, varios operadores y vendedores del equipo están usándolo para todas las fases de LTE, incluso la inicial.

Entonces, relataré un poco la historia atrás de la definición de 4G. Todo esto dio inicio cuando ITU-R (la parte de radiocomunicaciones de ITU) empezó su estudio para evaluar los candidatos de sistemas 4G que pudieran cumplir con los requisitos del documento llamado "IMT-Advanced". Según su conclusión en octubre del 2010, sólo dos soluciones llegaron al final, que son "LTE-Advanced" (la versión avanzada de LTE), y "WirelessMAN-Advanced" (IEEE 802.16m, es decir, "WiMAX 2") como aparecen en la figura 3. Entonces, ITU-R reconoce hasta hoy en día sólo estos dos sistemas 4G mientras la interpretación de la industria parece ser algo más liberal. Probablemente la industria ya usaba el término 4G públicamente mientras ITU-R todavía trabajaba sobre esta evaluación, o quizá la industria simplemente no esté de acuerdo con el resultado. De todas formas, investigando los detalles de la documentación de IMT-Advanced, está claro que la versión inicial de LTE no es capaz de cumplir con los valores de rendimiento, como el de 1 Gb/s en la recepción del servicio móvil estático. Afortunadamente, los operadores están construyendo LTE-A, es decir, Release 10 de 3GPP de manera acelerada siendo de esta manera compatibles con 4G de ITU.

¿PERO DÓNDE ESTÁ 5G?

A pesar de varios pilotos para evaluar las velocidades de datos extremas relativamente pronto, los sistemas 5G estandarizados están aún en fase de concepto y bajo la lluvia de ideas mientras la meta es empezar la construcción de las primeras redes interoperables posiblemente a partir del año 2020. Por eso, necesitamos tener paciencia por unos años más para poder experimentar el rendimiento concreto de 5G – que podrá ofrecernos velocidades de datos 10-50 veces más rápidas en comparación con las de 4G.

CONCLUSIÓN

La industria ha típicamente interpretado LTE siendo como representante de generación 4G desde la fase inicial. La explicación puede ser que el rendimiento de LTE está de todas formas relativamente cerca de los requisitos 4G al menos en comparación con el rendimiento más modesto de las redes UMTS/HSPA. Otra razón es el tiempo que toma la realización de nuevos estándares, y la industria ha obviamente querido diferenciar LTE ya desde principio.

Sin importar la definición de las generaciones en diferentes fases de LTE – sea el ultimo paso de 3G o paso preliminar de 4G, la realidad es que LTE está abriendo puertas para una época de comunicación móvil completamente renovada, y que eventualmente proveerá las velocidades de datos cumpliendo con los requisitos de ITU-R 4G. Varios operadores ya están en la fase "Release 10" de LTE-A, añadiendo poco a poco las opciones que sirven como elementos necesarios para cumplir al final con los requisitos de ITU 4G. Aunque no necesariamente todavía podemos ver las velocidades en rango de Gb/s por la falta del último toque en el soporte de las redes y terminales, estamos firmemente en el camino. Parece que la otra variante de 4G, WiMAX, tiene retos importantes en lograr su éxito, así que LTE puede representar por fin un sistema verdaderamente global y único.

Cabe mencionar que la experiencia 4G es una combinación de tecnologías involucradas tales como antenas evolucionadas (MIMO), agregación de frecuencias (CA), y nuevas categorías de terminales. Para que las redes y nuevos terminales soporten estas funcionalidades, tomará su tiempo y así nosotros los consumidores veremos el rendimiento superior de manera gradual. Por mientras, en realidad no es tan importante sea lo que sea la tecnología atrás de los servicios ya que la experiencia del usuario se está mejorando. Así que, queridos lectores, ¡disfrutemos las comunicaciones más avanzadas de todos los tiempos sin preocuparnos demasiado de la terminología!

Generación	Definición
1G	Analógicas, primeras redes casi completamente automáticas dirigidas para los usuarios de llamadas móviles de voz. Durante la evolución se introdujo terminales móviles cada vez menos pesadas y voluminosas. Las redes 1G han desaparecido ya completamente.
2G	El diferenciador más importante es la funcionalidad completamente digital de 2G. Eso facilitó la adaptación de servicios basados en datos y señalización avanzada, como SMS de GSM. La generación 2G está todavía activa.
3G	La evolución de los estándares dio resultado los sistemas 3G diseñadas especialmente para multimedia. 3G ofrece velocidades superiores de datos en comparación con 2G. Basado en los requisitos de ITU para el rendimiento, las redes iniciales de LTE pertenecen todavía a 3G.
4G	ITU-R ha definido los requisitos para los sistemas 4G. Actualmente LTE-A y WirelessMAN-Advanced cumplen con estos requisitos. Con la competencia más agresivo que nunca, hay varias interpretaciones sobre la definición de 4G. Muchas veces, Release 8 de LTE ha sido interpretado como 4G, y en algunos casos incluso HSPA+ se considera pertenecer a 4G.
5G	Todavía en esta fase, 5G es solo un abanico de ideas en fase posterior de IMT avanzado para proveer datos considerablemente más rápidos. La meta de los primeros despliegues estandarizados está en 2020.

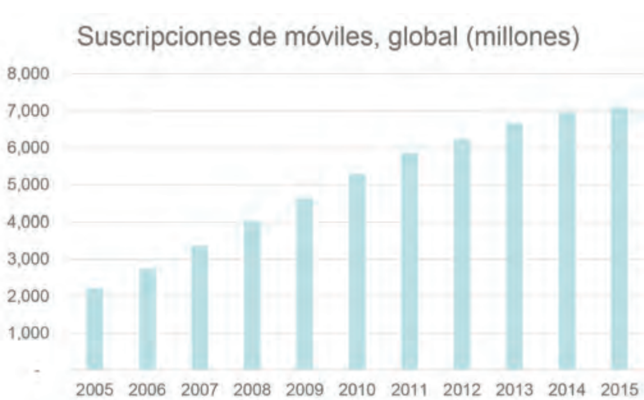

Figura 1 - La evolución global de suscripciones de sistemas móviles según las estadísticas de ITU.

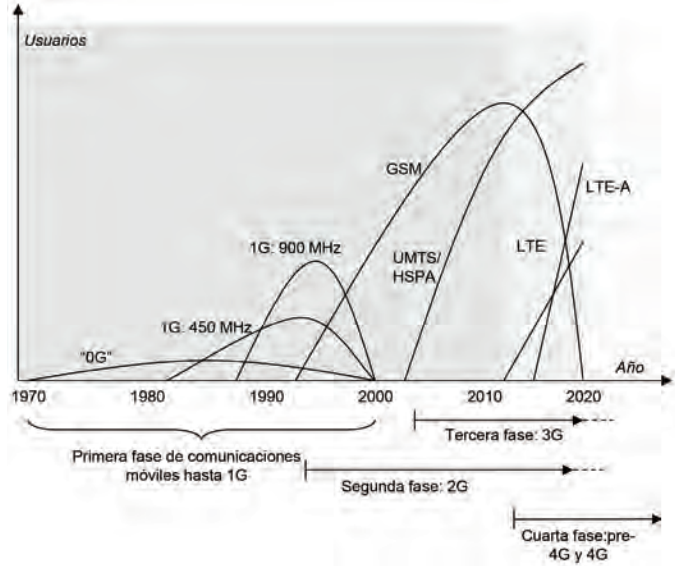

Figura 2 - Los mercados de telefonía móvil hasta LTE avanzado. Los sistemas 1G ya se han terminado. GSM ha dominado la época 2G y todavía es una base muy útil especialmente para servicio de llamadas de voz, y para reorganización de frecuencias para liberar eficientemente y gradualmente más espacio para los sistemas 3G y 4G.

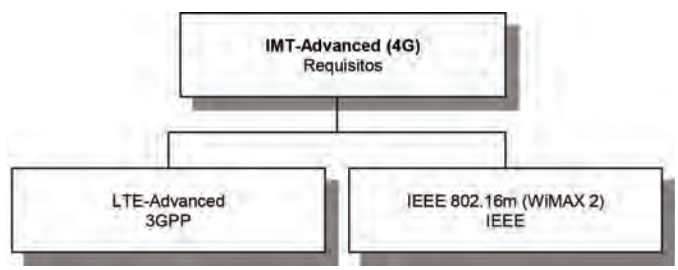

Figura 3 - Los sistemas 4G aprobados oficialmente por ITU-R.

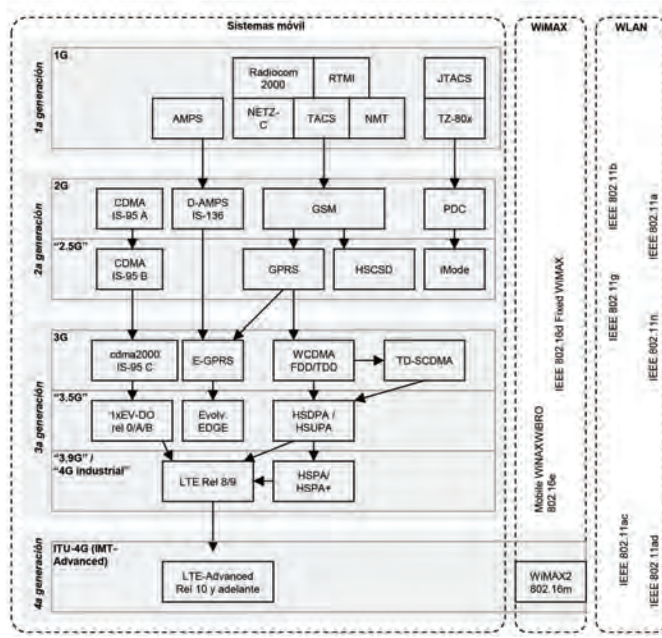

Figura 4 - Algunos sistemas comerciales de 1G, 2G, 3G y 4G. La época 4G significa básicamente la convergencia de sistemas inalámbricos de LAN y de móviles.

ABBREVIACIONES

AMPS	Advanced Mobile Phone System (1G)
cdma2000	Sistema 3G americano
D-AMPS	AMPS digital (2G)
EDGE	Enhanced Data Rates for Global Evolution, GPRS mejorado
E-GPRS	Enhanced GPRS, GPRS mejorado
GPRS	General Packet Radio Service of GSM
GSM	Global System for Mobile communications (2G)
HSPA	High Speed Packet Access, servicio de datos UMTS
IS-95	Red CDMA (2G)
JTACS	Japan Total Access Communications System (1G)
LTE	Long Term Evolution (pre-4G)
LTE-Advanced	Sistema 4G definido por 3GPP
Netz-C	Red 1G (Alemania, Portugal y África Sur)
NMT	Nordic Mobile Telephone (1G) en Países Nórdicos, Holanda, Suiza, Europa del Este, y Rusia
Radiocom 2000	1G network in France
RTMI	Radio Telefono Mobile Integrato (1G) en Italia
TACS	Total Access Communications System (1G) en Reino Unido
TZ-801/ 802/803	Red 1G en Japón (NTT)
UMTS	Universal Mobile Telecommunications System (3G)
W-CDMA	Wideband CDMA (UMTS)

FUENTES

The LTE/SAE Deployment Handbook, Wiley, 2011.
The Telecommunications Handbook: Engineering Guidelines for Fixed, Mobile and Satellite Systems, Wiley, 2015

SOBRE EL AUTOR

El autor de este artículo, Dr. Jyrki Penttinen, ha estado inmerso tanto en teoría como en práctica de manera profesional en todas las experiencias que expone en este artículo, desde la primera generación hasta la última. Actualmente trabaja para Giesecke & Devrient America, Inc. enfocándose en el área de seguridad móvil. Anteriormente, ha trabajado con operadores de telefonía móvil y proveedores del equipo en puestos de experto y dirigente en EE.UU., Finlandia, España y México, y como consultor independiente en Europa y América Latina. Sus áreas de interés han incluido GSM, UMTS, LTE y TV móvil, planificación, optimización, estandarización e investigación de redes radio y fijo. También imparte educación técnica y escribe publicaciones sobre telecomunicaciones. Es autor de varios libros, siendo los últimos *The Telecommunications Handbook* (Wiley 2015), *The LTE/SAE Deployment Handbook* (Wiley 2011) y *The DVB-H Handbook* (Wiley 2009) de los cuales se puede encontrar más información en www.tlt.fi.

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Zastosowanie Środowiska LabView do Automatycznej Weryfikacji Sygnałów Impulsowych Wykorzystywanych w Badaniach Kompatybilności Elektromagnetycznej

KRZYŚZTOF SIECZKAREK
ADAM MACKOWIAK
Instytut Logistyki i Magazynowania Poznań
Laboratorium Urządzeń Elektronicznych

OVERVIEW

The aim of this work was to create an application dedicated to the automatic verification of test equipment used in electromagnetic compatibility testing. In order to perform it the LabView programming environment was chosen – a versatile tool with a graphical programming language. This paper presents the normative requirements analysis, LabView environment outline and description of created software. To read this article in English, go to our website www.interferencetechnology.com.

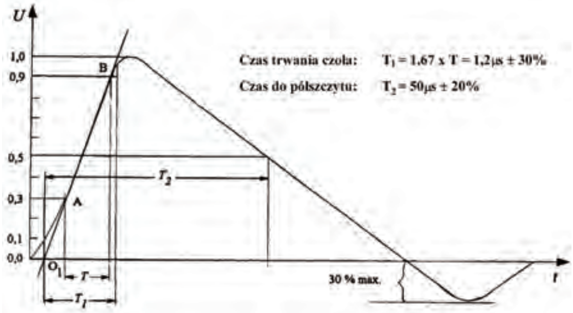
WSTęP

FUNKCJONOWANIE AKREDYTOWANEGO laboratorium wykonującego badania kompatybilności elektromagnetycznej wiąże się z koniecznością systematycznej weryfikacji aparatury pomiarowej. Ze względu na dużą ilość parametrów podlegających weryfikacji jest to proces czasochłonny i wymagający dobrej znajomości aparatury sprawdzającej (np. oscyloskopu cyfrowego) zarówno w zakresie jej obsługi jak i zabezpieczenia oraz dopasowania torów pomiarowych do przebiegów wysokonapięciowych. Powody te zdecydowały o stworzeniu takiego narzędzia do automatycznej weryfikacji aparatury probierczej, które minimalizowałoby udział personelu podczas sprawdzeń okresowych i jednocześnie znacznie skracało czas ich trwania.

WYMAGANIA NORMATYWNE

Generator udarów SURGE

Metody badań i pomiarów odporności na udary powodowane przez przepięcia łączeniowe i piorunowe stany przejściowe zawiera norma [1]. Norma ta określa również dokładne wymagania odnośnie aparatury pomiarowej oraz parametrów sygnałów probierczych. Generator dostarcza



Rys. 1. Kształt przebiegu napiecia obwodu otwartego wraz ze sposobem wyznaczania parametrów czasowych [1].

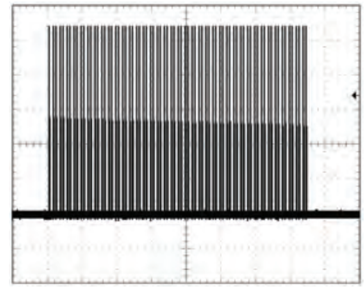
	Przebieg napięciowy	Przebieg prądowy
Amplituda	0,5 – 4 kV	0,25 – 2 kA
Czas narastania	1,2 μs	8 μs
Czas trwania (na poziomie 50 %)	50 μs	20 μs

Tabela 1. Parametry sygnałów probierczych wymaganych w badaniach odporności na udary.

Czas narastania	5 ns
Czas trwania impulsu	50 ns
Częstotliwość powtarzania impulsów	5 kHz albo 100 kHz
Czas trwania serii	15 ms albo 0,75 ms
Okres serii	300 ms
Napięcie	0,25; 0,5; 1; 2; 4 kV

Tabela 2. Parametry sygnałów probierczych wymaganych podczas weryfikacji generatora stanów przejściowych.

udar napięciowy 1,2/50 μs (w warunkach obwodu otwartego) oraz udar prądowy 8/20 μs w stanie zwarcia. Parametry te określone są jako czas narastania / czas trwania impulsu. Norma [1] przyjmuje ich definicje według normy IEC 469-1, a sposób ich wyznaczania pokazano na przykładzie udaru napięciowego na rysunku 1.



Rys. 3. Rzeczywisty widok pakietu impulsów BURST.

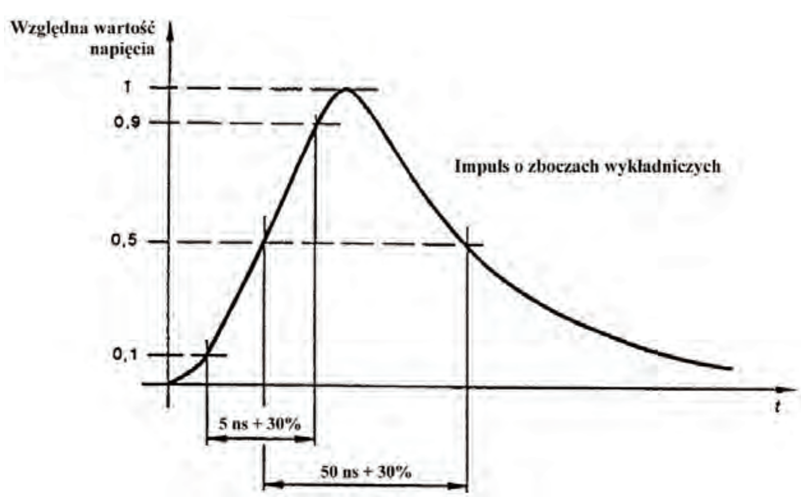
W tabeli 2 zawarto zestawienie wymagań dotyczących parametrów sygnałów probierczych stosowanych w badaniach odporności na udary.

Generator stanów przejściowych BURST

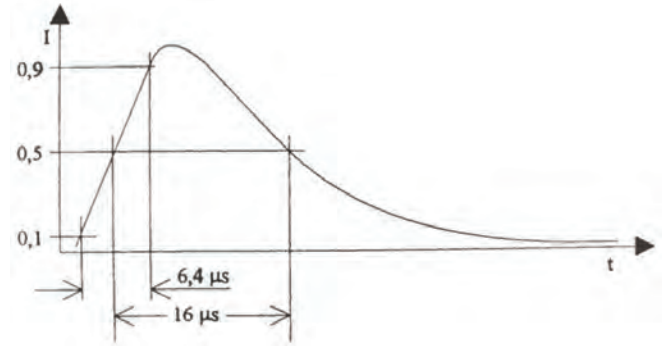
Wymagania w zakresie odporności oraz metod badań sprzętu elektronicznego i elektrycznego w odniesieniu do powtarzalnych, szybkich, elektrycznych stanów przejściowych zawarto w normie [2]. W normie tej zawarto również wymagania dotyczące generatorów pomiarowych oraz parametrów sygnałów probierczych. W celu weryfikacji sygnałów probierczych konieczne jest sprawdzenie czasu narastania, czasu trwania i częstotliwości powtarzania impulsów w odniesieniu do pojedynczej serii. Graficzną interpretację niektórych z powyższych parametrów pokazano na rysunku 2.

Na rysunku 3 pokazano rzeczywisty przebieg pakietu impulsów BURST zarejestrowany za pomocą oscyloskopu.

Procedura weryfikacyjna zawarta w normie [2] wprowadza ponadto konieczność sprawdzania częstotliwości powtarzania impulsów w zależności od wartości szczytowych napięcia wyjściowego. W tabeli 2 zawarto zestawienie wymagań dotyczących parametrów sygnałów probierczych stosowanych w badaniach odporności na serie szybkich elektrycznych stanów przejściowych.



Rys. 2. Kształt pojedynczego impulsu serii szybkich przebiegów przejściowych wraz ze sposobem wyznaczania.



Rys. 4. Kształt impulsu pradowego pola magnetycznego wraz ze sposobem wyznaczania parametrów czasowych [3].

Generator impulsowego pola magnetycznego

Metody badań i pomiarów odporności na impulsowe pole magnetyczne zawiera norma [3]. Norma ta określa również dokładne wymagania odnośnie aparatury pomiarowej oraz parametrów sygnałów probierczych. W celu weryfikacji generatora pomiarowego należy sprawdzić podstawowe parametry prądu wyjściowego, który płynie w dołączonej do generatora znormalizowanej cewce indukcyjnej. Konieczne jest sprawdzenie szczytowej wartości prądu wyjściowego oraz czasu narastania i czasu trwania impulsu. Graficzną interpretację powyższych parametrów pokazano na rysunku 4.

W tabeli 3 zawarto zestawienie wymagań dotyczących parametrów sygnałów probierczych stosowanych w badaniach odporności na impulsowe pole magnetyczne.

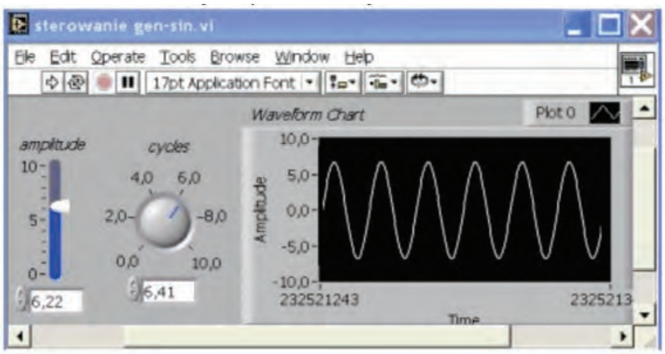
ŚRODOWISKO LABVIEW

LabVIEW (Laboratory Virtual Instrument Engineering Workbench) jest środowiskiem programistycznym opartym na graficznym interfejsie użytkownika (język G) [4]. W pełni wykorzystuje ono komunikację z urządzeniami poprzez porty GPIB, VXI, PXI, RS-232, RS-485, oraz urządzenia plug-in podłączane do komputera. Posiada on także wbudowane biblioteki do komunikacji za pośrednictwem sieci (TCP/IP) oraz kontrolki ActiveX. LabView przeznaczony jest, dzięki wykorzystaniu 32-bitowego kompilatora, do szybkiego zbierania, przetwarzania oraz przedstawiania danych pomiarowych.

Dzięki użyciu środowiska graficznego w łatwy sposób można stworzyć oprogramowanie przetwarzające dane

Current	0,25 – 2 kA
Rise time	6,4 µs
Impulse duration (50% value)	16 µs

Tabela 3. Parametry sygnałów probierczych wymaganych podczas weryfikacji generatora impulsowego pola magnetycznego. magnetycznego. magnetycznego.



Rys. 5. Przykładowa aplikacja stworzona w środowisku LabView.

Rys. 6. Diagram blokowy aplikacji pokazanej na rysunku 5.

Rys. 7. Konfiguracja układu do weryfikacji generatora udarów.

pomiarowe (program tworzony jest za pomocą bloków, w których wykonywane są odpowiednie działania – reprezentowane są one na ekranie w postaci ikon). Na rysunkach 5 i 6 pokazano stworzoną w środowisku LabView przykładową aplikację generującą przebieg sinusoidalny o zadanej amplitudzie i ilości okresów oraz jej kod źródłowy (diagram blokowy) w języku G.

APLIKACJE WERYFIKACYJNE

Generator udarowy SURGE

Weryfikacja generatora udarów odbywała się w konfiguracji pokazanej na rysunku 9.

Do laptopa z zainstalowanym pakietem LabView podłączono generator PSURGE 4.1 firmy Haefely oraz oscyloskop cyfrowy TDS694C firmy Tektronix. Wyjście liniowe generatora połączono z wejściem oscyloskopu poprzez sondę P6249 firmy Tektronix, o przekładni 1000.

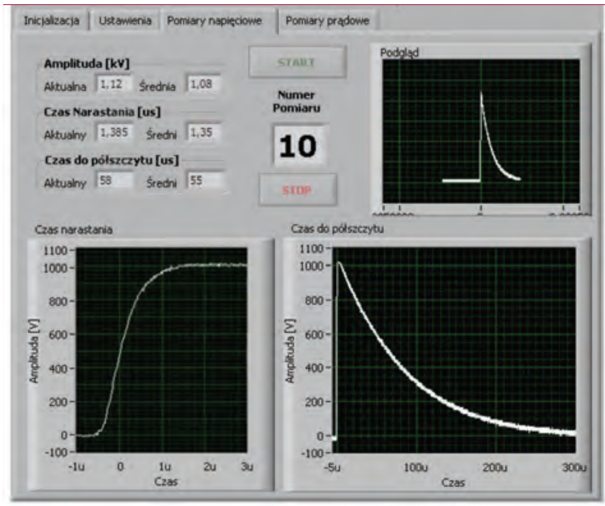
Stworzona aplikacja składała się z 3 zasadniczych bloków funkcjonalnych:

- inicjalizacja urządzeń współpracujących,
- konfiguracja urządzeń współpracujących,
- akwizycja danych.

W części inicjalizacyjnej programu wyświetlane są informacje o sposobie podłączenia urządzeń współpracujących (generatora oraz oscyloskopu) oraz wykonywana jest procedura ich rozpoznania i inicjalizacji według adresów GPIB wprowadzonych przez użytkownika.

W części konfiguracyjnej programu użytkownik ma możliwość wyboru nastaw oscyloskopu i generatora. Aby wyeliminować możliwość doboru nastaw, które uniemożliwiłyby prawidłowe próbkowanie wprowadzono tutaj opcję synchronizacji. Polega ona na tym, że po wybraniu parametrów sygnału probierczego generatora automatycznie dopasowane zostają nastawy oscyloskopu tak, aby zapewnić optymalne odwzorowanie sygnału. Istnieje również możliwość wyłączenia synchronizacji i ręcznego doboru nastaw obydwu urządzeń. Ustawienia generatora i oscyloskopu mogą być zapisywane i odczytywane z pliku. Pozostałe nastawy oscyloskopu konfigurowane są automatycznie, bez udziału użytkownika.

Zasadniczą częścią programu do weryfikacji generatora udarów jest moduł akwizycji i przetwarzania danych. Odpowiada on za rozpoznanie wystąpienia sygnału probierczego na wejściu oscyloskopu i dalszą jego analizę. Po rozpoznaniu wyzwolenia oscyloskopu następuje tutaj akwizycja przebiegu wraz z jego graficznym przedstawieniem w panelu programu oraz wykonywane są pomiary istotnych parametrów przebiegu. Aktualnie zmierzone wartości wyświetlane są w panelu programu; w panelu tym wyświetlane są również ich wartości średnie w danym momencie serii pomiarowej. Widok panelu



Rys. 8. Panel weryfikacji przebiegów napieciowych generatora udarów.

wizualizującego proces weryfikacji przebiegów napięciowych generatora pokazano na rysunku 8.

Generator stanów przejściowych

Weryfikacja generatora stanów przejściowych odbywała sie w układzie pokazanym na rysunku 9.

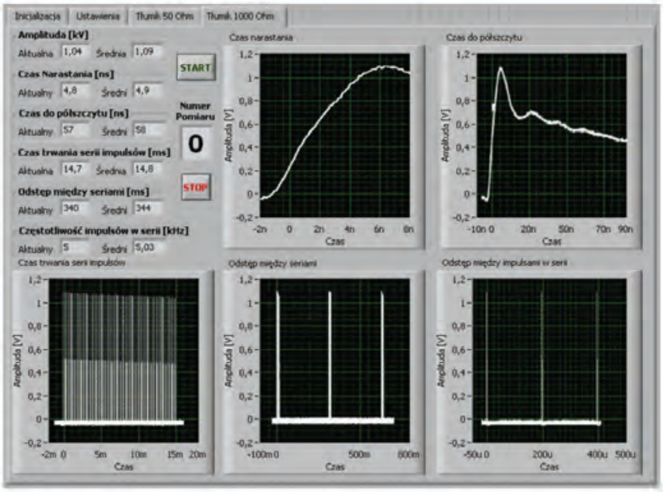
Do laptopa z zainstalowanym pakietem LabView podłączono generator PEFT1 firmy Haefely oraz oscyloskop

Rys. 9. Konfiguracja układu do weryfikacji generatora stanów przejściowych.

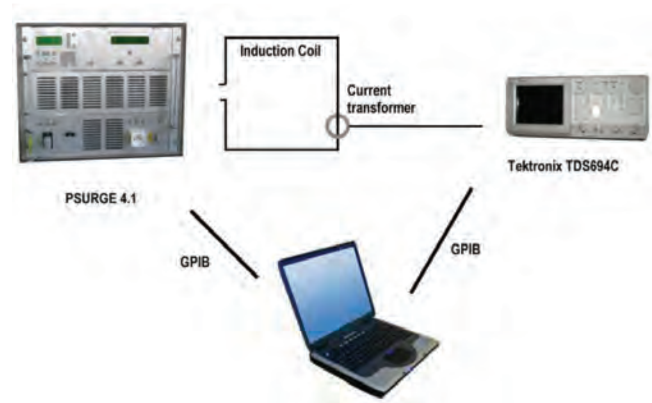
cyfrowy TDS694C firmy Tektronix. Wyjście wysokiego napięcia generatora połączono z wejściem oscyloskopu poprzez tłumik o oporności najpierw 50, później 1000 Ω.

W części inicjalizacyjnej programu wyświetlane są informacje o sposobie podłączenia urządzeń współpracujących (generatora oraz oscyloskopu) oraz wykonywana jest procedura ich rozpoznania i inicjalizacji według adresów GPIB wprowadzonych przez użytkownika – domyślnie ustawione są adresy wstępnie zdeklarowane w urządzeniach.

W części konfiguracyjnej programu użytkownik ma



Rys. 10. Panel weryfikacji przebiegów napieciowych generatora stanów przejściowych.



Rys. 11. Konfiguracja układu do weryfikacji generatora impulsowego pola magnetycznego.

możliwość wyboru wyłącznie nastaw generatora. Decyzja taka spowodowana była faktem, iż w związku z dużą liczbą parametrów mierzonych podczas weryfikacji generatora przebiegów przejściowych konieczna jest kilkukrotna zmiana podstawy czasu oscyloskopu. W związku z tym niemożliwe jest jednorazowe dobranie takich nastaw oscyloskopu, które umożliwiłyby poprawne rozpoznanie wszystkich wymaganych parametrów. Ustawienia generatora mogą być zapisywane i odczytywane z pliku.

Zasadniczą częścią programu do weryfikacji generatora stanów przejściowych jest moduł akwizycji i przetwarzania danych. Odpowiada on za rozpoznanie wystąpienia sygnału probierczego na wejściu oscyloskopu i pomiar parametrów wymaganych w procedurze weryfikacyjnej.

Dodatkowym utrudnieniem podczas weryfikacji generatora stanów przejściowych jest stosunkowo duża liczba parametrów wymagających zarejestrowania, a przede wszystkim konieczność kilkukrotnej zmiany podstawy czasu oscyloskopu w czasie próbkowania. Aby zapewnić najlepsze odwzorowanie przebiegów nastawy oscyloskopu zmieniane są 4-krotnie w czasie jednego pomiaru.

Widok panelu akwizycyjnego aplikacji do weryfikacji generatora przebiegów przejściowych pokazano na rysunku 10.

Generator impulsowego pola magnetycznego

Weryfikacja układu do badań odporności na impulsowe pole magnetyczne odbywa się w konfiguracji pokazanej na rysunku 11. Probiercze pole magnetyczne wytwarzane jest tutaj w wyniku przepływu prądu w znormalizowanej cewce indukcyjnej. Do pomiarów parametrów impulsu prądowego w cewce indukcyjnej wykorzystywana jest cewka pomiarowa o przekładni 1 A / 0,01 V. Dodatkowo, wejście oscyloskopu zabezpieczane jest sondą P6249 firmy Tektronix chroniącą przed przekroczeniem dopuszczalnego poziomu napięcia.

Ze względu na zbliżone parametry czasowe impulsów prądowych w cewce indukcyjnej a także identyczne wyposażenie stanowiska pomiarowego weryfikacja systemu MSURGE może odbywać się za pomocą, opisanej wcześniej, aplikacji do weryfikacji generatora udarowego.

PODSUMOWANIE

Celem prac zaprezentowanych w niniejszym artykule było wykonanie oprogramowania przeznaczonego do automatycznej weryfikacji aparatury probierczej używanej przez Laboratorium Urządzeń Elektronicznych. Do realizacji tego zadania wybrano środowisko programistyczne LabView firmy National Instrument w wersji 7. Wybór taki podyktowany został dużą uniwersalnością pakietu, zapewniającą stosunkowo łatwą realizację komunikacji z większością pomiarowych urządzeń elektronicznych funkcjonujących na rynku.

Efektem prac było powstanie dwóch aplikacji przeznaczonych do automatycznej weryfikacji systemów do badań odporności na udary powodowane przez przepięcia łączeniowe i piorunowe stany przejściowe PSURGE 4.1 (program SURGE) oraz do badania odporności na powtarzalne, szybkie, elektryczne stany przejściowe PEFT1 (program BURST). Aplikacja SURGE umożliwia również weryfikację systemu do badań odporności na impulsowe pole magnetyczne. Wszystkie aplikacji zostały wdrożone do użytku w normalnym reżimie pracy laboratorium zdecydowanie upraszczając i przyspieszając proces okresowej weryfikacji aparatury badawczej.

O FIRMIE

Laboratorium Urządzeń Elektronicznych Instytutu Logistyki i Magazynowania w Poznaniu prowadzi badania naukowe oraz zajmuje się oceną techniczną w obszarze kompatybilności elektromagnetycznej i bezpieczeństwa elektrycznego. Laboratorium posiada akredytację w zakresie normy EN ISO/IEC 17025 oraz notyfikację Komisji Europejskiej w zakresie dyrektyw EMC, LVD i RTTE. www.ilim.poznan.pl/LA **https://youtu.be/h4F4qi-r-r0**

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[4] LabView7 Express – Getting Started with LabVIEW, National Instrument, April 2003 Edition.

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SAMENVATTING

ALLE ELEKTRISCHE EN ELEKTRONISCHE apparaten moeten worden getest op hun afgestraalde RF-emissie en hun immuniteit tegen RF instraling. Dit gebeurt vaak op een meetveld (open area test site (OATS)) of in een afgeschermde ruimte (semi-anechoische ruimte (SAR)). Het te meten elektrische of elektronische apparaat wordt dan opgesteld op een draai-plateau (floor-standing equipment) of op een tafel geplaatst (table-top equipment). Indien er kabels aangesloten moeten worden blijft dit een onderwerp van discussie m.b.t. de functionele en common-mode impedanties die daaraan verwacht (mogen of moeten) gaan worden, i.h.b. voor de lichtnetaansluiting.

In de diverse EMC-normen worden stralingseisen gesteld m.b.t. wat een elektrisch of elektronisch apparaat mag afstralen. Hierbij worden dan metingen uitgevoerd op 3, 10 of zelfs 30 meter afstand van het te meten apparaat. Deze meetplaatsen moet voldoen aan genormaliseerde antenne-overdrachten (normalised site-attenuation (NSA)) opdat de stralingsmetingen gemeten op de ene meetplaats overeen zouden kunnen komen met de resultaten gemeten op een andere meetplaats. Hiervoor worden dan twee of drie gekalibreerde antennes gebruikt.

Indien er daarna een elektrische of elektronische apparaat wordt neergezet b.v. op de plaats waar de zendantenne heeft gestaan (bij RF emissie metingen), dan moet het apparaat worden aangesloten om te kunnen functioneren: lichtnet, signaalkabels e.d. Deze aangesloten kabels vormen dan een niet nader beschreven antenne aan het te meten apparaat en bepalen in hoge mate de efficiëntie van de afstraling t.o.v. de interne bronnen in het te meten apparaat.

OVERVIEW

Most, if not all electrical and electronic appliances have to be tested on their radiated RF emission and their immunity against RF radiated fields. This radiated testing occurs either on an open area test site (OATS) or in an anechoic or semi-anechoic room (SAR). The electrical and electronic appliance to be measured will be put on a turntable with a 0,8 to 1,0 m high table (table-top equipment) or floor (floor-standing equipment). Cables to be connected to operate the appliance as intended are an everlasting point of discussion w.r.t. their functional and common-mode termination against the metal reference plane/floor of the OATS or SAR, in particular for the mains lead connection. To read this article in English, go to our website www.interferencetechnology.com.

Bij het meten in een afgeschermde ruimte of OATS met een metalen vloer met draaitafel, worden de kabels vanuit het te meten apparaat naar de vloer gebracht. De kabellengten, hun ligging en de resulterende kabelstromen bepalen dan de uitgestraalde energie die ontstaat. De kabelstromen worden weer sterk beïnvloed door de functionele en common-mode afsluitimpedanties die aanwezig zijn aan het uiteinde van deze kabels.

Voor de aansluiting van de lichtnetkabels kan gebruik gemaakt worden van een Artificial Mains Netwerk (AMN, IEC CISPR-16-1-2) waarvoor geldt dan de serie-impedantie naar de referentie (= metalen vloer) voor de veiligheidsgeleider (protective earth (PE)) gelijk is aan nul. De impedanties van alle fase en neutrale draden naar PE worden voorgesteld met een impedantie gelijk aan 50 Ω // (50 µH + 5 Ω) of er wordt een CDN of AAN toegepast welke in common-mode een impedantie representeert van ~150 Ω naar deze metalen bodemreferentie.

Bij het opbouwen van meetkooien worden er zware netfilters geplaatst op de buitenwand van de meetkooi, meestal ver verwijderd van de wandcontactdoor in het draaiplateau waarop het elektrische of elektronische apparaat is opgesteld. M.a.w. omdat nagenoeg alle netfilters een π-structuur hebben kan de uitgang van het filter gezien worden als een RF-kortsluiting (= spanningsknoop). Doordat de lichtnetvoorziening (óók niet in meetkooien) op geen enkele wijze RF-matig is opgebouwd, zijn de karakteristieke impedantiewaarden gemeten op een wandcontactdoos (WCD) van alle mogelijk propagatie-modi op die kabel onbekend en is de impedantie die ontstaat aan het uiteinde van de lichtnetkabel volledig onbestemd, mogelijk met één uitzondering, wanneer het PE/randaarde contact in de wandcontactdoos lokaal aan de metalen bodemreferentie is verbonden. Voor de fase en de neutrale geleiders geldt dat daarvoor de asymmetrische impedantie ongedefinieerd is. Het toepassen van een AMN of een CDN bij deze impedantie-onbestemde lichtnetaansluiting (WCD in de draaitafel) lijkt dan de enige oplossing.

Indien het apparaat voorzien is van meerdere aansluitingen, al dan niet afgeschermd, dan is het voor de hand liggend dat alle afschermingen met het metaal van de draaitafel/ bodemreferentie direct worden verbonden. Bij niet-afgeschermde signaal en/of voedingslijnen kunnen alle variaties weer optreden, want deze kunnen RF-matig weer worden verbonden met de referentie, worden afgesloten met een nog nader te bepalen common-mode impedantie of blijven hangen. Dit laatste kan b.v. met een batterij-gevoede interface of een elektrisch naar optische verbinding. Ook indien het elektrische of elektronische apparaat accu-gevoed is dan kan dit vanuit een galvanisch ‘zwevende’ accu situatie (zoals aan boord van een schip) of een geaarde situatie (zoals in elke conventionele auto met verbrandingsmotor) of, in het beste geval, via een gedefinieerde common-mode impedantie. Deze laatste 3 opties: open, kortgesloten of afgesloten leveren de 3 extremen op bij de RF emissiemetingen en bepalen of er een knoop, buik of een volledig gedempte situatie optreedt aan het einde van de kabel. Deze opties leveren ook een marge van +/- 20 dB wanneer er gemeten wordt bij een enkele frequentie, wanneer de kabel waarom het gaat dominant is t.o.v. de totale afstraling van het apparaat, zie figuur 1 voor de asymmetrische impedantie gemeten aan een 1,5 meter lang verlengsnoer wat aan de WCD is opengelaten, afgesloten met 50 Ω of is kortgesloten.

De frequentieschaal loopt van 1 tot 300 MHz en de absolute impedantie schaal loopt van -10 dBΩ (= 0,3 Ω) tot 90 dBΩ (= 30 kΩ). De stralingsmetingen beginnen normconform meestal vanaf 30 MHz, daar waar de impedantie-resonanties voor een 1,5 meter lang snoer al gaan plaatsvinden. Indien er ‘verborgen’ bekabeling in de meetkooi aanwezig is tussen de WCD en het netfilter, dan zullen deze resonanties al vanaf veel lagere frequenties optreden.

INCONSISTENTIE IN DE MEETNORMEN

De diverse EMC normen schijven soms een AMN, dan weer een CDN of (MDS, EM of ferriet) clamp of soms helemaal niets voor m.b.t. de impedantiedefinitie aan de lichtnetaansluiting tijdens een RF emissie of RF immuniteitstest. Zoals al aangegeven kan dit zo’n 40 dB verschil opleveren bij een specifieke frequentie en zal zo’n vaart niet lopen wanneer het gaat om een breedbandige stoorbron, dan is er altijd wel een stoorcomponent met een frequentie die samenvalt met een maximum efficiëntie van de impedantie afstemming van die lengte van de lichtnetkabel.

Helaas wordt in de laatste IEC CISPR 32 weer referentie gemaakt naar een AMN i.p.v. een CDN. Hierdoor ontstaat er dan weer ‘harde’ knopen voor de PE geleider van de lichtnetaansluiting maar wel een eenduidig bepaalde impedantie voor de asymmetrische fase(n) en neutrale geleider t.o.v. PE. Door toepassing van een AMN in een RF impedantie ongedefinieerde lichtnetvoeding ontstaat aan de EUT nul/ fase aansluiting van de AMN een minimale impedantie variatie t.o.v. PE, zie figuur 2 van 34 dBΩ (= 50 Ω).

Figuur 2, laat zien, in tegenstelling tot de eisen van IEC

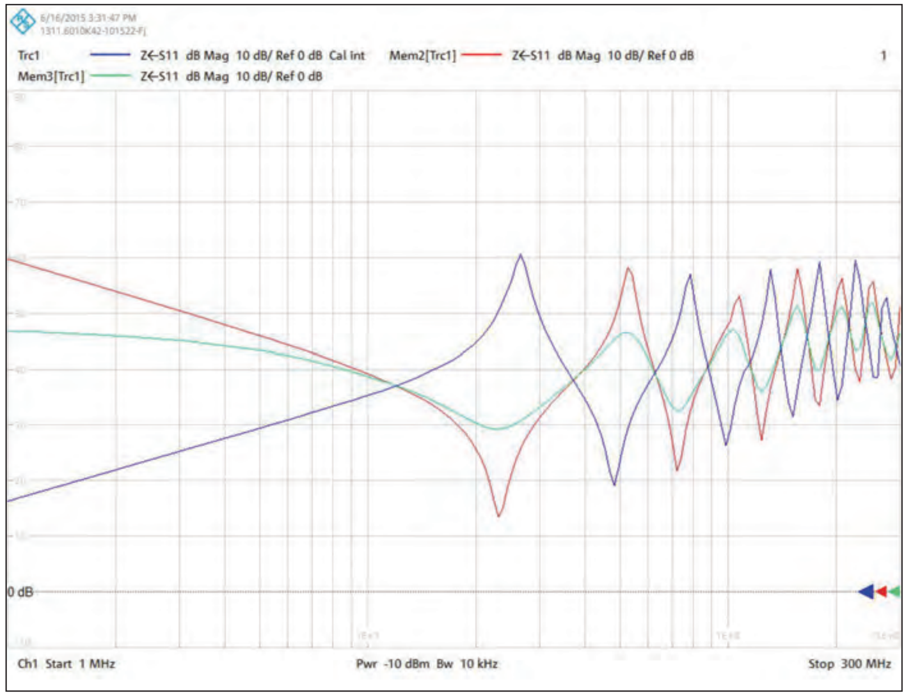
Figuur 3 - Foto van dummy AMN en dummy CDN met kalibratie-netwerk met een open, afgesloten en RF-matig kortgesloten WCD aansluiting.

CISPR 16-1-2 dat een dummy AMN gemaakt kan worden, zie figuur 3, welke een redelijke impedantie kan realiseren van 50 Ω tot ver boven de 30 MHz, iets wat voor een (commercially of the shelf (COTS)) AMNs meestal niet geldt.

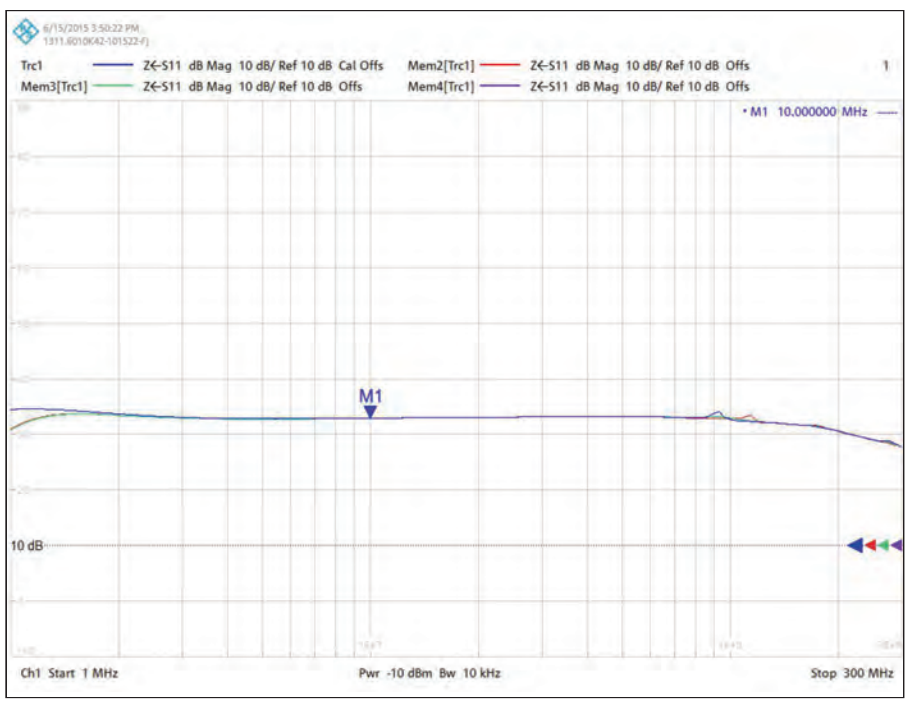
Het blijft hierbij wel een voorwaarde dat de WCD waarin de dummy AMN wordt gestoken zijn PE aansluiting direct met de metalenbodemreferentie verbonden heeft. Een alternatief wordt dan een extra aansluiting aan de dummy AMN waarmee dit lokaal bij de WCD van de draaitafel wordt gedaan.

Het andere pad, wat ook al een aantal maal in de revisies van IEC CISPR 22 is gepoogd, is om een ferriet-clamp (b.v. de MDS-clamp) op de lichtnetkabel (en eventueel ook andere kabels) te gebruiken om hiermee de common-mode impedantie te stabiliseren. Common-mode impedantie waarden tussen 50 en 500 Ω waren hiervoor als doel gesteld. Voor de lichtnetkabel of een andere 2 of 3-aderige onafgeschermde signaal of voedingskabel zou je dit met een 50 Ω afgesloten CDN M2 of M3 (conform IEC 61000-4-6) kunnen doen. Ook hier is het relatief simpel, indien dit dummy CDN netwerk niet voor meetdoeleinden wordt gebruikt, om dit in een kleine behuizing onder te brengen, zie figuur 3, waarbij de dummy CDN functie in dezelfde behuizing als een dummy AMN is ondergebracht. In tegenstelling tot de dummy AMN heeft de dummy CDN voor alle geleiders totaal een common-mode impedantie van 150 Ω, oftewel 44 dBΩ, dit met de impedantie toleranties zoals ook aangegeven in de IEC 61000-4-6, zie figuur 4. In figuur 4 zijn de 3 condities die op kinnen treden aan de WCD: open, afgesloten en hoogohmig gebruikt om de variatie van de common-mode impedantie aan de WCD zijde van de dummy CDN weer te geven. De waarde van de absolute impedantie zou voor frequenties boven de 26 MHz mogen variëren tussen 106 en 212 Ω, oftewel 44 dBΩ ± 3 dB = 41 tot 47 dBΩ.

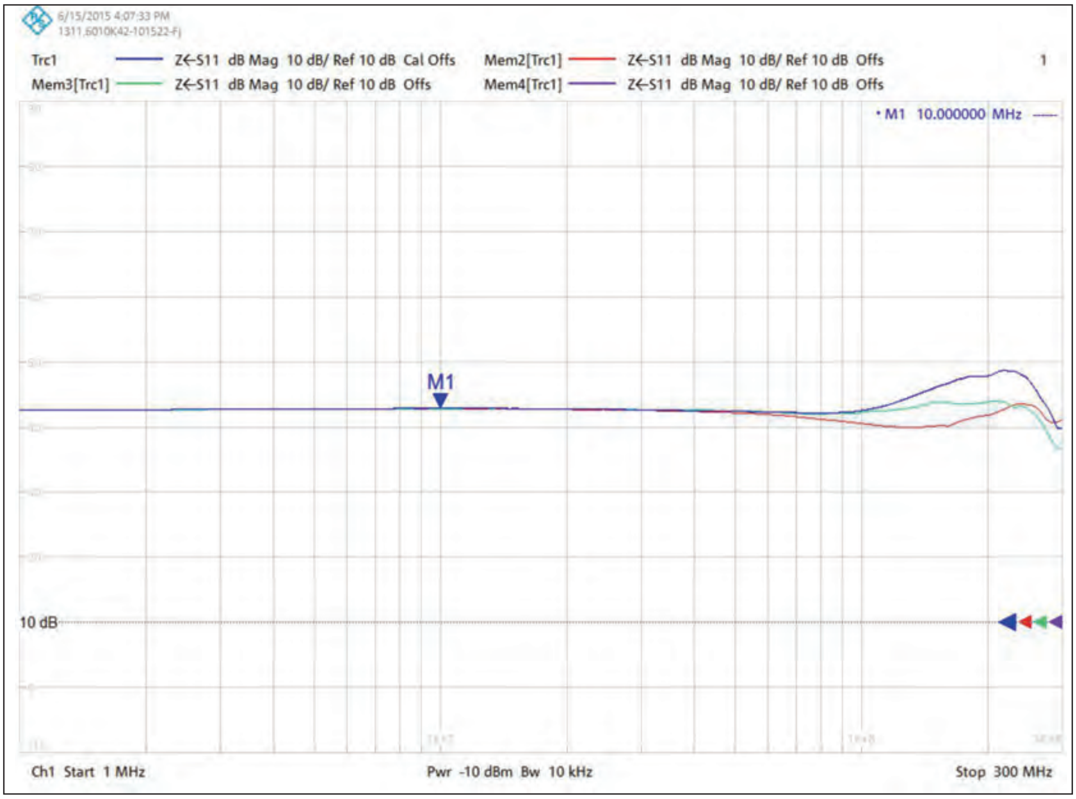
Zonder dergelijke common-mode stabiliserende maatregelen aan de WCD zou deze weer kunnen variëren van een open, afgesloten of RF-matig kortgesloten condities, zie figuur 5. Hierbij is de parasitaire impedantie van een rand-geaarde steker meegenomen als extra pad-lengte (= inductie) en extra capaciteit tussen de aansluitpennen naar de metalen bodemreferentie. Wanneer je dit gaat meten na 1,5 meter lichtnetkabel, dan worden de impedanties weer onbestemd, zie figuur 6.



Figuur 1 - Asymmetrische impedantie gemeten aan een 1,5 meter lang netsnoer, met open, kortsluiting en een 50 Ω afsluiting aan de stekerzijde.



Figuur 2 - Asymmetrische impedantie aan de EUT zijde van een AMN bij open, kortsluiting en 50 Ω aan de voedingszijde.



Figuur 4 - Common-mode impedantie aan de EUT zijde van een dummy CDN waarbij de ingang open, afgesloten met 50 Ω en RF-matig kortgesloten is.

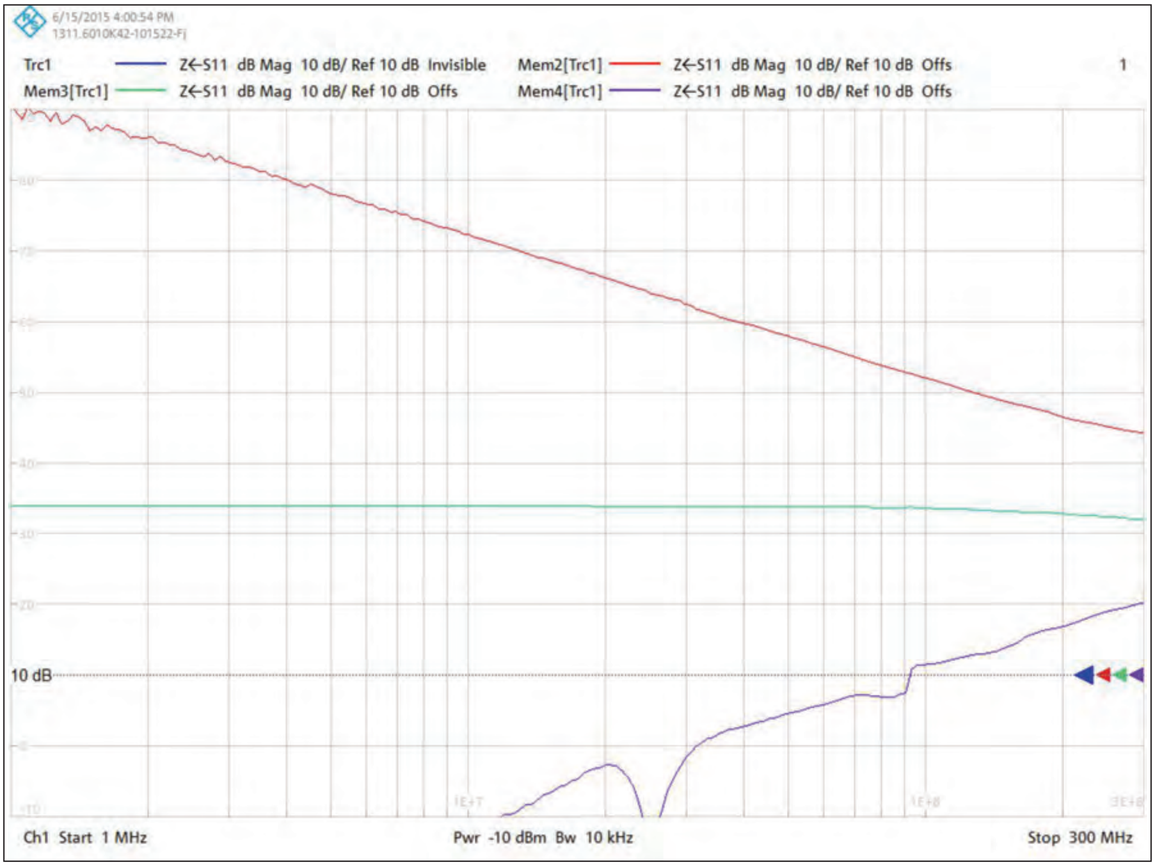
CONCLUSIES

Indien een elektrisch of elektronisch apparaat bij de ‘radiated’ RF emissie en/of RF immuniteitstesten faalt, dan dient men zich af te vragen of de kabel-afsluitimpedanties overeen komen met wat men ervan verwacht. Zelfs bij een goedkeur, zou men zich moeten afvragen of dit dan bij alle toepassingen het geval zou kunnen zijn.

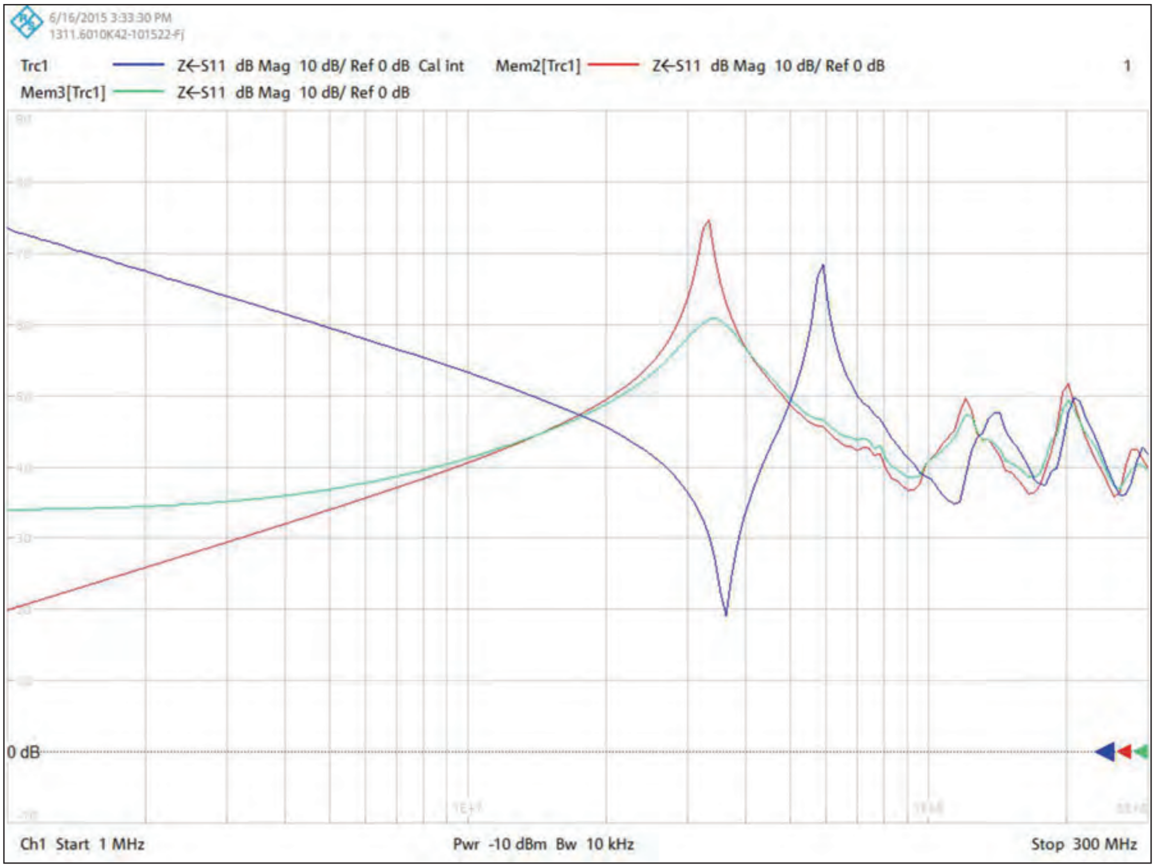
Bij een groot aantal EMC meetinstituten zijn de impedantie achter de WCD (geldt ook voor de andere niet-afgeschermde signaal en/of voedingssignalen) bij de EMC meetkooien (geldt ook voor TEM-cellen, G-TEM cellen, mode-stirred chambers (MSC))) niet eenduidig bepaald en mogelijk een oorzaak voor grote verschillen van de resultaten/bevindingen i.h.b. in de frequentieband beneden de 300 MHz.

De verschillende EMC standaarden zijn niet eenduidig over de wijze waarop de lichtnetkabel qua impedantie moet worden aangesloten naar de metalen bodemreferentie bij deze ‘radiated’ opstellingen, en zo een bron voor ‘eigen’ interpretaties.

M.b.v. een of twee eenvoudige dummy netwerken: AMN, CDN, kan de invloed van de RF-afsluiting van een lichtnetkabel worden gecontroleerd en kan in hoge mate de reproduceerbaarheid van de meetresultaten worden verhoogd.



Figuur 5 - Common-mode impedantie aan een randaarde steker wanneer deze aan zijn contacten open, afgesloten met 50 Ω en RF-matig kortgesloten is.



Figuur 6 - Common-mode impedantie aan de EUT zijde van een AMN na 1,5 meter lichtnetkabel bij een open, kortsluiting en 50 Ω aan de voedingszijde.

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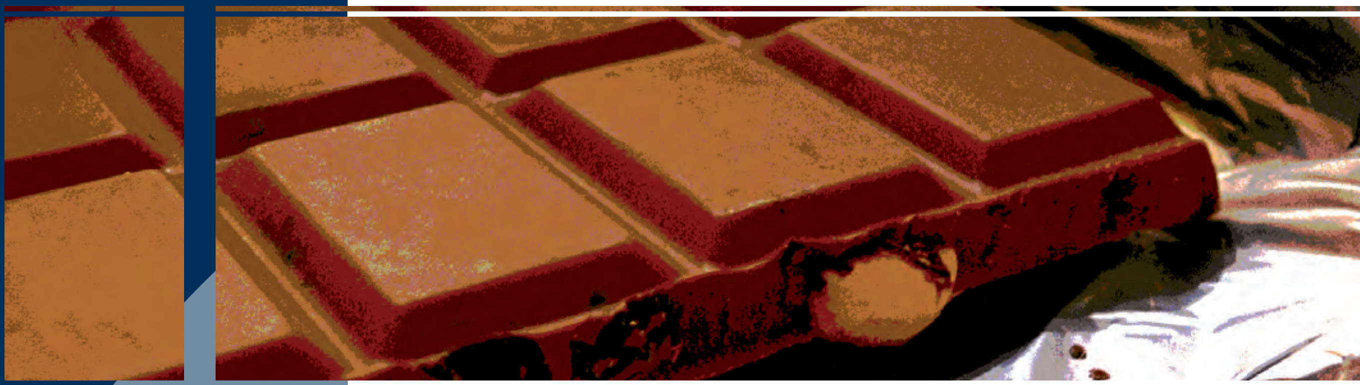
SCHWEIZ



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Warum die ANSI/ ESD S20.20 1-Fuß-Regel (0,3 m) für Aufladungsverursacher für die Luft- und Raumfahrt und im militärischen Sektor auf 1 Meter erhöht werden muss

BOB VERMILLION
Consultant
RMV Technology Group, LLC

OVERVIEW

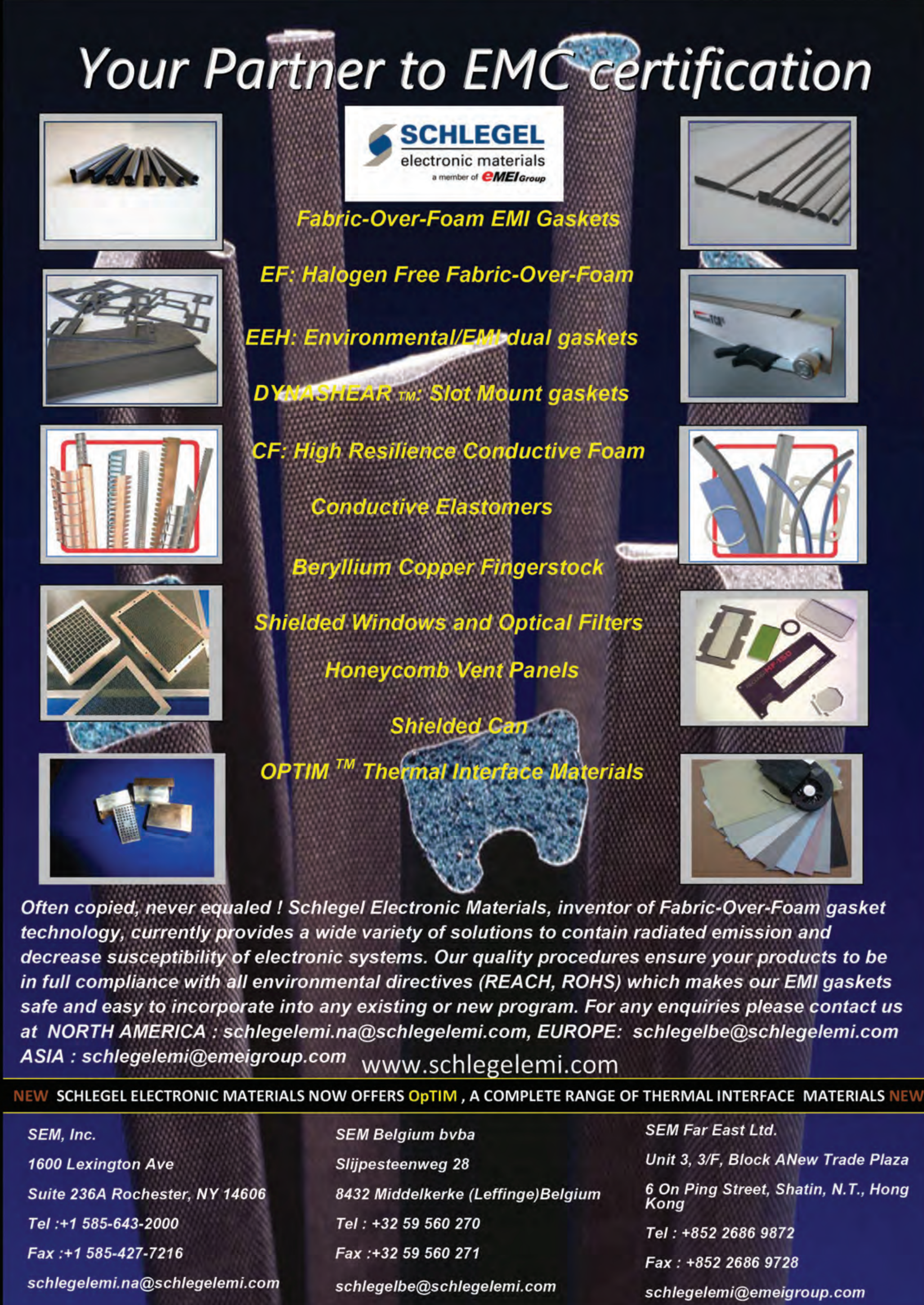
This article discusses how in the semiconductor sector today, ESD sensitive devices can be damaged at <+/-50 volts. Aerospace & Defense cannot issue a Returned Materials Authorization (RMA) for an ESD sensitive device that fails in space or a nonfunctioning weapon system in-theatre. The article will show why the ANSI/ESD S20.20 1-foot rule for charge generators needs to be increased to 1-meter for aerospace and defense. To read this article in English, go to our website www.interferencetechnology.com.

INTRODUCTION

IN DER MODERNEN HALBLEITERINDUSTRIE Halbleiterindustrie können ESD-gefährdete Bauelemente bei <+/-50 Volt beschädigt werden. In der Luft- und Raumfahrt sowie im militärischen Sektor kann ein ESD-gefährdetes Bauelement, das im Weltraum defekt wird, bzw. ein im Einsatz nicht funktionsfähiges Waffensystem nicht mit einer RMA-Nummer (Returned Materials Authorization) zurückgeschickt werden.

Extrudierte Folie kann sich bei weniger als 20 % relativer Luftfeuchtigkeit auf über +/-100.000 Volt aufladen. Für Hersteller von Polymeren und Kartonagen seit Jahren ein Problem. Die Santa-Ana-Winde in Südkalifornien und die winterlichen Bedingungen in Colorado können zu einer relativen Luftfeuchtigkeit (RLF) von <4 % RLF führen. Kurz nach dem Start kann die RLF von 60 % auf dem Rollfeld nach 20 Minuten Flugzeit auf <9 % in der Flugzeugkabine abfallen1.

In der pharmazeutischen Industrie können mikroprozessorgesteuerte LCD-Waagen aufgrund elektrostatischer Entladung



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Laden bei niedriger und hoher relativer Luftfeuchtigkeit (RLF)

ELEKTRISCHE SPANNUNG AUFGRUND VON LADEVORGÄNGEN	20 % RLF	80 % RLF
GEHEN AUF VINYLBODEN	12 kV	250 V
GEHEN AUF SYNTHETISCHEM TEPPICH	35 kV	1,5 kV
AUFSTEHEN VON SCHAUMSTOFFPOLSTER	18 kV	1,5 kV
AUFHEBEN EINER PLASTIKTÜTE	20 kV	600 V
SCHIEBEN EINER STYROPORBOX AUF TEPPICH	18 kV	1,5 kV
ABZIEHEN VON MYLAR-BAND VON COMPUTERPLATINEN	12 kV	1,5 kV
AUFBRINGEN VON SCHRUMPFFOLIE AUF COMPUTERPLATINEN	16 kV	3 kV
ENTFERNEN VON LOT MIT EINEM VAKUUMKOLBEN	8 kV	1 kV
STROMKREIS-AEROSOLKÜHLSPRAY	15 kV	5 kV

Militärisches Handbuch 263

Tabelle 1

In Tabelle 1 - sind einige Beispiele für den nachweislichen Zusammenhang zwischen Aufladung und RLF-Werten aufgeführt.

in unmittelbarer Nähe von Teflon-Fördersystemen "einfrieren". Ein triboelektrischer Effekt oder eine Aufladung dieser Größenordnung stellt für viele Bereiche des Halbleitersektors möglicherweise kein Problem dar.

In der Luft- und Raumfahrt und im militärischen Sektor gibt es viele Bereiche, in den Aufladungsverursacher nicht nur ESD-gefährdete Bauelemente beschädigen, sondern auch Mitarbeiter gefährlicher elektrischer Spannung aussetzen können. Der Autor hat persönliche Erfahrung mit großen elektrostatischen Feldern, die durch pinkfarbene antistatische Palettenbeutel aus Polyethylen, Handhabung von Klebeband, fördersystembedingte Aufladung und Satellitenabdeckungsaufladung hervorgerufen werden. Ein Abstand von einem Meter ist daher für die in Tabelle 2 aufgeführten Aufladungsverursacher möglicherweise nicht ausreichend.

In einem elektrostatisch geschützten Bereich (EPA) werden als ESD-Schutzmassnahme in der Regel 30 % bis 70 % RLF angestrebt. Eine hervorragende Quelle für entsprechende Richtlinien ist Abschnitt 6.1 der Norm Workmanship NASA-STD 8739.6.

6.1 TEMPERATUR UND RELATIVE LUFTFEUCHTIGKEIT (RLF)

6.1.1 Temperatur und relative Luftfeuchtigkeit (RLF) müssen im Verarbeitungsbereich überwacht und innerhalb der folgenden Grenzwerte gehalten werden (Bedingung):

a. Für Temperatur: 18 °–30 °C (65 °–85 °F)

b. Maximale relative Luftfeuchtigkeit: 70 Prozent RLF

c. Minimale Luftfeuchtigkeit für ESD-gefährdete Hardware: 30 % RLF

d. Minimale Luftfeuchtigkeit für ESD-gefährdete Hardware, HBM Klasse 0: 40 % RLF

6.1.2 Für Gegebenheiten, in denen die Aufrechterhaltung des in den vorstehenden Punkten c. oder d. aufgeführten RLF-Werts nicht zweckmäßig ist, müssen spezielle Methoden, Verfahren, Ausrüstungen und Sicherheitsmaßnahmen angewendet werden, um den Risiken von relativen Luftfeuchtigkeitswerten unter 30 % RLF entgegenzuwirken, und müssen im jeweiligen ESD-Kontrollprogrammplan dokumentiert werden.

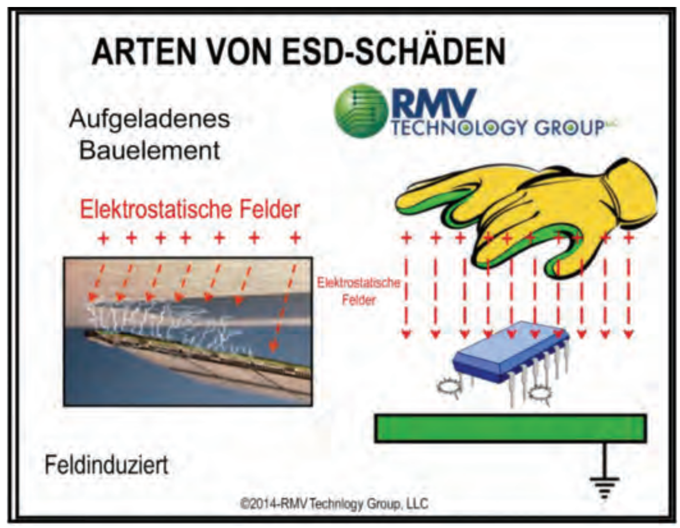


Abbildung 1

Nicht geerdete Satellitenabdeckungen	Styroporplatten	Entfernen und Einlegen von Müllbeuteln
Solarzellenbewegung innerhalb eines EPA	Öffnen und Schließen einer Lexan-Zugangsklappe bei unterschiedlichen Druckverhältnissen	Entfernen und Anbringen von Kunststoffbeuteln auf Paletten
Abrollen antistatischer Luftpolsterfolie von einer Rolle	Betanken eines Hubschraubers in unmittelbarer Nähe drehender Rotorblätter	Elektrische Aufladung durch Niederschlag oder Wolken ("P-Static") bei Bergungsarbeiten der US-Küstenwache mit Rettungskorb
Satellitengehäusebewegung	Bekleidungsstücke (Einweg)	Flachbildschirme
Nicht geerdete Typ-I- und III-Folien für Satellitenabdeckungen	Schaumpolster	Antistatische Abdeckungen

Tabelle 2

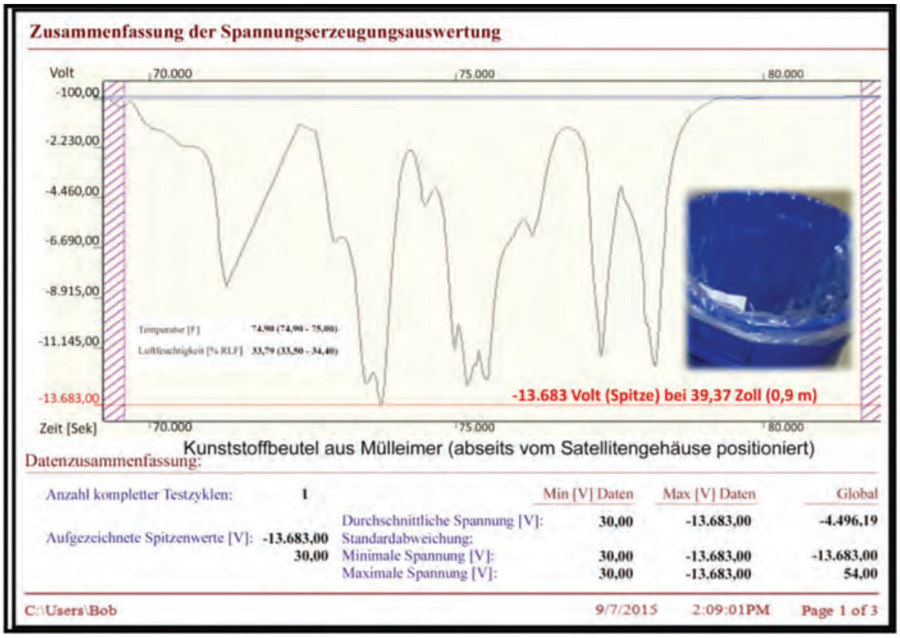
Die 1-Fuß-Regel ist für Isolatoren ungeeignet, die in einer Entfernung von über 1 Meter (3,28 Fuß) eine elektrische Spannung erzeugen können, die weit über 2000 Volt/cm liegt. Bei mäßiger bis niedriger Luftfeuchtigkeit können große aufladungsverursachende Isolatoren für ESD-gefährdete Bauelemente weiterhin problematisch sein.

ANSI/ESD S20.20 gemäß gilt Folgendes: Wenn das am erforderlichen Isolator gemessene Feld grösser als 125 Volt/Zoll ist und der Abstand zwischen dem erforderlichen Isolator und dem ESD-gefährdeten Bauelement weniger als 2,5 cm (1 Zoll) beträgt, müssen die vorgenannten Schritte A und B ausgeführt werden. Es bleibt zu erwähnen, dass verschiedene Endnutzerorganisationen in- und außerhalb der Luft- und Raumfahrtindustrie und des militärischen Sektors für extrem ESD-gefährdete Bauelemente einen Grenzwert von <+/-100 Volt festlegen.

Im ersten Beispiel wurde ein blauer Kunststoffmülleimer falsch mit 6 Zoll (15 cm) Abstand zu einem ANSI/ESD S4.1 Satellitengehäuse positioniert. Die Ruhespannung betrug gemessen am Kunststoffmüllbeutel -4.490 Volt/Zoll. Wurde der Abstand vom Müllbehälter zum Satellit vergrößert und der durchsichtige Kunststoffbeutel aus dem blauen Kunststoffbehälter entnommen, erreichte die Spannung bei 1 Meter eine Voltspitze von -13.683 Volt. Hinweis: Der Bediener war während des Messvorgangs geerdet (Satellit ist nicht abgebildet).

Ein Abstand von 1 Fuß (0.3 m) zum Solarmodul führte zu einer elektrischen Spannung von 20.400 und -5.011 Volt.

Zur Simulation von Aufladungsverursachern bei einem Abstand von 1 Fuß (0,3 m) wurden in der Laborumgebung für 48 Stunden Bedingungen von 30 % RLF bei 73 0F +/-5 0F geschaffen. Zur Durchführung des Tests wurde die isolierende Styroporplatte geerdet. Zur Ladungstrennung (Reibung) bzw. Kontakttrennung wurde die Platte einfach von einem Stapel Platten genommen. Die Styroporplatte wurde mit einem Abstand von 1 Fuß (0,3 m) zu einem kontaktlosen Spannungsmessgerät positioniert, die gemessene Spannung betrug -12.440 Volt (Abbildung 3). Die von Isolatoren erzeugte Spannung ist für ESD-gefährdete Bauelemente eindeutig ein Risiko, wenn in einem EPA der Luft- und Raumfahrt die Regel >1 Meter nicht eingehalten wird.



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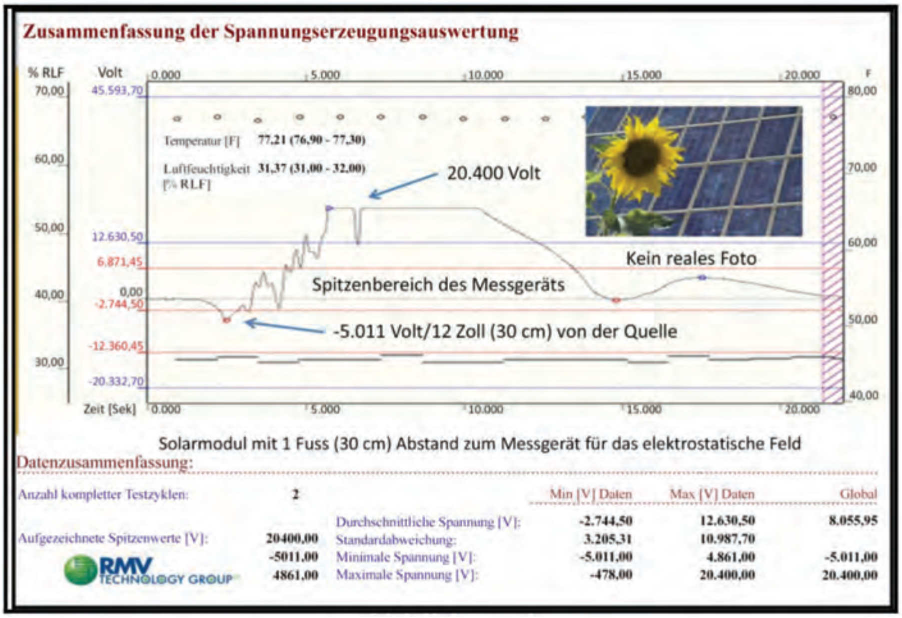

Abbildung 2

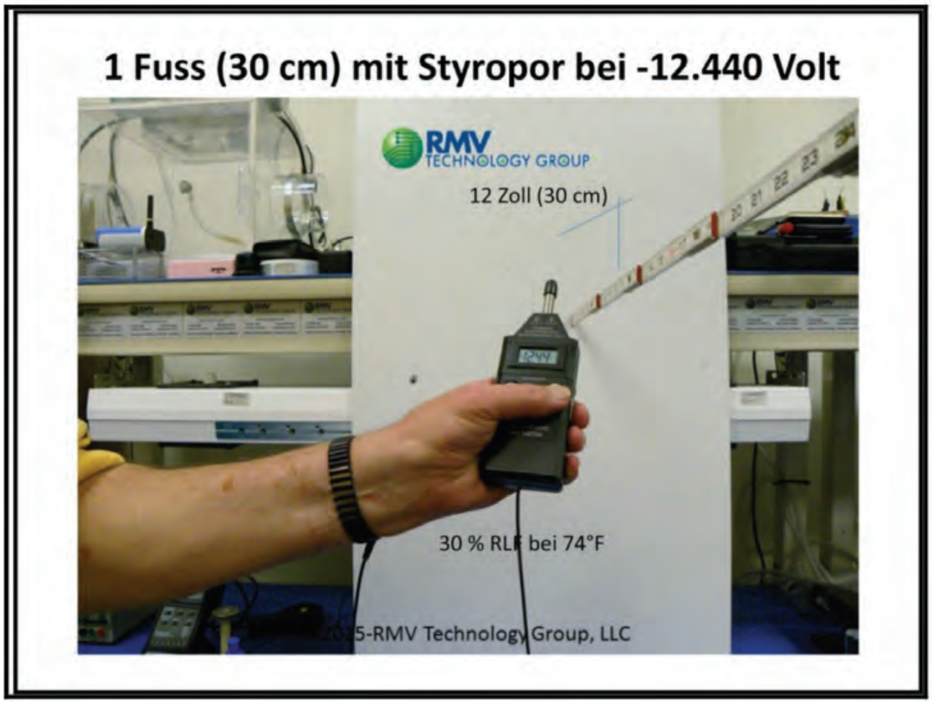

Abbildung 3

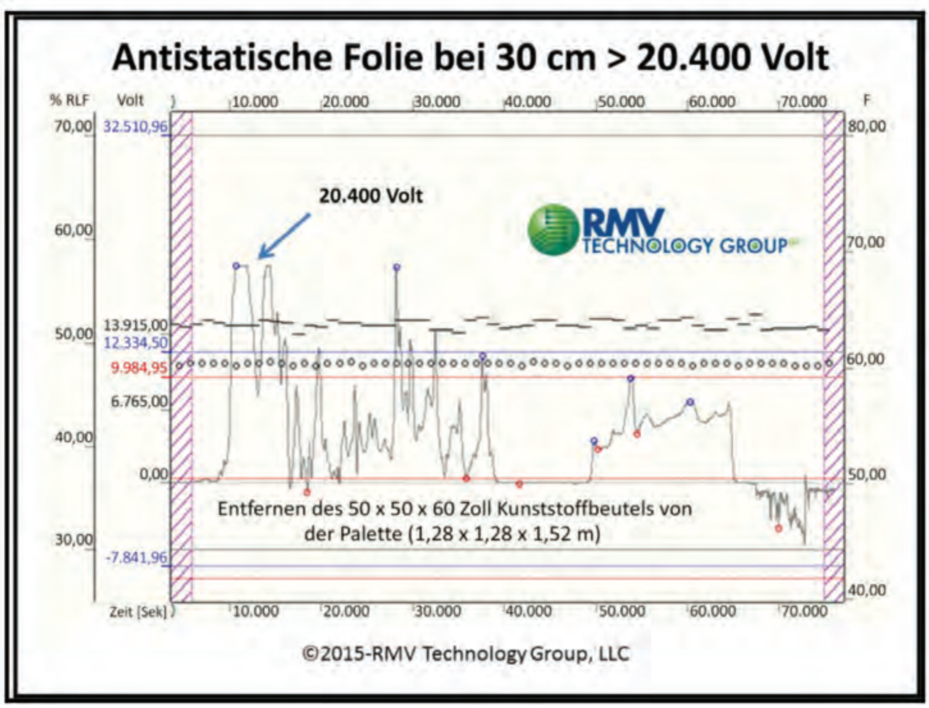

Abbildung 4

Wenn sich in unmittelbarer Nähe ESD-gefährdeter Bauelemente ein elektrostatisches Feld befindet, kann es zu einer feldinduzierten Entladung kommen. In Abschnitt 8.3.1 der Norm ANSI/ESD S20.20-2014 findet sich folgende Information zu Isolatoren: „Wenn das auf dem erforderlichen Isolator gemessene Feld grösser ist als 2000 Volt/cm und der Abstand des erforderlichen Isolators zum ESD-gefährdeten Bauelement weniger als 0,3 m beträgt, muss wie folgt vorgegangen werden:

A) Zwischen dem erforderlichen Isolator und dem ESD-gefährdeten Bauelement für mehr als 30 cm (12 Zoll) Abstand sorgen, oder

B) Mithilfe von Ionisation oder anderen aufladungsmindernden Techniken, die Aufladung neutralisieren.

In Abbildung 4 erreichte die antistatische Folie einen Spitzenwert im Messbereich des Feldstärkemessgeräts (>20.400 Volt), da das topische Antistatikum eine Aufladung nicht angemessen minimieren konnte. Beschleunigte Alterungstests für ein Antistatikum dauern schätzungsweise ca. 12–14 Tage2. Ein Tag bei 160 0F entspricht 17 Tagen bei Zimmertemperatur. Ein topisch beschichtetes antistatisches Element kann innerhalb von 204 bis 289 Tagen (ungefähre Werte) seine Fähigkeit verlieren, einen triboelektrischen Effekt zu vermeiden.

Antistatika für Langzeitaufbewahrung weisen bezüglich Langlebigkeit und humider Belastbarkeit während Transport und Lagerung Mängel auf. Nach John Kolyer, Ph.D. (Boeing, emeritiert, bereits verstorben) können Antistatika ihre Wirksamkeit bei 9 % oder 10 % RLF verlieren.

Nicht behandeltes Lexan-Polycarbonat kann ein Aufladungsproblem verursachen. Das Produkt wurde auf einem Fördersystem mit ca. 18 Zoll (45 cm) Abstand zur Ladequelle vorgeschoben. Im Inneren des geschlossenen Lexan-Gehäuses herrschten 20 % RLF und 80 0F, in der äußeren Umgebung 50 % RLF und 60 0F. Als die Lexan-Zugangsklappe von einem Techniker geöffnet wurden, erzeugte die schnell an der Polycarbonatklappe vorbeiströmende Luft bei einem Abstand von 6 Zoll (15 cm) 147.400 Volt. Gemessen wurde dies mit einem speziellen Statik-Messgerät mit einem Messbereich von +/-100 Volt bis +/-200.000 Volt. Das Produkt war beschädigt.

Mit einem Abstand von 18 Zoll (45 cm) wurden zwei Ionisatoren betrieben. Die Spannung der Fördersystempalette aufgrund der aufladungsverursachenden Lexan-Zugangsklappe betrug 6.010 Volt. Die Oberflächen der Zugangsklappe wurden mit leitfähiger Polymerfolie versehen und die Lexan-Zugangsklappe wurde geerdet, um die Aufladung abzuschwächen.

Aus Abbildung 8 ist ersichtlich, dass das Entfernen von 4

Flachbildschirmelementen aus einer Lagerungs- und Transportvorrichtung bei einer mäßigen relativen Luftfeuchtigkeit von 39,5 % zu großen elektrostatischen Feldern führte. Zu beachten ist, dass die Transport- und Lagerungsvorrichtungen für die Flachbildelemente nicht geerdet waren, da sowohl die feststellbaren Räder als auch der Fliesenboden isolierende Wirkung hatten.

Zusammenfassend lässt sich sagen, dass größere isolierende Plattformen, wie in Tabelle 4 gezeigt, einen Abstand von über 1 Fuß (0,3 m) benötigen, und in bestimmten Fällen sogar mehr als einen Meter, um elektrostatische Felder zu minimieren.

Ein zukünftiger Artikel zu feldinduzierter Entladung wäre wünschenswert, um die Beziehung zwischen Aufladung und ESD-Ereignissen aufzuzeigen. Sofern es sich um einsatzkritische ESD-gefährdete Bauelemente handelt muss die 1-Meter-Regel entsprechend NASA-HANDBOOK 8739.21 eingehalten werden.

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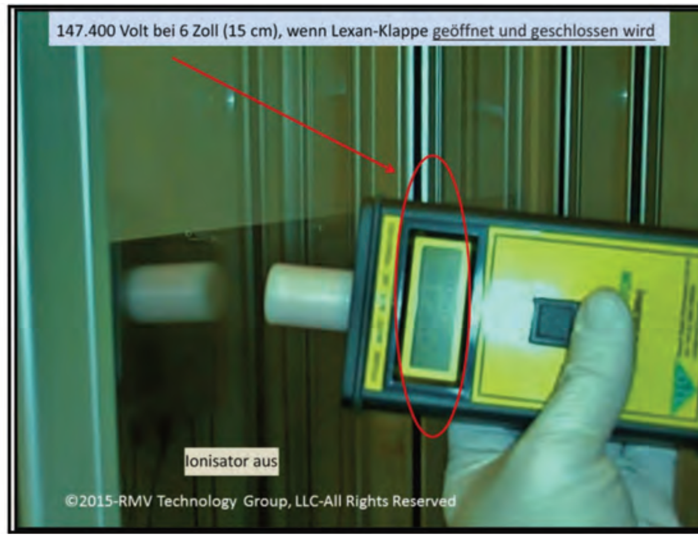

Abbildung 5

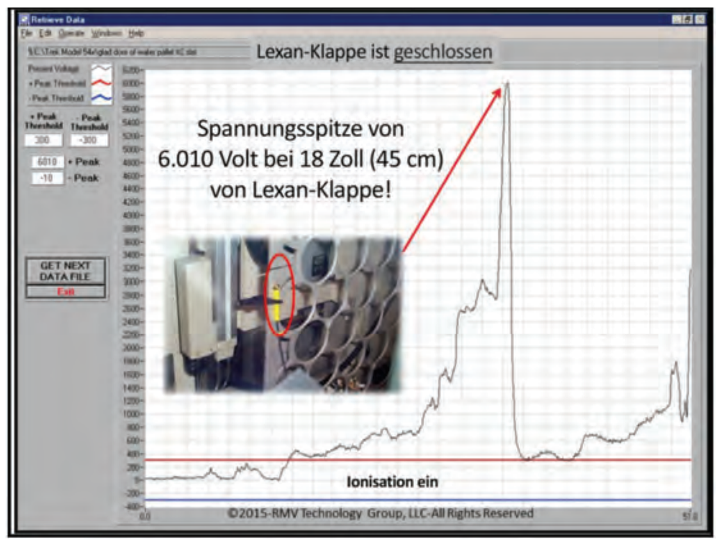

Abbildung 6

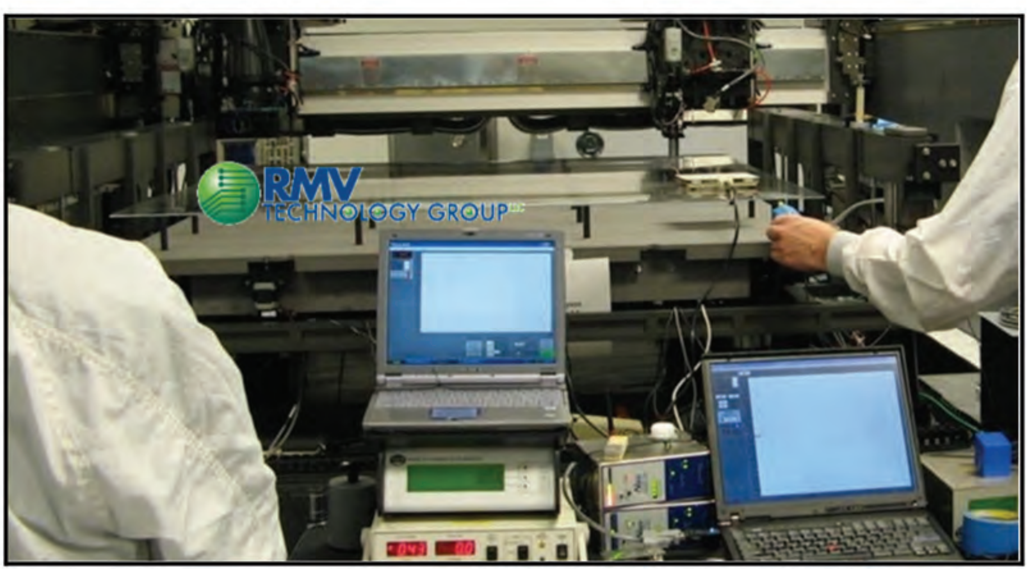

Abbildung 7

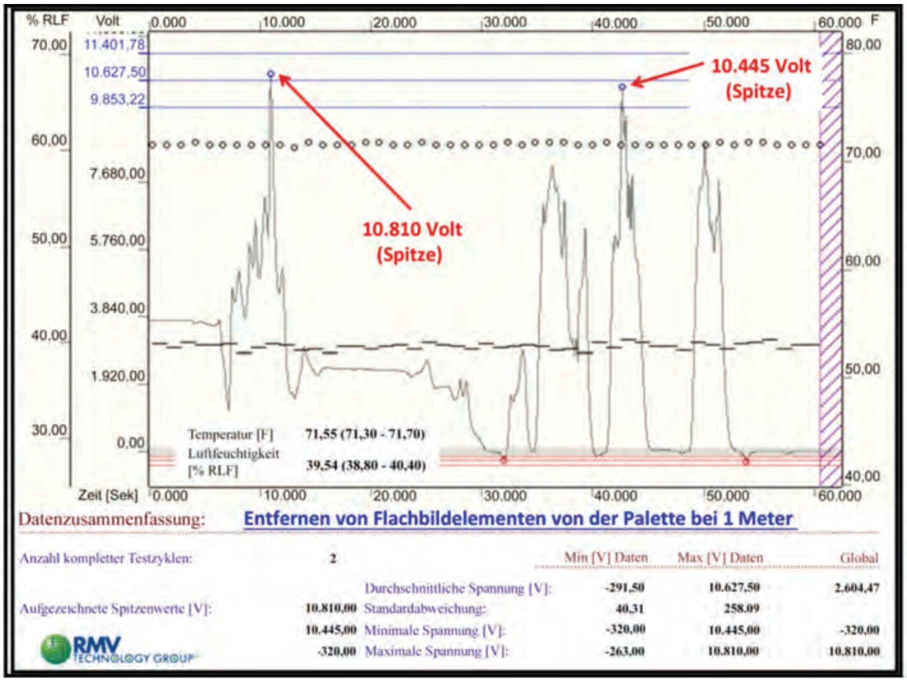

Abbildung 8

ÜBER DEN AUTOR

Bob Vermillion, CPP/Fellow, ist ein Certified ESD & Product Safety Engineer-iNARTE mit praktischer Erfahrung in der Abschwächung des triboelektrischen Effekts bei Materialien auf einer Marsoberfläche und der Fehlerbehebung für Robotertechnik oder Systeme in Luft- und Raumfahrt, im Datenträgersektor, für medizinische Geräte und im pharmazeutischen, Automobil- und Halbleitersektor. Bob ist Mitautor verschiedener ANSI-konformer ESD-Dokumente und er ist Mitglied des ESD Association Standards Committee. Er leitet ESD-Seminare in den USA und im Ausland und wurde mehrfach als Gastredner von der California State Polytechnic University, der San Jose State University, der University of California in Berkeley und der Clemson University engagiert. 2015 leitete Bob auf Einladung ein Seminar an der Oxford University. Bob ist Chief Technology Officer der RMV Technology Group, LLC, einem Drittdienstleister für ESD-Materialtests, Schulungen und Beratung. Sie erreichen Bob unter 650-964-4792 oder bob@esdrmv.com

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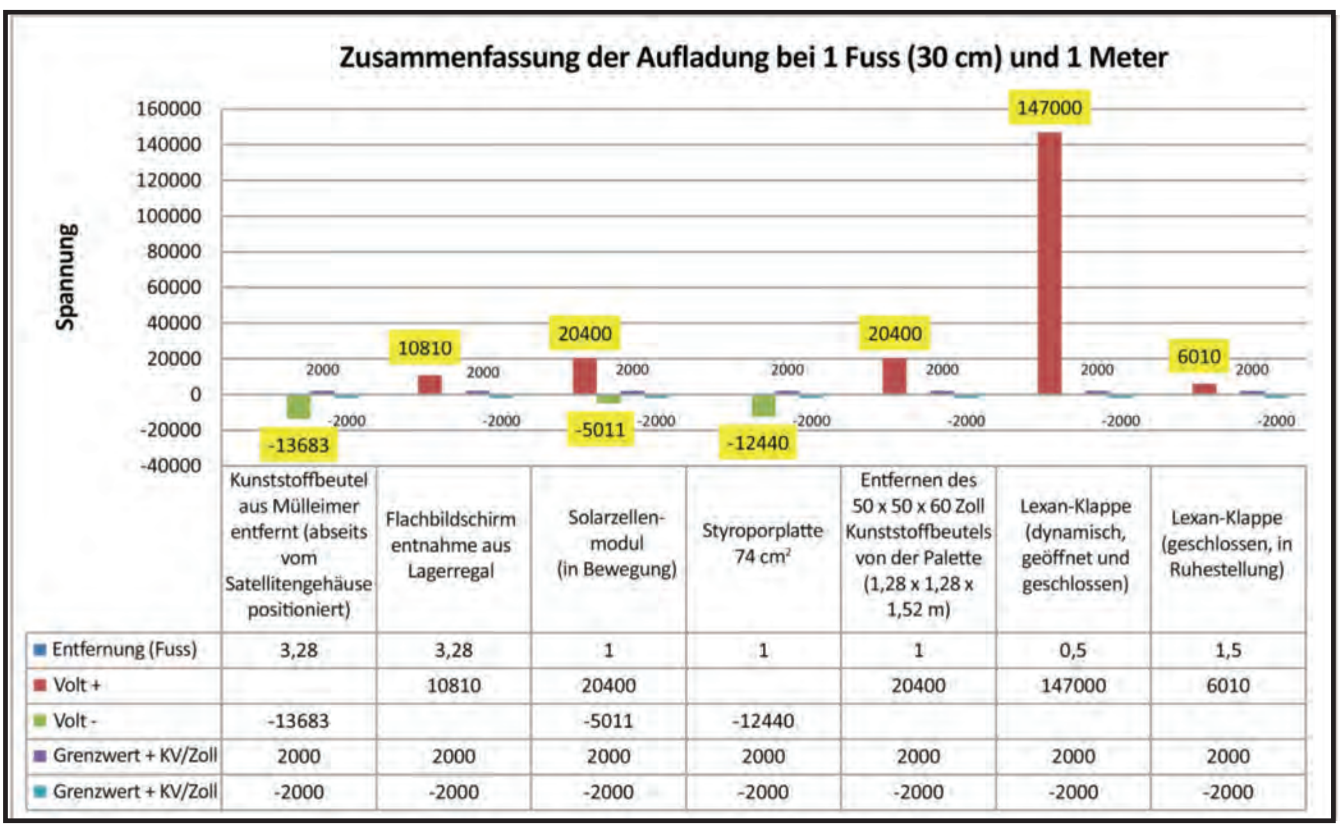

	Kunststoffbeutel aus Mülleimer entfernt (abseits vom Satellitengehäuse positioniert)	Flachbildschirm entnahme aus Lagerregal	Solarzellen-modul (in Bewegung)	Styroporplatte 74 cm²	Entfernen des 50 x 50 x 60 Zoll Kunststoffbeutels von der Palette (1,28 x 1,28 x 1,52 m)	Lexan-Klappe (dynamisch, geöffnet und geschlossen)	Lexan-Klappe (geschlossen, in Ruhestellung)
Entfernung (Fuss)	3,28	3,28	1	1	1	0,5	1,5
Volt +		10810	20400		20400	147000	6010
Volt -	-13683		-5011	-12440			
Grenzwert + KV/Zoll	2000	2000	2000	2000	2000	2000	2000
Grenzwert + KV/Zoll	-2000	-2000	-2000	-2000	-2000	-2000	-2000

Tabelle 4

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Mobile Generations Explained

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The evolving mobile communications technologies provide us with vastly increasing data rates, faster response times and increasingly fluent means to access more contents than ever in the history of telecommunications. Along with the development of the standards, the commercial solutions keep appearing for our selection. Often in this highly dynamic environment, the vast amount of technical and marketing terms gives us challenges in capturing the real meaning of the messages that operators, device vendors and service providers want to give us. One of the most confusing topics in this field is the definition of the "mobile communications generations", so let's solve the mystery.

INTRODUCTION

GENERATION ZERO SHOWED POTENTIAL Early mobile networks paved the way to a totally new era liberating users from communicating in fixed locations back in late 80s. In fact, there were some much earlier systems deployed although they have been basically forgotten in the history. As an example, Swedish automatic MTA (Mobile Telephony System version A) was deployed already in 1956 for operative use in Stockholm and Gothenburg. As the equipment was bulky, it was suitable merely for car mounted environment. This initiation was still ahead of time, so it did not have commercial success. As another example from 1971, the technology was finally mature enough in Finland for the commercial launch of ARP (Auto Radio Phone), which functioned in 160 MHz band until 2000 – serving customers especially in remote areas whole 3 decades. Parallel systems were adopted also in many locations in 450 MHz band. All these initiations may be referred to as "Generation 0" with relatively small user base and still portability limitations.

ANALOGUE ERA KICKED OFF MOBILE COMMUNICATIONS

The evolution started to really take off during 1980s along with the first generation mobile communications networks that had fully automatic functionalities for establishing voice calls. Some examples of the 1G networks were AMPS (Advanced Mobile Phone System) in Americas and TACS (Total Access Communications System) in the UK. There also were a diversity of similar kind of networks in other locations of the globe, of which the slightly more international variant was NMT 450 (Nordic Mobile Telephony) and its enhanced version NMT 900 in Nordic countries.

Now obsolete, the 1G cellular networks showed concretely the benefits of location and time independent communications which has resulted in dominating position of mobile users compared to land line subscriptions already for years ago. Looking back at history, the growing popularity of the voice service – thanks especially to the 1G systems – came often as a complete surprise to operators and regulators in late 80s and early 90s which caused challenges in keeping up with the capacity demand. The more accessible prices of the devices and their utilization triggered the sudden interest which in turn made mobile business growing faster than any estimation was capable of indicating at that time whatsoever. The mobile user base still keeps increasing, and thanks to the raising popularity of multiple subscriptions per customer, we are still far away from the saturation levels as can be seen from ITU (International Telecommunications Union) statistics (Figure 1). Furthermore, the growing business for Internet of Things will contribute to the total growth figures as the automatized communications between machines requires ever increasing number of subscriptions.

DIGITAL ERA EXPLODES THE BANK

The offered capacity of the 1G systems was rather limited, and regardless of some international functionality especially via NMT, the roaming concept was still fairly new and limited. These were some of the reasons for the further development of fully digitalized, second generation mobile communication systems like CDMA-based IS-95 in Americas. As for the number of users, GSM (Global System for Mobile Communications) has been the most popular 2G variant up to date. GSM also introduced the separation of the terminal and subscriber data storage (SIM, Subscriber Identity Module) for easier changing of the device yet maintaining the mobile telephone number. The 2G systems started to include growing set of enhanced services, from which the Short Message Service (SMS) is an example of the most successful mobile communications solutions of all times.

The digital 2G systems contained already in-build capabilities for data transmission, and after the further specification efforts, the mobile data services started to take off in the beginning of 2000 along with the packet switched data transmission. This can be interpreted as the starting point for the development of mobile communications towards the all-IP environment. As an example of today, GSM is able to offer data speeds of over 500 kb/s which is pretty amazing achievement for a 2G system comparing it to the original 9.6 kb/s back in 90s.

3G INITIATES THE MOBILE MULTIMEDIA

Regardless of the highly advanced and novelty solutions 2G networks have offered, their limits were understood in relatively early phase which triggered the standardization of even more advanced 3G systems. As a result, American cdma2000 and European UMTS (Universal Mobile Telecommunications System) were ready to be deployed in early 2000. One of the main benefits of 3G is the considerably higher data rates, e.g., via 1x-EV-DV of cdma2000 and HSPA (High Speed Packet Access) of UMTS. The basic guideline for 3G systems comes from ITU (International Telecommunications Union) which has accepted a set of commercial 3G systems under the IMT-2000 (International Mobile Telecommunications) umbrella. UMTS (with few variants) and cdma2000 comply with these requirements together with EDGE, DECT and WiMAX.

Ever since, higher data rates have been desired and offered. The main driver for the 3G systems was in fact the need of higher data rates as base for the fluent consumption of increasingly advanced multimedia services. Since the early days of 3G networks, the mobile data services have developed drastically from the original, some hundreds of kb/s speeds up to current tens of Mb/s category.

DEVELOPED 3G ERA ENSURES HIGH-SPEED DATA FOR ALL

Even if it is technically doable to enhance further the older technologies like CDMA and GSM, there is a limit as for the techno-economic feasibility, which justifies the introduction of modernized technologies within the 3G path. The basic reason for this is the better spectral efficiency the post-2G systems which is a result of the advances in the overall telecommunications technologies, processor performance and due to better understanding of the theories in the constant efforts to reach the performance limits. This is thus a logical moment for continuing the deployment of enhanced 3G systems of which LTE (Long Term Evolution) is the most popular representative that started to be available by first operators as of 2010-11. It is capable of offering better spectral efficiency than any of the previous systems have been able to do and moves the data service reference to new decade by providing hundreds of Mb/s data rates. WiMAX is another representative in the advanced 3G path, although its wider commercial use is yet to be seen.

4G CONFUSES AND ENHANCES

Up to 3G era, the terminology for distinguishing between the mobile system generations has been mostly understandable and the commonly agreed definition of 3G, based on ITU's IMT-2000 requirement umbrella, is logically aligned with the previous 2G and 1G networks. Nevertheless, the term "4G" seems to be somewhat confusing. There are several interpretations, the strictest one coming from the ITU that accepts only the evolved versions of LTE and WiMAX to the 4G category. Logically thinking, the basic version of LTE that is defined in the 3GPP Release 8 specifications is relatively close to 4G and could thus be considered as a "beyond 3G, pre-4G" system, also sometimes referred to as 3.9G technology in a non-standard communications. In practice, many operators and device manufacturers are interpreting LTE to belong to fourth generation as such.

Investigating the history behind the definition of 4G, ITU's Radiocommunication Sector ITU-R completed the assessment of six candidate submissions for the global 4G mobile wireless broadband technology by 21 October 2010. According to the ITU-R terminology, the fourth generation refers to IMT-Advanced that contains various technical requirements, e.g., for the data rates. The proposals resulted in two 4G technologies, "LTE-Advanced" and "WirelessMAN-Advanced", i.e., IEEE 802.16m which also is commonly known as "WiMAX 2". Only these solutions have been recognized officially by ITU-R as 4G technologies by now, although the practical interpretation of the mobile telecommunications industry is somewhat more liberal (Figure 3).

Looking at the IMT-Advanced documentation, it is clear that the initial version of LTE is not capable for meeting with the expected 4G performance values. As an example, LTE prior to the Release 10 is not able to provide the 1 Gb/s data rate in downlink which is one of the requirements of IMT-Advanced. Yet, it is common to see the early version of LTE and sometimes even UMTS HSPA+ networks being called as 4G.

WHERE IS 5G?

Interestingly, as the utilization of term "4G" has been used actively in the commercial pre-LTE-A Rel. 10 era, there seems to be some kind of inflation noted in the terminology as some systems might be called already as "5G". Nevertheless, the ITU-compliant 5G is still only a concept that is currently under brainstorming, and the potential 5G deployment could take place around 2020 time frame. We thus need to wait still for a while to be able to experience the forthcoming performance of the real 5G.

CONCLUSION

The mobile telecommunications industry has typically interpreted that the basic LTE may already be called as 4G. The practical explanation of these statement could be that LTE, in fact, is much closer to 4G than to 3G, and thus the 4G as a term has already been adopted in the marketing of LTE. Another reason is also the relatively long time the standardization takes, and the industry has obviously wanted to distinguish already between the older 3G era with the introduction of LTE. Thirdly, markets have simply decided that the final word for the practical definition of term "4G" is not written on stone so it is only fair to have some level of freedom for interpretation.

Regardless of the classification of LTE as a last step of 3G, or as a first or pre-step in 4G era, it paves the way to the actual ITU-R –defined 4G, and latest by the deployment of LTE-Advanced providing the gigabit experiences, the networks can be claimed to represent full-bloodied 4G system. Depending on the final role and success of WiMAX, this might be actually the first time in mobile communications history for the real merging of the solutions into a single solution, based on the LTE.

It is good to remember that the 4G experience is a sum of many items like evolved antenna technologies, carrier aggregation and new mobile device categories so the highest data rates will be available for us consumers in a gradual manner. It also is important to note that the latest 4G performance requires the support of these functionalities from both network and user equipment. Meanwhile, it is after all not so big deal what performance is behind the term 4G whilst the user experience proofs clear difference between the older solutions and the new ones. So folks, let's enjoy the most advanced mobile communications without worrying too much about the terminology!

ABBREVIATIONS

AMPS	Advanced Mobile Phone System, 1G network in North America and Australia
cdma2000	American 3G network
D-AMPS	Digital AMPS, 2G network
EDGE	Enhanced Data Rates for Global Evolution, evolved GPRS
E-GPRS	Enhanced GPRS
GPRS	General Packet Radio Service of GSM
GSM	Global System for Mobile communications, 2G network
HSPA	High Speed Packet Access, evolved 3G data service of UMTS
IS-95	CDMA-based network, 2G network
JTACS	Japan Total Access Communications System, 1G network
LTE	Long Term Evolution, pre-4G system
LTE-Advanced	4G system defined by 3GPP
Netz-C	1G network in Germany, Portugal and South Africa
NMT	Nordic Mobile Telephone, 1G system in Nordic countries, Netherlands, Switzerland, Eastern Europe and Russia
Radiocom 2000	1G network in France
RTMI	Radio Telefono Mobile Integrato, 1G network in Italy
TACS	Total Access Communications System, 1G network in the UK
TZ-801/ 802/803	Japanese 1G networks of NTT
UMTS	Universal Mobile Telecommunications System, 3G network
W-CDMA	Wideband CDMA (belonging to UMTS)

SOURCES

The LTE/SAE Deployment Handbook, Wiley, 2011.
The Telecommunications Handbook: Engineering Guidelines for Fixed, Mobile and Satellite Systems, Wiley, 2015

ABOUT THE AUTHOR

The author of this article, Dr. Jyrki Penttinen has insights to the telecom world as a result of professional experiences from all the mobile system generations. He has worked with mobile network operators and OEMs in technical management and expert positions in the USA, Finland, Spain and Mexico, and as independent consultant in Europe and Latin America. His technical interest areas include GSM, UMTS, LTE and mobileTV, and he has performed related activities in radio and core network planning, optimization, standardization and research. Currently, he works in mobile security domain in New Jersey with Giesecke & Devrient America, Inc. He also is active lecturer and contributor to technical publications, the most recent ones being The Telecommunications Handbook (Wiley 2015) and The LTE/SAE Deployment Handbook (Wiley 2011) of which more information can be found from www.tlt.fi. In his free time, he enjoys communicating via Morse code at his ham radio stations.

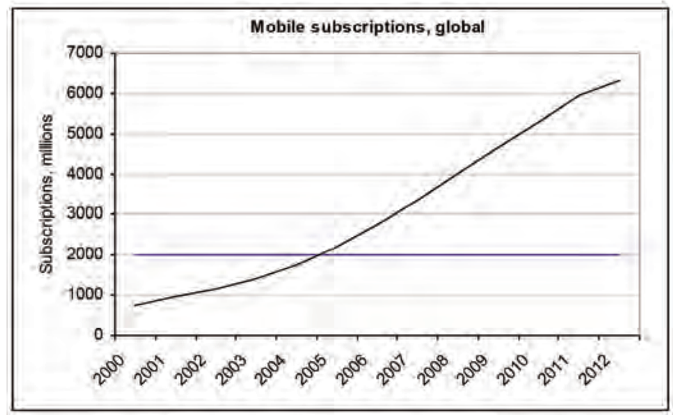

Figure 1 - Global evolution of the mobile subscriptions (ITU statistics).

Generation	Definition
1G	Analogue, first completely or almost completely automatic mobile networks that were meant for only voice calls, although accessory-based solutions were possible to adapt for data usage. The initial systems were based on vehicle mounted user equipment which could also be used as portable devices. The weight was typically several kilograms, and there was a separate auricular. Some examples of this phase of 1G are NMT-450, Netz-C, AMPS. In the further development of 1G, there were also hand-held devices introduced although the first ones were large and heavy compared to modern devices – those were definitely not meant for pockets. Example of this phase is NMT-900 that was launched in Nordic countries 1986-87.
2G	The most important differentiator of 2G was the digital functionality which provided integration of also data services into the system and devices. Examples of this generation are GSM and IS-95.
3G	The further development of multimedia-capable systems led into the third generation. The main differentiator of this generation is the possibility to use considerably higher data rates. According to the original set of ITU's performance requirements, LTE belongs still to the 3G phase.
4G	ITU-R has defined a set of principles and performance requirements for the fourth generation systems. In the initial phase of the compliance review by ITU, there were 2 systems that complied with the requirements, i.e., the advanced version of LTE (LTE-A, as of Release 10) and WiMax (as of WirelessMAN-Advanced). As the mobile telecommunications markets have been growing heavily, and the competition is tougher than ever, there have been also parallel interpretations of the 4G capabilities. Often, the Release 8 LTE is interpreted to belong to 4G, and also HSPA+ is considered by various operators to be a 4G system.
5G	Ideas beyond IMT-Advanced to provide much higher data rates, with focus on the expected deployment in 2020.

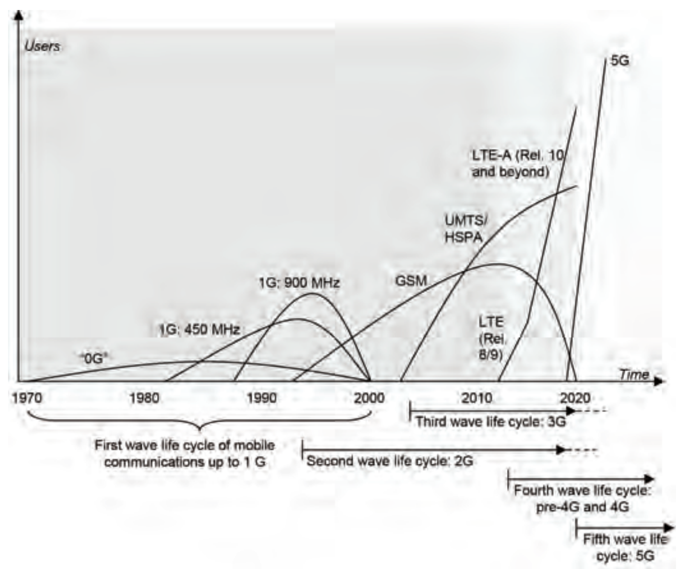

Figure 2 - The trends of the mobile evolution paths, including LTE-Advanced. The 1G systems are already obsolete. GSM has dominated the 2G era and it still functions as a useful base especially for voice communications and for re-farming the services to more spectral efficient 3G and 4G systems.

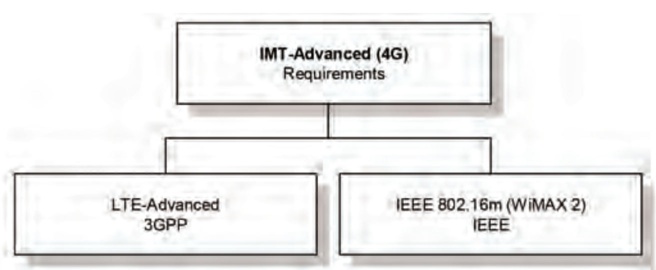

Figure 3 - The 4G systems approved by ITU-R.

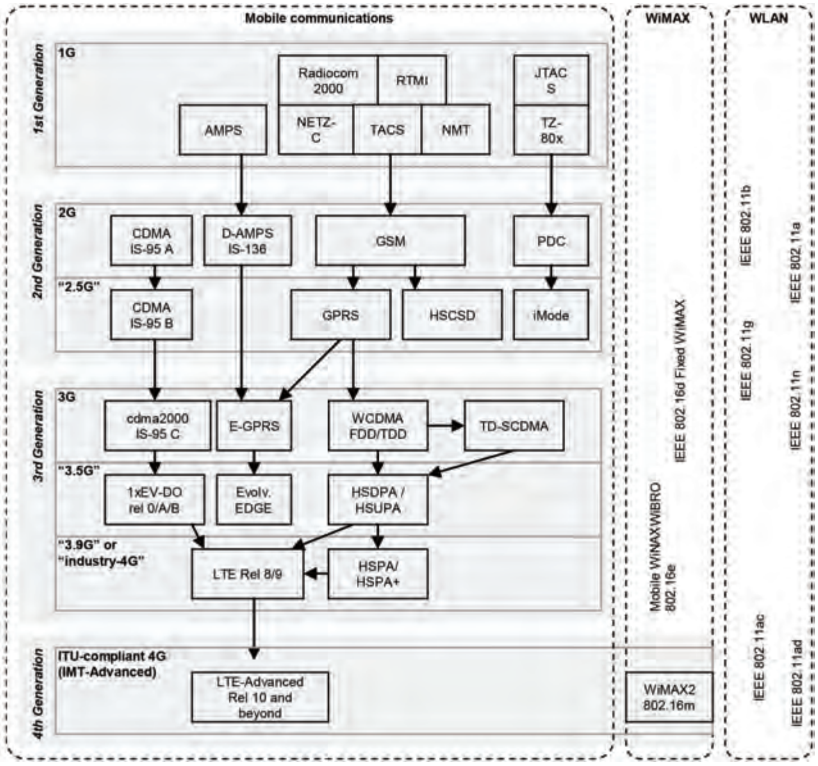

Figure 4 - Some commercial mobile systems of 1G, 2G, 3G and 4G. The 4G era converges the mobile and wireless LAN.

Why ANSI/ESD S20.20 1-Foot Rule for Charge Generators needs to be Increased to 1-Meter for Aerospace & Defense

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INTRODUCTION

IN THE SEMICONDUCTOR SECTOR TODAY, ESD sensitive devices can be damaged at <+/-50 volts. Aerospace & Defense cannot issue a Return Materials Authorization (RMA) for an ESD sensitive device that fails in space or a nonfunctioning weapon system in-theatre.

The fact that extruded film can charge up to over +/-100,000 volts below 20% RH has been problematic for polymer and paperboard manufacturers for years. The Santa Ana Winds of Southern California and winter conditions of Colorado can produce relative humidity (RH) levels at <4% RH. Shortly after takeoff, the RH can drop from 60% on the tarmac to <9% in the cabin after 20 minutes in flight[1].

In the pharmaceutical industry, microprocessor driven liquid crystal display scales can freeze up due to electrostatic discharge in proximity of Teflon conveyor systems. However, this magnitude of scale for Triboelectrification or charge generation may not be an issue for many areas of the semiconductor sector.

Charging at Low and High Relative Humidity (RH)

VOLTAGES FROM CHARGING ACTIONS

	20% RH	80% RH
WALKING ACROSS VINYL FLOOR	12KV	250 V
WALKING ACROSS SYNTHETIC CARPET	35KV	1.5KV
ARISING FROM FOAM CUSHION	18KV	1.5KV
PICKING UP POLY BAG	20KV	600V
SLIDING STYRENE BOX ON CARPET	18KV	1.5KV
REMOVING MYLAR TAPE FROM PC BOARDS	12KV	1.5KV
SHRINKING FILM ON PC BOARDS	16KV	3KV
TRIGGERING VACUUM SOLDER REMOVER	8KV	1KV
AEROSOL CIRCUIT FREEZER SPRAY	15KV	5KV

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Table 1 - A well-known charge relationship between charging and RH levels is illustrated in Table 1.

The Aerospace & Defense sector has many areas in which charge generators can not only damage ESD sensitive devices but can also pose issues with personnel due to shock. The author has personally been involved with large electrostatic fields produced from antistatic pink poly pallet bags, taping operations, conveyorized charge generation issues and satellite shroud charging. Consequently, in some cases, a distance of one meter may not be far enough for charge generators listed in Table 2.

Traditionally, in the EPA, 30% to 70% RH has been targeted as an ESD control measure. One excellent source for traceability is the Workmanship NASA-STD 8739.6, Section 6.1.

6.1 TEMPERATURE AND RELATIVE HUMIDITY (RH)

6.1.1 Temperature and relative humidity (RH) shall be monitored in the processing area and maintained within the following limits (Requirement):

a. For temperature: 18° - 30° C (65° - 85° F)
b. Maximum relative humidity: 70 percent RH
c. For ESD-sensitive hardware, minimum humidity: 30% RH
d. For ESD-sensitive hardware, HBM Class 0, minimum humidity: 40% RH

6.1.2 For instances where maintaining an RH level shown in c. or d. above is not practical, special methods, procedures, equipment, and assurance requirements designed to overcome the risks of relative humidity levels below 30% RH shall be used and documented in the applicable ESD Control Program Plan.

If an electrostatic field is in proximity to ESD sensitive devices, then a Field Induced Model (FIM) discharge can take place. Section 8.3.1 on Insulators of ANSI/ESD S20.20-2014 states: "If the field measured on the process required insulator is greater than 2000 volts/inch and the process required insulator is less than 30 cm (12 inches) from the ESDS item, steps shall be taken to either:

A) Separate the required insulator from the ESDS item by a distance of greater than 30 cm
B) (12 inches); or
B) Use ionization or other charge mitigating techniques to neutralize the charge."

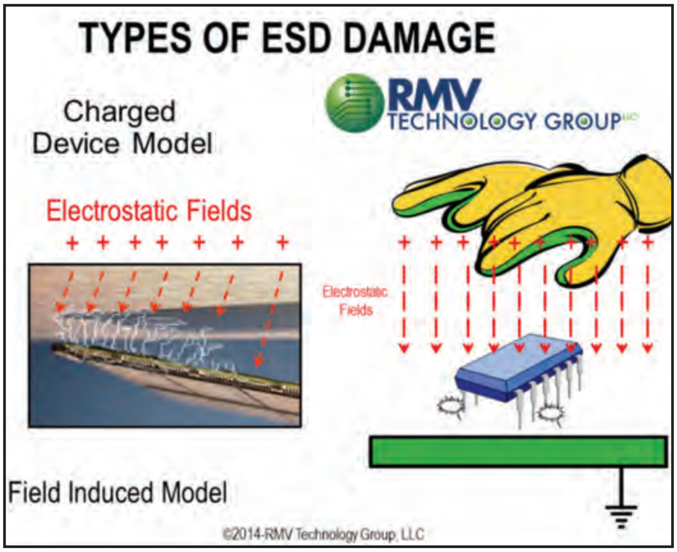

Figure 1

Ungrounded Satellite Shrouds	Polystyrene Sheets	Trash Bag Removal and Insertion
Solar Array Movement within EPA	Lexan Door Opening or Closure where there exists difference in pressure	Polybag removal and placement on Pallets
Antistatic Bubble Removal from Roll	Helicopter Fueling In Proximity to Rotor Blade Motion	US Coast Guard P-Static During Rescue Operations with Basket Retrieval and Placement
Satellite Chassis Movement	Wearable Garments (throwaway)	Flat Panel Displays
Ungrounded Type I & III Films for Satellite Covers	Foam in Place	Antistatic Shrouds

Table 2

The 1 foot rule is inadequate for insulators that can produce far greater voltages than 2000 volts/inch at a distance greater than 1 meter (3.28 feet). At moderate and low RH conditions, large charge generating insulators can still pose problems with ESD sensitive devices.

ANSI/ESD S20.20 states: "If the field measured on the process required insulator is greater than 125 volts/inch and the process required insulator is less than 2.5 cm (1 inch) from the ESDS item, steps A and B above shall be taken. It should be noted that several end user organizations inside and outside the aerospace & defense sector set a limit of <+/-100 volts for ultra-sensitive ESD devices.

In the first example, a blue polymer trash bin was incorrectly positioned approximately 6 inches from an ANSI/ESD S4.1 safe satellite chassis. The resting voltage measured -4,490 volts/inch from the polymer bag trash bin liner. When the trash receptacle was moved away from the satellite, voltage measured -13,683 peak volts at 1 meter when the clear polybag liner was removed from the blue plastic container. Note: The operator was grounded during the measurement process (satellite is not pictured).

Moving approximately 1 foot away from the solar panel array produced voltages of 20,400 and -5,011 volts (Figure 2).

To simulate charge generators at 1.0 foot, the laboratory environment was preconditioned to 30% RH at 73^0F +/-5^0F for 48 hours. In facilitating this test, the insulative polystyrene sheet was grounded. The sheet was simply lifted from a set of several sheets to enable charge-separation (friction) or contact separation. The polystyrene sheet was positioned 1 foot from a non-contact voltage meter and measured -12,440 volts (Figure 3). Clearly, the voltage from insulators can pose a risk to ESD sensitive devices if the >1 meter rule is not enforced within an aerospace EPA.

In Figure 4, the antistatic film peaked out the measuring range of the electrostatic field meter (>20,400 volts) because the topical antistat was inadequate to minimize charge bleed-off. It has been estimated that antistat accelerated aging testing takes approximately 12-14 days[2]. One day at 160^0F equals 17 days at room

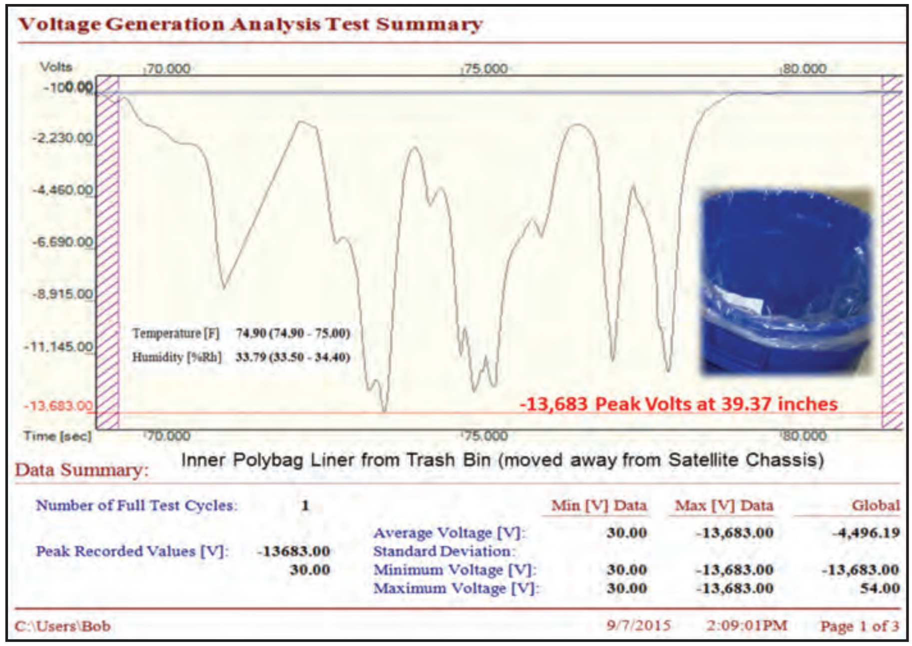

Figure 1

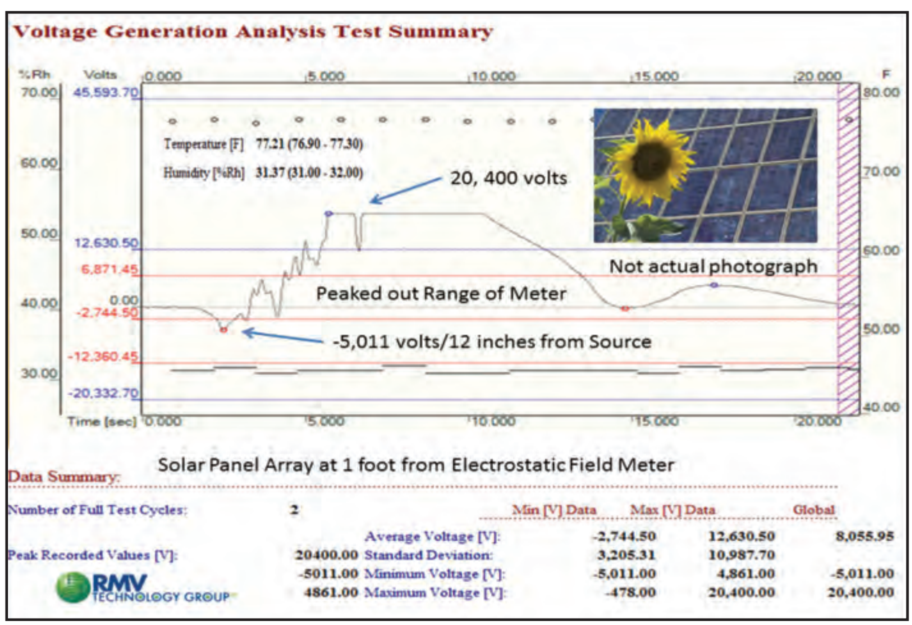

Figure 2

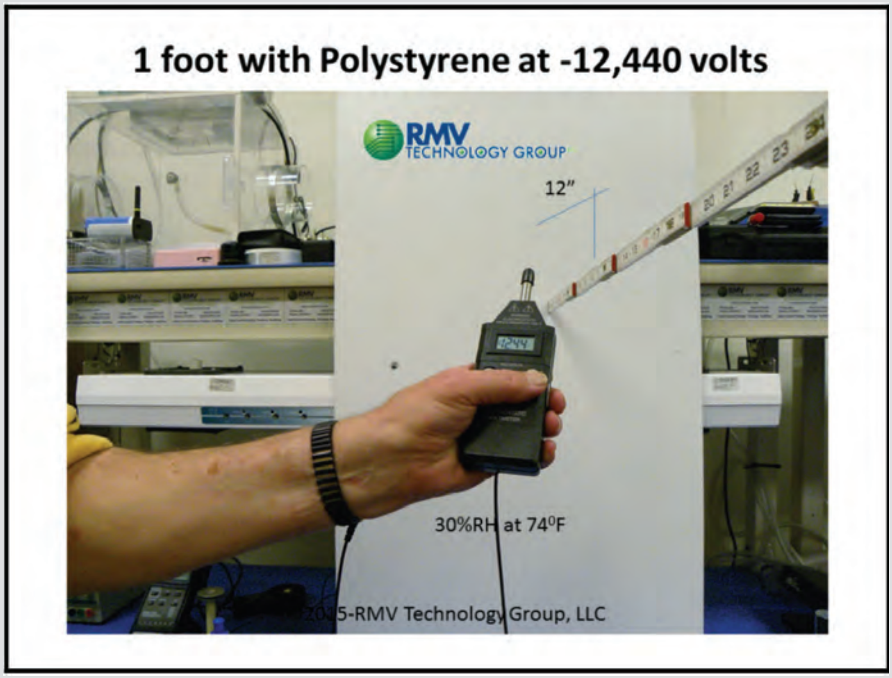

Figure 3

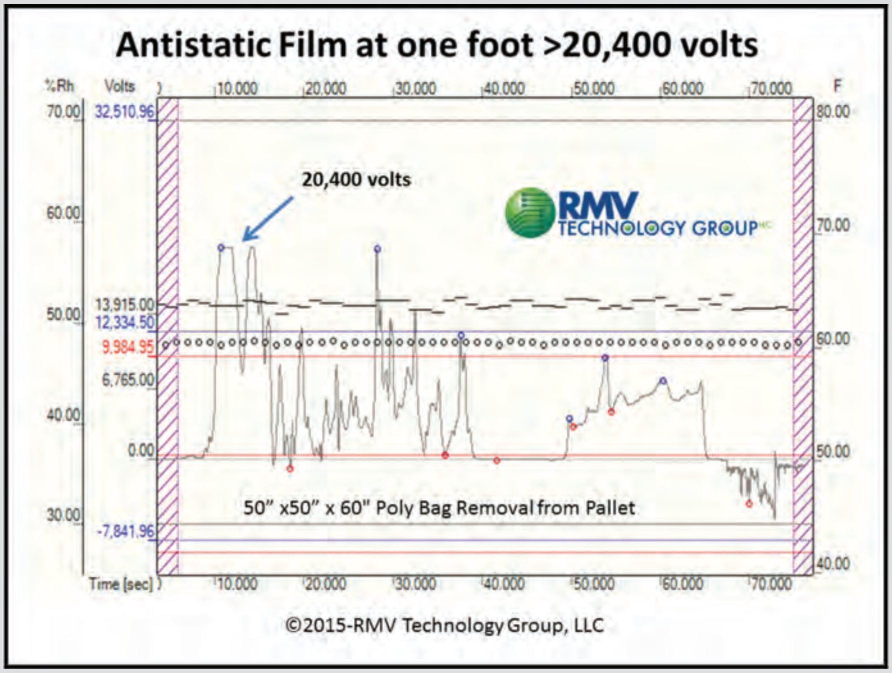

Figure 4

temperature. Thus, a topically coated antistatic sheet may lose the ability to prevent triboelectrification in 204 to 289 days (more or less).

Antistats for long term storage pose issues with longevity and humidity performance during transport and storage. According to the late John Kolyer, Ph.D. (Boeing, retired), antistats can lose effectiveness at 9% RH.

Non-treated Lexan polycarbonate can pose a problem with charging. Product moved along a conveyorized system about 18 inches from the charge source. The inside of the Lexan enclosed environment measured 20%RH, 80^0F; the outside environment measured 50% RH, 60^0F. When the Lexan door was opened by a technician (Figure 5), the rapid rush of air against the polycarbonate door generated 147,400 volts at a distance of 6" using a special static locator capable of measuring between +/-100 volts to +/-200,000 volts. Damage to the product had taken place.

At a distance of 18 inches, two ionizers were in operation. The voltage seen on the conveyorized pallet due to the charge generating Lexan door (Figure 6) produced a reading of 6,010 volts. Treatment of the door's surfaces with an inherently conductive polymer film was utilized while grounding the Lexan door to mitigate charging.

In Figure 8, the reader can see that removal of 4 flat panel display sheets from a storage and transport mechanism accounted for large electrostatic fields at a moderate 39.5% RH level. It should also be noted that transport-storage mechanisms for flat panels (type used in Figure 7) were not grounded as the locking wheels and tile flooring were both insulative.

In summary, one can see from Table 4 that larger insulative platforms require greater distances in excess of 1 foot, and, in some cases, more than one meter to minimize the effects of electrostatic field generation.

A future article mapping Field Induced Model (FIM) discharge would be beneficial to demonstrate the relationship between charge generation and ESD events. If there are mission critical ESD sensitive devices, then one needs to adhere to the 1 meter rule as referenced in the NASA-HANDBOOK 8739.21.

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ABOUT THE AUTHOR

***Bob Vermillion**, CPP/Fellow, is a Certified ESD & Product Safety Engineer-iNARTE with practical and "hands-on" expertise in the mitigation of material Triboelectrification on a Mars surface and in troubleshooting robotics or systems in aerospace, disk drive, medical device , pharmaceutical, automotive and semiconductor sectors. A co-author of several ANSI level ESD documents, Bob is a member of the ESD Association Standards Committee and conducts ESD Seminars in the USA and abroad, including guest speaker engagements for California State Polytechnic University, San Jose State University, University of California at Berkeley, Lawrence Berkeley National Laboratory and Clemson University. In 2015, Bob has been invited to conduct a seminar at Oxford University. Bob is Chief Technology Officer of RMV Technology Group, LLC, a 3rd Party ESD Materials Testing, Training and Consulting Company. Bob can be reached at 650-964-4792 or bob@esdrmv.com*

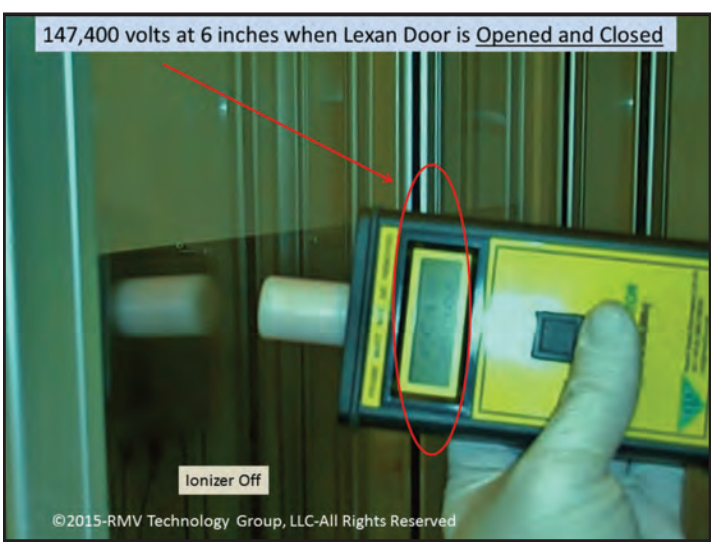


Figure 5

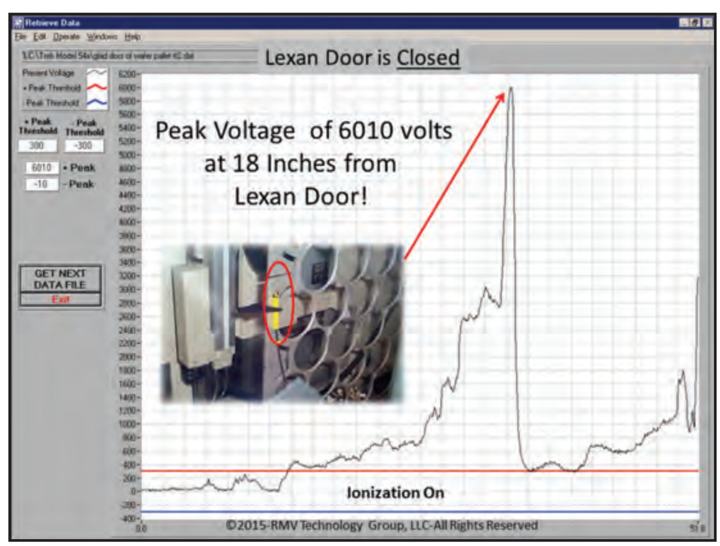


Figure 6

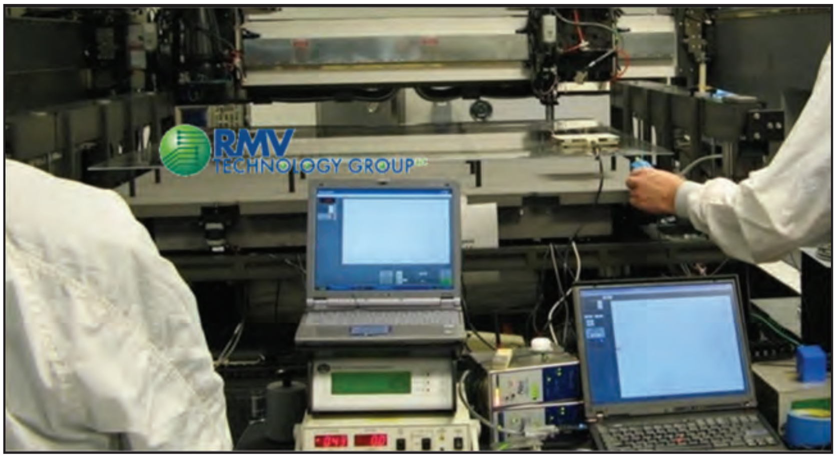


Figure 7

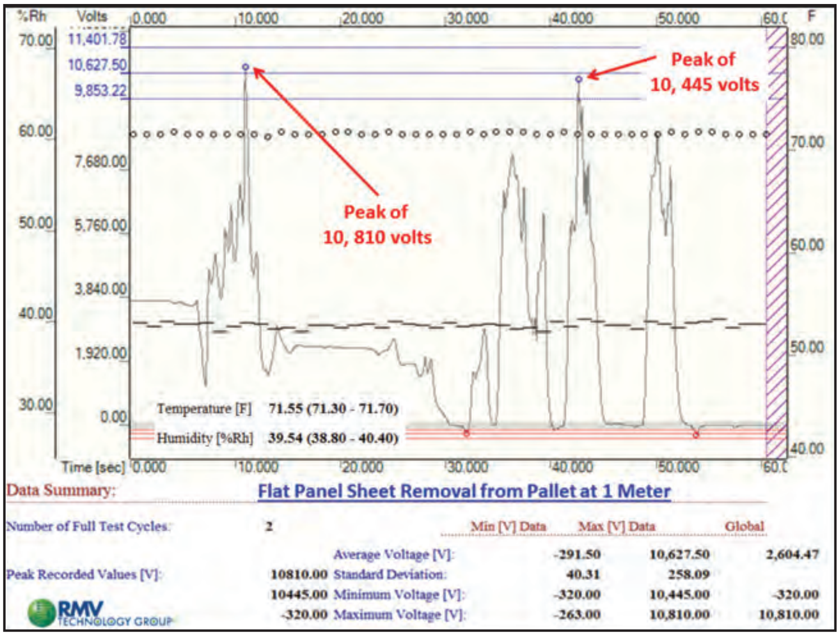
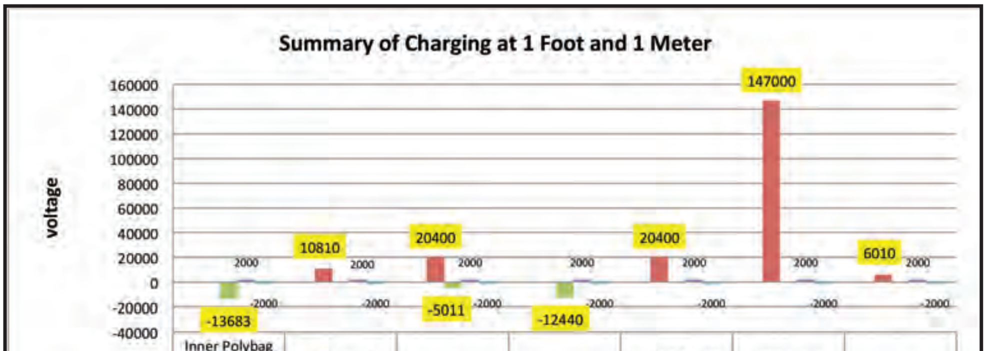


Figure 8



	Inner Polybag Liner Lifted from Trash Bin (moved away from Satellite Chassis)	Flat Panel Display Removal from Storage Rack	Solar Array Panels (in motion)	Polystyrene Sheet 8 Square Feet	50" x50" x 60" Poly Bag Removal from Pallet	Lexan Door (Dynamic, Opened and Closed)	Lexan Door (Closed, at Rest)
Distance (Feet)	3.28	3.28	1	1	1	0.5	1.5
Volts +		10810	20400		20400	147000	6010
Volts -	-13683		-5011	-12440			
Limit + kV/In	2000	2000	2000	2000	2000	2000	2000
Limit -kV/In	-2000	-2000	-2000	-2000	-2000	-2000	-2000

Table 4


interference technology
Home
Buyers' Guide
Articles
Digital Magazines
Europe
About Us
Health Concerns Over Electromagnetic Radiation in India
SUBSCRIBE TO OUR WEEKLY NEWSLETTER
We Got You Covered.
EMC ZONE - LATEST BLOG POSTS
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Is EMC prepared to handle the challenges of the Internet of Things?

GUNTER LANGER
Beratender Ingenieur
Langer EMV-Technik GmbH

INTRODUCTION

THE NUMBER OF MOBILE DEVICES such as smart phones, tablets and wearables has risen significantly over the past years. At the same time, wireless communication has increased due to higher data rates. Will the growing number of wireless devices multiply the EMC problems? Is today's industry able to cope with the EMC requirements that the Internet of Things has in store for us?

If more devices have to interact with each other and their EMC quality remains at the present level, this will lead to more EMC problems from a statistical point of view. Furthermore, a device may be incompatible in practice even though it has passed the compliance test. Let us assume that an electronic device has passed the emission compliance test according to IEC 61000-6-3, IEC 61000-6-4, for example. In contrast to the test, the electronic device may be located near a metallic object such as a housing in practice. This may lead to field coupling which in turn results in higher emissions than in the test. The dimensions of the metallic object are essential in this context. The field may stimulate standing waves that fit the dimensions of the metallic object and then cause additional emissions.

This means that in future, not only will wireless transmission problems arise but also problems due to emissions from devices.

Stricter device standards will not necessarily solve this compatibility issue.

The example above shows that the current compliance tests usually do not take any field coupling mechanisms into consideration. The field coupling mechanisms may induce some helpful ideas on how to solve the problem.

It remains to be seen whether the measuring principles

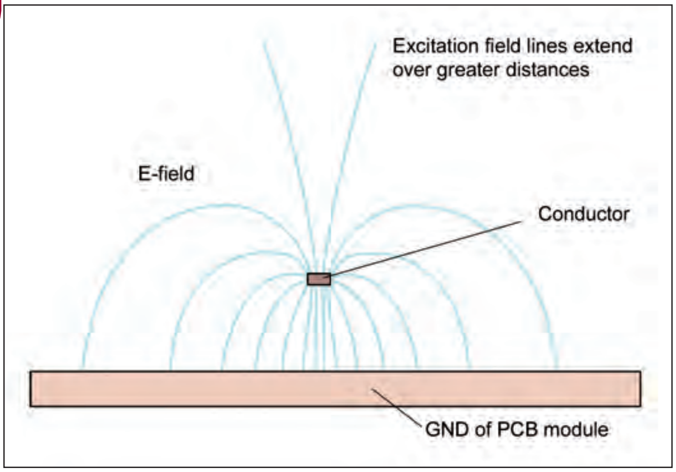


Figure 1 - Electric field of a conductor trace.

specified by the current standards are sufficient or whether new measuring principles will have to be developed.

Furthermore, new requirements are emerging in the field of EMC standards for ICs (IEC 61967 and IEC 62132). Concrete IC EMC parameters will be needed as input values for EMC development tools / simulation programs for PCBs in future. It would be sensible to obtain these EMC parameters from measurements according to IC EMC standards. Unfortunately, the results of standard measurements are currently inadequate for such a purpose.

This procedure will become more important for IC development in the future.

These are the reasons why one should consider adapting the test methods of the standard measurement to this task. This will be shown below for ICs by taking conducted emissions as an example.

The interference suppression strategies currently used in electronics development come up against their limits. ICs as potential emission sources are not noticed as troublemakers until the first development sample has been completed. The developer comes across them when taking interference suppression measures in the device or on the PCB. Near-field probes are used to locate RF sources in the electronics. These do not identify the IC itself as the disturbance source but PCB traces into which the IC feeds disturbance currents and disturbance voltages. The electronics will then be modified with additional components, copper foil or other means. Last but not least, EMC measurements are carried out to confirm the success of the interference suppression measures taken after the redesign of the PCB.

This approach is very time-consuming and expensive. One big problem here is that selective EMC measures cannot be taken until the first functional development sample has been completed. Insights which could be crucial for EMC are gained when it is too late. Important decisions are taken in the development process without considering the results of the EMC test. Problems are almost inevitable because the EMC test results are obtained at such a relatively late point in time.

However, the industry demands faster and more efficient developments in compliance with EMC. This can only be achieved by taking a completely new approach. This has to begin early on in the development process and delves deep into the emissions' chains of action. Only hands-on knowledge of the emission source allows the developer to follow this path. Once ICs have been described more precisely as potential sources of emissions, appropriate measures can be taken much earlier and more efficiently to stabilize the whole device's EMC.

Appropriate EMC parameters are a prerequisite and are thus subject to high demands. They have to describe the EMC problem zones of the ICs for practical use in industry. This means they must be suitable for the development of PCBs in compliance with EMC requirements. In addition, the IC's EMC parameters must be linked with practical measures and strategies.

This approach should define electronics development in terms of EMC. On account of extreme miniaturisation, a higher susceptibility to electromagnetic disturbances is experienced in the field of device development today. The device manufacturers make increasing efforts to address the problems so as to suppress interference in devices and comply with the corresponding standards.

The problems described in the example above aggravate the situation even more. An important requirement for the Internet of Things in particular is that the devices function properly and reliably in their environment.

The extent to which device manufacturers can continue to master the EMC situation which is aggravated on account of the miniaturisation and to suppress interference in devices by spending more time and money on this work remains to be seen. Development in compliance with EMC requirements will represent an increasing share of the costs in device development. It is doubtful whether the EMC objectives will be able to be fulfilled at all. This problem can be mitigated by providing better EMC parameters in the fields of IC research and IC development in future. However, this means that more time and money will have to be spent here too. Of course, this relates to the wireless devices. German industry has started to respond to this mounting pressure.

Companies now work together with EMC advisors in solving EMC-related problems in the development of devices and complex systems by using new EMC technologies from the very beginning of the development process.

MAIN PART

Due to internal functional operations, ICs generate RF voltages, currents and fields. Different physical mechanisms are responsible for these entering cable harnesses in the form of emissions or the surrounding open space in the form of radiation. ICs may have the following effects:

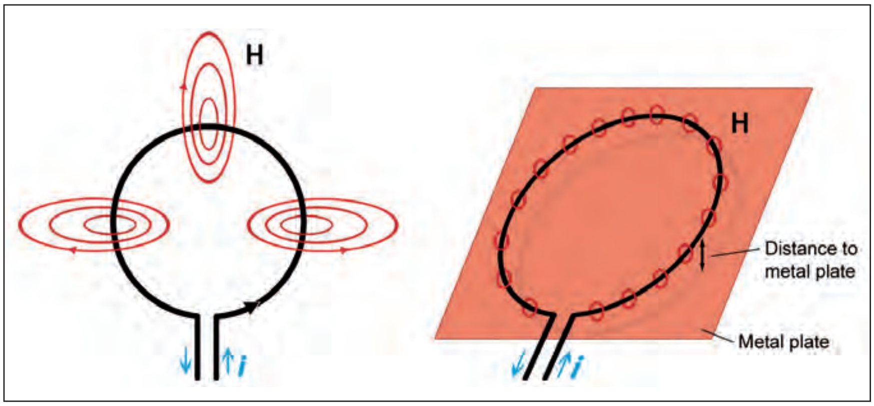


Figure 2: Blocking of a loop antenna's magnetic field by a metal plate. While the magnetic field is blocked, the loop antenna's near fields can stimulate the metal plate to radiate emissions (other radiation characteristics). If the gap between the loop antenna and metal plate is zero, the H-field is also zero.

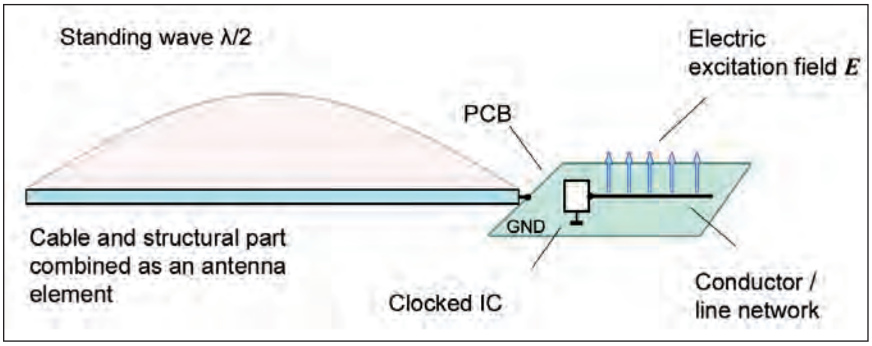


Figure 3: Stimulation of radiated emissions via electric excitation field lines

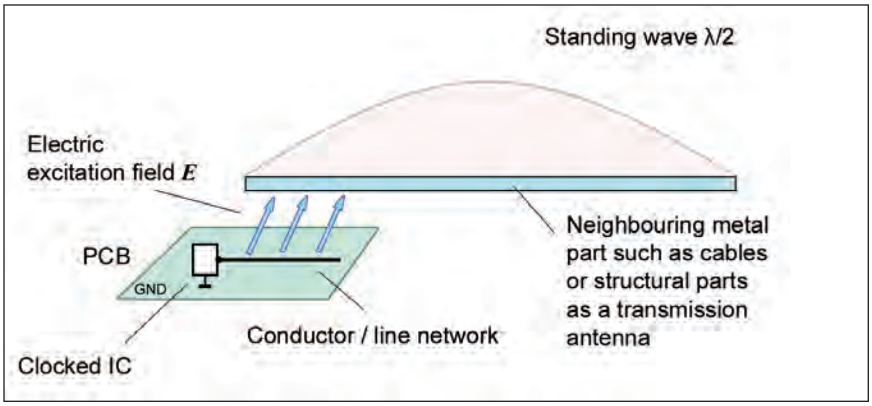


Figure 4: Overcoupling of excitation field lines to neighbouring metal parts

1. **Conductive:** emission of RF currents and voltages via the IC pins into the PCB traces,
2. **Capacitive/inductive:** emission of E- and H-near fields from the die or connections of the IC,
3. **Radiative:** direct emission of electromagnetic waves. Direct emissions are usually only crucial in the Gigahertz range for ICs with very high clock rates in practice.

The following section describes Item 1 and 2: conductive, capacitive and inductive effects in the PCB.

Emissions follow a closed loop. The driving RF-current and RF-voltage sources are located inside the IC. They drive RF into the PCB traces via the bonding wire, lead frame and pin where the current generates magnetic near fields and the voltage generates electric near fields. The electric and magnetic near fields would build up undisturbed if a PCB trace were to be freely positioned in space. The fields are similar to the E-fields and H-fields of an antenna. The electric field is closely coupled to the magnetic field via the antenna element, its current and voltage. This electric field pattern results in the emission of electromagnetic waves. The PCB trace acts as a transmission antenna.

The situation, however, is usually quite different on the PCB. The PCB contains metal surfaces. These metal surfaces usually extend over the entire PCB and have ground or supply voltage potential. The gap between these metal surfaces and the PCB traces is normally < 1 mm. These ground surfaces affect the distribution of the trace's electromagnetic field. The effect can best be described by taking a loop antenna as an example. A loop antenna can emit electromagnetic radiation if positioned freely in space. If the loop antenna is placed on a ground surface, this will prevent the emission of electromagnetic radiation. This is because the corresponding conductive metal surfaces block the magnetic field in the opening of the loop an account of current / field displacement effects (skin effect). The loop antenna's magnetic field can no longer build up around the antenna and is practically no longer present. Radiated emissions from the loop antenna are thus reduced considerably (Figure 2).

The PCB trace reacts in precisely the same way. Direct emissions from the trace are prevented as soon as the ground surfaces in the PCB are large enough. Emissions from the trace will not increase until this is at a certain distance from the ground surface. The required distance depends on the length of the trace. Practical experience shows that the gap must be > 0.5 cm to cause any effective emissions (frequency range < 1 GHz) with a trace length of > 10 cm.

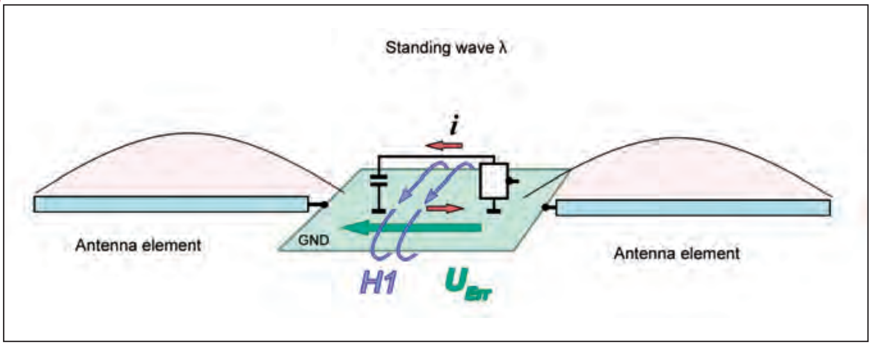


Figure 5: Stimulation of radiated emissions through mutual induction

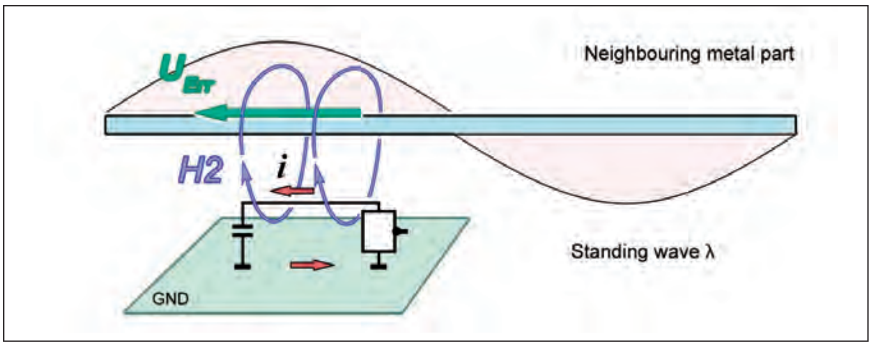


Figure 6: Stimulation of radiated emissions through mutual induction

This means that emissions take other ways from a PCB, namely via its near fields.

These near fields cause emissions through interaction with metal parts (Vdd/Vss surfaces, large metal components, cables and lines, metallic structural parts).

RELATIONSHIP BETWEEN IC VOLTAGE AND EMISSIONS

We refer to the PCB trace in the following text. The traces inside the IC follow the same principles. The statements on the PCB trace can thus be transferred to the traces inside the IC. The pin voltage which is present on the PCB trace or the trace inside the IC builds up an electric field around this trace (Figure 1). Most of the field lines lead to the PCB's GND surface. Only a few field lines leave the PCB vertically upwards and penetrate into open space. The closer the trace is to the edge of the GND system, the more field lines penetrate the space.

These field lines (excitation field lines) leave the PCB's GND system and carry displacement current through space which stimulates the entire metal system (PCB with cables and metallic structural parts) to vibrate electrically (Figure 3).

The standing waves on the metal system may cause emissions. The electric excitation field may reach metal parts (cables, structural parts, shielding plates, Figure 4) located opposite the PCB and these may be stimulated to vibrate electrically by the transferred displacement current.

RELATIONSHIP BETWEEN IC CURRENT AND EMISSIONS

The IC's current loops can either be located inside on the die or loops can be formed by the IC's pins. These loops run through the ground system of the PCB, pin, lead frame, bonding wire and die. This type of loops can be formed via Vdd or Vss pins, for example. The Vdd / Vss loops that penetrate to the outside may be much larger than the loops located inside the die. The larger outer loops can generate a stronger magnetic field and are usually responsible for the highest emissions.

We refer to the PCB trace in the following text. The traces inside the IC follow the same principles.

The statements on the PCB trace can thus be transferred to the traces inside the IC.

The pin current which flows into the PCB trace builds up a magnetic field H2 (Figure 5). The returning pin current also generates a magnetic field H1 in the GND system (Figure 6). It is assumed that the PCB ground is a metal surface which extends over the entire PCB. The trace is so close to the ground that it can usually only generate insignificant emissions, as in the loop antenna example above. The field H1 of the returning current induces a self-induction voltage UErr. in the GND plane of the PCB (metal surface). This voltage drives cables and structural parts that are connected to it like an antenna. The cables and structural parts emit electromagnetic waves as a result.

The magnetic field H2 (Figure 5) of the trace cannot generate any radiated emissions in open space. This is due to the fact that the trace is close to the ground plane, similar to the loop antenna example above, thus preventing emissions. There is another chain of interactions that causes the magnetic field to radiate emissions. This is similar to the one described for the field H1 above. A metal part has to be inserted into the field H2 for this purpose. An excitation voltage is only induced there via mutual induction if the magnetic field encloses a metal part. The excitation voltage stimulates the metal part to act as an antenna. The metal part emits electromagnetic waves. A steering column, a metal strut or a cable in the PCB's neighborhood in a vehicle is taken as an example.

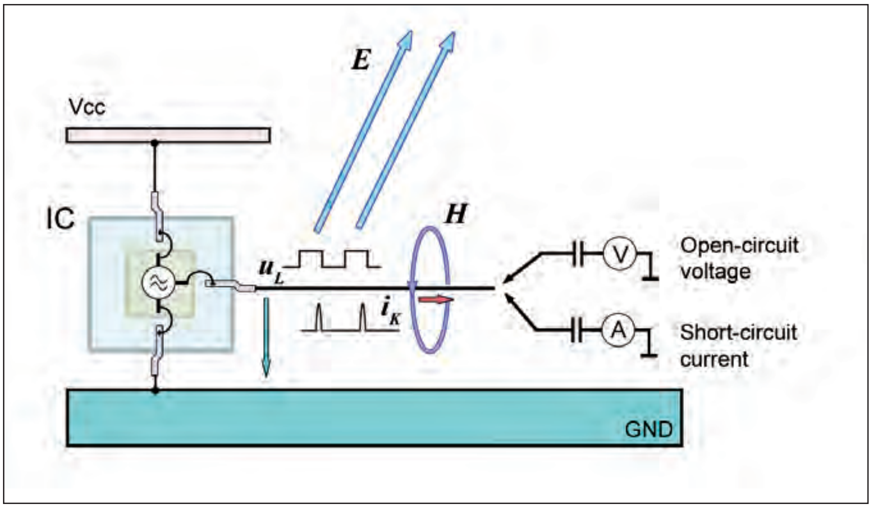


Figure 7: Measurement of pin parameters close to short-circuit and open-circuit conditions.

EMC PARAMETERS FOR IC PINS

The IC pin current and IC pin voltage are the pin-related EMC parameters of an IC. The IC's electric near field and magnetic near field are the field-related EMC parameters of an IC. All four parameters (u, i, E, H) of the IC have to be detected by suitable measuring devices.

The electric near field of the PCB traces is proportional to the pin voltage and the magnetic near field of the conductor loops of the PCB is proportional to the pin current of the IC. The pin current and pin voltage depend on the load to which the pin is subjected through the connected PCB trace.

The values of the cases in which the highest pin voltage and the highest pin current are generated have to be used for the IC parameters.

The current and voltage of the traces depend on the driving voltage in the IC and on the impedance of the load on the PCB traces.

The maximum possible pin current is measured if the pin is operated under short-circuit conditions. The maximum possible pin voltage is measured if the pin is operated under no-load conditions (open circuit). The maximum possible values have therefore been determined and all values from practical operation (determined in a large number of measurements on different PCBs) are equal or smaller.

The voltage, and thus the electric near field, are highest under open-circuit conditions in the PCB traces in special cases. The emission potential is then at its greatest.

The corresponding EMC parameter of the IC is its open-circuit voltage Ul(f).

The magnetic near field is proportional to the current flowing through the trace. The current depends on the IC's driving voltage and the load of the trace. A short circuit may occur in special cases. The current, the magnetic field and thus the emissions are then at their greatest.

The corresponding EMC parameter of the IC is its short-circuit current Ik(f).

The maximum pin current and pin voltage values (Ul(f), Ik(f)) are produced under short-circuit or open-circuit pin conditions. In these cases, the highest emissions are generated via the coupling mechanisms described above.

Hence, it follows that each pin of an IC has its own EMC parameters for conducted emissions. An IC pin's EMC parameters are its open-circuit voltage and its short-circuit current.

The open-circuit voltages and short-circuit currents can be determined for most pins of the IC through measurements under close to open-circuit and short-circuit conditions. Two spectra for each pin result in 128 spectra for a 64-pin IC, for example. Furthermore, the pin can have different switching states (input, output H, L and high-impedance). The internal function may also assume different states (Clk-PLL OFF/ON).

The current in the power supply pins is measured according to the 1 Ohm method. If the resistance of 1 Ohm is too great, a 0.1 Ohm measuring resistor is used. This measurement can be carried out in both the Vdd and Vss. A corresponding high-impedance probe and a decoupling capacitor can be used to measure the RF open-circuit voltage on crystal oscillator pins. The crystal oscillator's filter capacitor may serve as a decoupling capacitor.

The measurements may produce a large amount of data and become difficult to manage. A 3D representation provides a clear overview of the results (Figure 8). A custom-developed measurement set-up with a corresponding software (ChipScan ESA) allows a semi-automatic recording of the pin spectra. The results are visualised in 3D. The representation can be switched over to 2D for selected pins (Figure 12).

USE OF IC PARAMETERS

The 3D spectra clearly reveal the problematic pins for practical applications. Open-circuit voltages in the range of 80 dBµV can lead to limit-exceeding emissions over trace lengths as short as approx. 10 mm (particularly problematic in automobiles). The critical frequency range can be read from the 3D – 2D spectrum. Figure 12 shows this for the crystal oscillator pin 15. The critical frequency range extends up to 600 MHz. The layout and design can be steered in the right direction on the basis of the EMC parameters of the IC pins to save time and money. There will be ICs where individual pins display high values in terms of conducted EMC parameters of the emissions. These values provide helpful advice on how to use the IC on the PCB in a compatible way. Consequently, these ICs need not be excluded from developments. IC users should determine the IC's EMC parameters before they start developing a PCB.

If ICs are integrated without this information (as it is still common practice today), problems will not arise until the

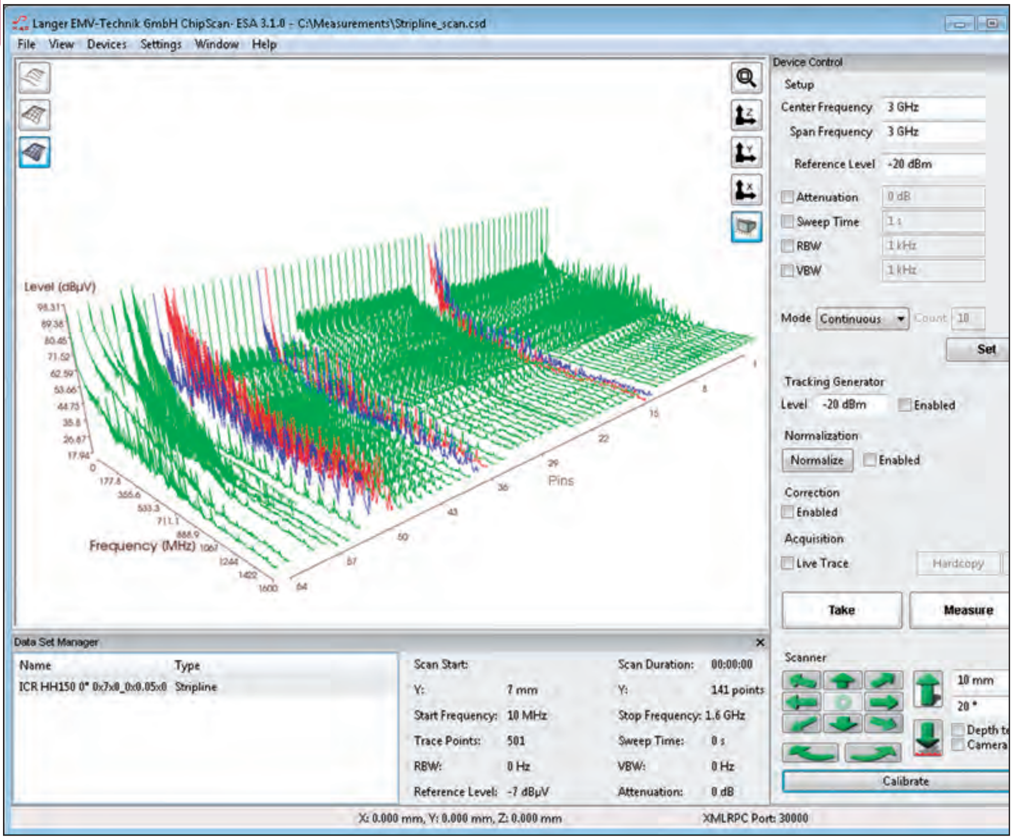


Figure 8: Open-circuit voltage of the test IC 01.

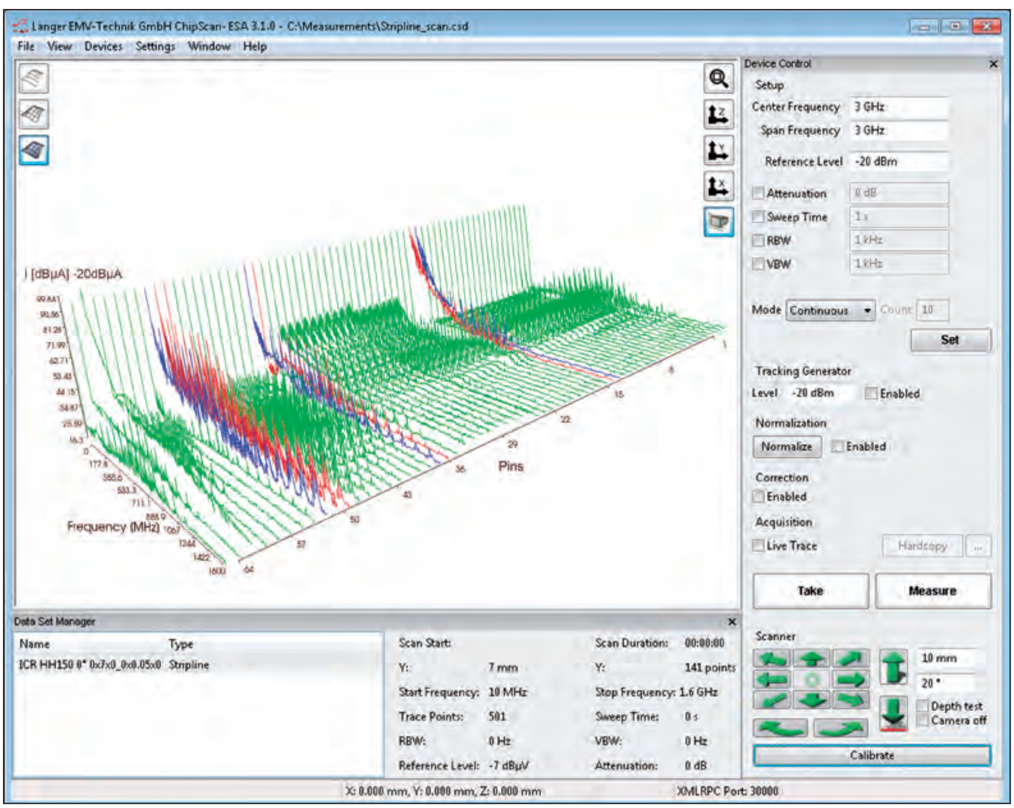


Figure 9: Short-circuit current of the test IC 01.

first development sample has been measured. This entails high costs for time-consuming interference suppression measures (layout changes, design modifications, etc.). This approach also permits an IC to be chosen from a range of alternatives because it will most likely cause lower emissions, and hence it will be easier and less costly to make its PCB assembly EMC compliant.

Two new helpful tools can be created for electronics development on the basis of the IC's EMC parameters:

1. Pin-related open-circuit voltage and short-circuit current spectra (3D / 2D)
2. Layout and design tips in conjunction with the EMC parameters of the IC pins

An EMC specialist can derive such design tips (counter-measures) from the pin spectra, interactions (items 1 and 2) and the character of the special application. However, design hints and tips should better be provided in the form of pin information in practice. The EMC parameters Ul(f), Ik(f) of the IC pins can be grouped in frequency-dependent level ranges with different risk potentials. A certain barrier of design measures has to be built up depending on the risk potential. This strategy will be the basis of EMC activities over the years to come.

Examples of pin-selective counter-measures in terms of open-circuit voltage:

The static port pins 16 to 35 (Figure 8) show high open-circuit voltages. This leads to emissions via the electric field if several port conductors are connected to PCB traces. As a counter-measure, the traces

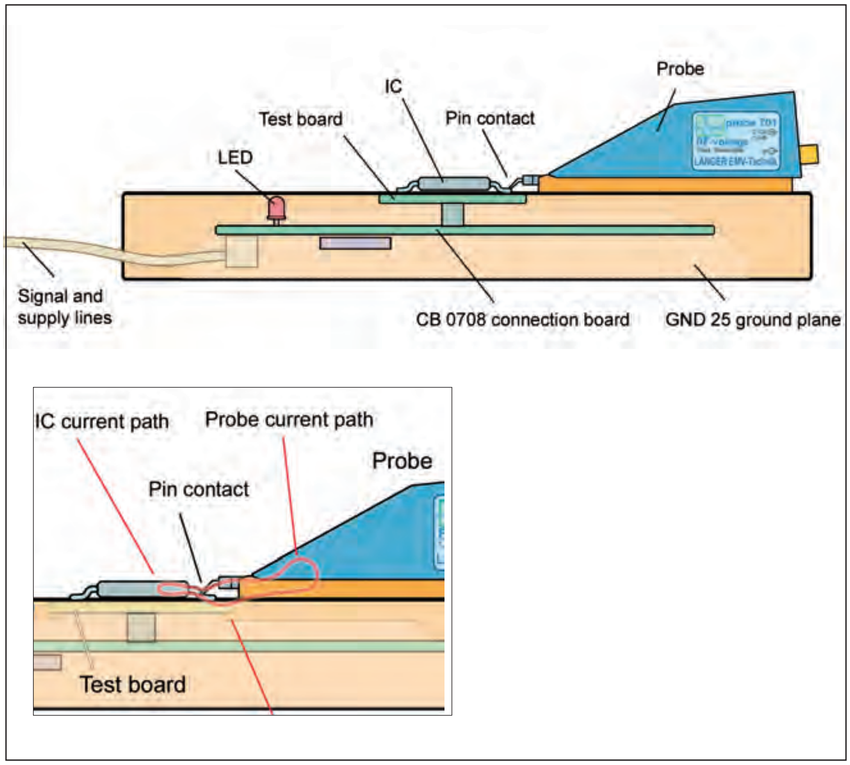


Figure 10: Measurement system for pin current and pin voltage.

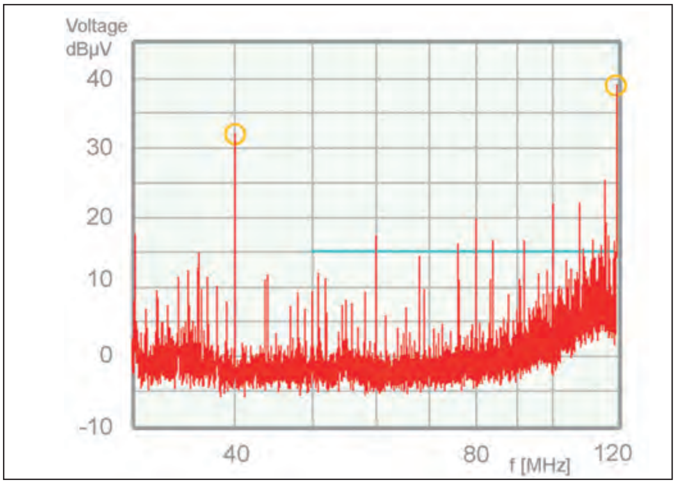


Figure 11: Measurement of an IC 02 application with a simulated on-board power system. Limit value violation of 24 dB at 120 MHz. Cause: E-field coupled out of a trace connected to the IC 02.

should be well enclosed by GND and not be located at the edge of the PCB.

Examples of pin-selective counter-measures in terms of short-circuit current

The port pins 16 to 35 also provide relatively high short-circuit values (Figure 9). Filter capacitors located further away can generate critical current loops. As a counter-measure, the filter capacitors should be located in the vicinity of the IC or series resistors should be inserted.

High values are obtained for the supply pins 12, 13 in the lower frequency range (< 100 MHz) and pins 50, 51, 52 in the medium frequency range (around 500 MHz). As a counter-measure, the current loop that passes over the blocking capacitor can be attenuated with a resistor (< 10 Ohm) or a soft ferrite. The blocking capacitors and the IC should not be too close to the edge of the PCB (> 20 mm). The IC should be positioned so that the IC current loop is orthogonal to the PCB's longest axis. This holds particularly true for PCBs that are not wider than 50 mm. The orientation of the IC current loops can be measured with field probes designed for RF field measurements on ICs and provided as IC EMC field parameters.

MEASUREMENT SYSTEMS FOR EMC PARAMETERS OF IC PINS

Figure 10 shows the measurement set-up for pin current and pin voltage measurements.

The test IC (DUT) is placed on a test board which is embedded in a ground plane. This provides a continuous GND surface as a prerequisite for measurements up to the GHz range.

A (voltage or current) measuring probe whose tip can be moved easily to contact each pin is placed on the GND plane. The measuring path (IC - pin contact - probe) is only a few millimetres long so that the measurement can be carried out at a short electrical distance. The IC is supplied and controlled by the connection board via filters (Figure 10). The connection board is integrated into the ground plane

PRACTICAL EXAMPLE

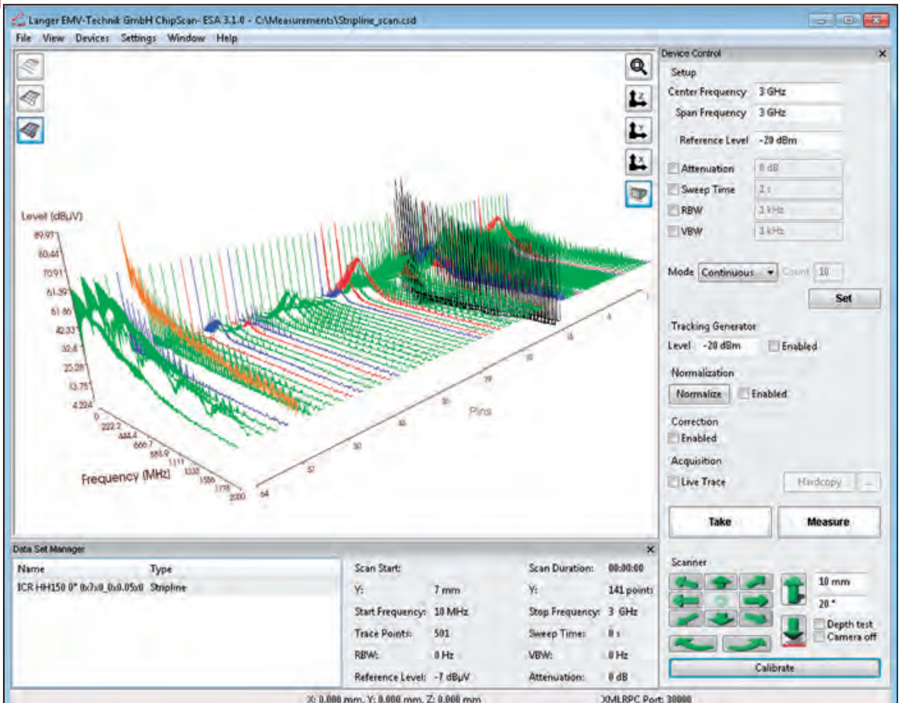
Figure 11 summarises the results of a measurement on vehicle components. The limit value violation of 24 dB occurs at 120 MHz due to an E-field. This problem was not discovered until the development sample was tested. A measurement of the open-circuit voltage Ul(f) of the IC pin as one of the IC EMC parameters reveals the cause.

Exceptionally high voltages (approx. 80 dBµV at 120 MHz) were measured on the IC pins for the crystal oscillator in a 40 MHz grid (shown in black in Figure 12).

All lines and metal parts connected to these pins emit an electric field as described under Item 1 of the physical mechanisms. The electric field is exceptionally strong and causes the PCB and the cable harness to vibrate electrically.

This means that the field is coupled out via:

- the bonding wires and lead frame of the IC pins that lead to the crystal oscillator,



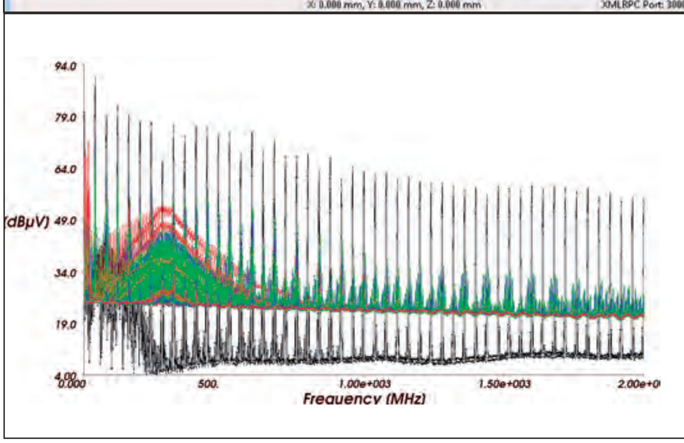
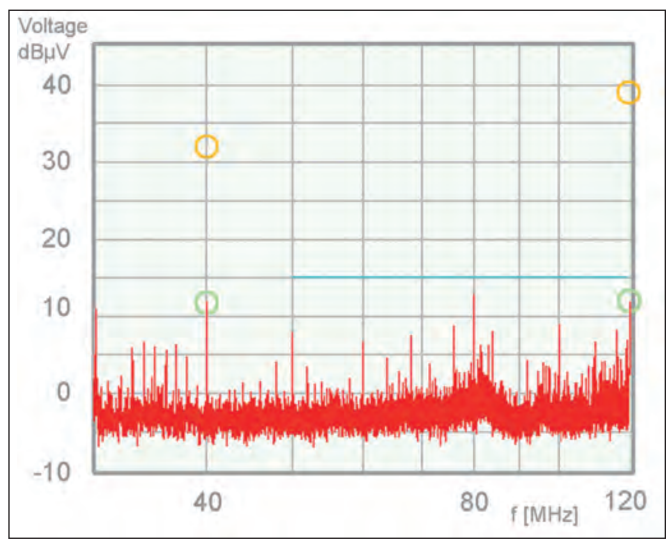


Figure 12 (left and bottom left): Open-circuit voltage measurement on IC 02 in 3D and 2D.

Figure 13 (below): Verification measurement after the counter-measure was taken: the IC 02 shielding prevents E-field from being coupled out.



- the 15 mm PCB traces from the IC to the crystal oscillator,
- the crystal oscillator housing and crystal oscillator wiring 3 x 0603 SMD components.

A suitable remedy in this case is to reduce the surface of these metal parts, i.e. to shorten the traces and embed them in GND, to use smaller crystal oscillator housings. However, these counter-measures are not sufficient in our example. The open-circuit voltage Ul (f) of the pin is so high that the metal surface of the bond wire and lead frame is large enough to cause a limit value violation during the component measurement. Filter capacitors cannot be used to reduce the voltage on the crystal oscillator. An E-field shielding directly above the IC can be used as a final remedy. Figure 13 shows the positive results achieved thanks to these counter-measures. The limit values are met.

The EMC characteristics of ICs can already be determined today. It is useful if values obtained are entered in product data sheets. This information allows the developer to already plan EMC measures that are necessary for the PCB during the development process, so that in principle they can use any IC.

Test methods to determine the IC EMC parameters enable the IC manufacturer to develop ICs more efficiently.

Due to the continued miniaturisation of modules and the high number of very complex electronic devices, the EMC assessment of ICs is a valuable prerequisite for the future development of electronic devices.

The use of IC EMC parameters will also have a positive effect on the development of the Internet of Things.