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What's In This Issue

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New appointments at the EMCTLA

It's all change at the EMCTLA with the resignation of two of the EMC Test Laboratories Associations key people. Tony Maddocks, of ERA Technology, announced his retirement in general, and therefore his retirement as Chairman of the EMCTLA, and Dave Imeson, of Compliance Europe, also announced that he is stepping down as Secretary of the Association. However, Dave retains his interest in the Association by remaining in his role as Treasurer.

The EMCTLA Steering Committee met in early June to fill these two vacancies. Jim Wood, the Associations Vice Chairman, steps up into the role of Chairman. From amongst the members, John Davies, formerly of Blackwood Labs and now with EMC Goggles, was unanimously voted to fulfil the role of Secretary.

Within the EMCTLA there are two main working groups; Working Group (A) which deals with military and aerospace EMC and Working Group (C) which is concerned with commercial EMC. Jim Wood retains his interest as Chairman of WG(A) and Chris Coleman, of Hewlett Packard, who has been involved with the EMCTLA for many years and has an excellent understanding of EMC standards, becomes the newly appointed Chairman of WG(C). John Davies will fulfil the role of Secretary for the Association in both working groups.

Chairman Jim Wood, of EMC Compliance Ltd, said, "The EMCTLA is a well-established and respected Association with excellent links to, and influences in, many standards bodies. I would like to thank Tony and Dave for all they have contributed to the EMCTLA over many years. It has been a pleasure working alongside them and I wish them both well in their new adventures. I am very pleased that Dave will remain with the Association as Treasurer and I wish to welcome both John and Chris into their new roles at the EMCTLA."

John is no stranger to WG(C) members as for the last six years he has represented the Association at both British Standards GEL 210-11 and GEL 210-12 committees. From his role within CISPR John also regularly presents at WG(C) meetings on the status of the forthcoming multimedia EMC standards. However, he will be less familiar to the WG(A) members having had little involvement in the operations of that Working Group until recently.

The Association, which next year will be celebrating its 20 anniversary, has an excellent presence in EMC standardisation committees with several representatives at the British Standards committees, some of whom go on to represent the UK National Committee at the IEC and at CISPR.

John Davies, the newly appointed Secretary is one such person. He says, "I have been involved with the EMCTLA for over 15 years and I am very excited by the challenge I now face of being its Secretary. Dave has done an exceptional job as Secretary for so many years and it will be extremely difficult for anyone to fill his shoes. The EMCTLA membership, mostly comprising of test houses and consultants, are dependent on test standards which are clear, technically correct and provide for a commonality of application. Within my new position I shall do all I can to help improve this not just for the benefit of our members but for the benefit of the EMC industry as a whole."

The full list of current appointments is as follows:

Chairman: Jim Wood.

Secretary: John Davies.

Treasurer: Dave Imeson.
Steering Committee members: Jim Wood, John Davies, Dave Imeson, Phil Carter & Ken Webb.
WG(A) Chairman: Jim Wood.
WG(C) Chairman: Chris Coleman.

Their next Working Group meetings are scheduled for 26th & 27 October.

www.emctla.co.uk

Front Cover

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Circle middle, Chomerics, page 23
Circle bottom, Rohde & Schwarz, page 22

Secretariat for EMCIA

emcia
Electromagnetic Compatibility Industry Association

The Trade Association for the EMC Industry.
Web: www.emcia.org

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Relocation of TRaC's Southern Labs creates unique Aerospace EMC test facility

TRaC is pleased to announce that in September 2011 it will greatly expand its EMC and Environmental testing facilities in the south of England; TRaC's new location near Wimborne, Dorset, will be a UK centre of excellence for, in particular, all aspects of EMC testing for the Aerospace and Defence industries, and enhancing the established local commercial EMC and Safety facilities currently serving the region.

TRaC South will host a range of test facilities including: three EMC chambers capable of testing to a broad range of military/aerospace standards; two further chambers for commercial testing (CISPR 16-1-4 compliant) in which European (CE Mark) and US (FCC) approvals can be secured; and a further chamber specifically dedicated to transient testing.

Coupled with existing lightning capabilities, TRaC will have a comprehensive capability to apply high-intensity radiated field (HIRF) tests, at field strengths up to 5000 V/m over a broad frequency range, within its chambers. This significant investment of reverberation chambers and very high power amplifiers will provide unrivalled RF fields for mission critical equipment for the aircraft and military market.

The new facilities take into account large heavy equipments and hence offer large doors for direct fork-lift access, space to manoeuvre large items and turntables capable of 2 tonne payloads.

The new site in the south of England will also provide environmental test facilities, including vibration and shock; temperature, humidity and salt-spray chambers; environmental noise assessment; and hydraulic fatigue testing. TRaC will install one of its largest and most powerful electromagnetic shaker tables at the facility, also with a 2-tonne load capability.

Our technical expertise and capabilities are underpinned by independent accreditation and approval to industry specific and international standards; The TRaC South facility will be accredited by UKAS to ISO 17025. As a CAA recognised test laboratory, our test reports are recognised and accepted by the global civil aviation industry. TRaC is a Notified Body under many CE marking directives in addition to the international recognition of equivalents around the world. TRaC is in an ideal position to offer not only testing services, but design advice, consultancy and diagnostic analysis on the outcome of test failures.

TRaC's new south of England site will open in September in Three Legged Cross, Wimborne, Dorset: it will consolidate – and greatly expand on – the services that TRaC presently provides from nearby locations at Ringwood and Wimborne, and represents an investment of close to £2million by the company. Newly constructed test chambers will be fully operational before the transition, allowing uninterrupted service.

www.tracglobal.com

HITEK goes from strength to strength

HITEK Electronic Materials Ltd the Scunthorpe based Distributor/Fabricator of specialised electronic materials is having an amazing year what with turnover exceeding last years already, the acquisition of AS9100 accreditation along side its ISO 9001-2008 listing, its work on SC21 and the new Apprentice programme which sees three new Apprentices joining the Company.

To top it all, winning the Kimberly-Clark Innovation award and the prestigious Forrestor Boyd Business Excellence award at the recent North Lincolnshire Business Awards 2011 event was the icing on the cake.

The event, at which HITEK had taken ten members of staff to celebrate the occasion, confirmed the great work being done by all the members of the team. John Terry, Managing Director said "We have always strived to be the best, to have the highest quality standards, the best delivery times, the most competent staff, and the best world class suppliers and winning these two major wards show that our achievements have been recognised by our peers".

Ten members of the Company plus the two awards at the Grimsby Auditorium 20th May 2011

The two beautiful cut glass awards will now take pride of place in the display cabinet.

www.hitek-ltd.co.uk

emcia Member

EADS Astrium antenna radio frequency measurement tool features AVS OpenViz software

EADS Astrium, the world leader in satellite systems design and manufacturing, has deployed a software system for measuring antenna radio frequencies that utilises OpenViz data visualization software from Advanced Visual Systems.

The system, known as EADS Astrium Advanced Antenna Measurement Software (AAMS), allows fully automated testing of antenna systems installed in ground vehicles, aircraft, unmanned aerial vehicles, missiles and satellites. OpenViz data visualization software enables AAMS test results to be presented using highly interactive graphs that quickly expose irregularities and allow test personnel to fully comprehend a broad range of sophisticated data inputs.

According to EADS Astrium, "Advanced developments in wireless communication technology require highly reliable radio transmission between ground, air and space systems and networks. Antenna performance plays a critical role in these systems and our AAMS technology relies on AVS data visualization software to help technicians properly understand extremely complex measurements through an intuitive and flexible user interface."

Measurements analysed using AAMS include radio frequency pattern, gain, polarisation, signal purity and other metrics that contribute to quality communication system design, maintenance and security. EADS Astrium selected OpenViz to visualise its sophisticated data because the AVS product enabled the design of extremely customised graphics that could be deployed to radio frequency engineers in a multi-function desktop application.

OpenViz is a comprehensive data visualization system for all Java and Microsoft platforms that enables solution development teams to create highly interactive visual presentations from any type of data. Featuring over 20,000 different types of technical and business charts and graphs, OpenViz is used by leading corporations and software vendors to create specialised applications that deliver rapid insight to all types of decision makers.

www.avs.com

EMCUK 2011

The Racecourse, Newbury
11 & 12 October 2011

Companies who have already Booked for 2011

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IEEE EMC Society UKRI Chapter
IO Electronics Ltd
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If you are interested in taking a stand please contact Lynne Rowland on +44 (0)1208 851530 or email: lynne@theemcjournal.co.uk

To Visit the Exhibition, register for your FREE Exhibitor Ticket Now at www.emcuk.co.uk/visitors/registration.asp

Steering Committee

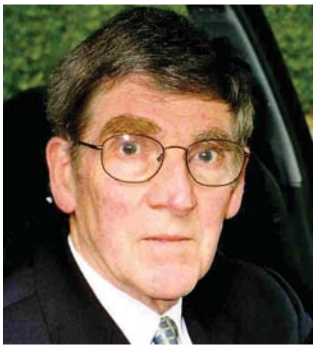
Keith Armstrong CEng FIET SMIEEE ACGI
Cherry Clough Consultants

John Davies
Managing Director
EMC Goggles Ltd

Paul Duxbury
CST UK Ltd

Steve Hayes CEng MIET
Managing Director
TRaC EMC & Safety Ltd

Ian MacDiarmid BEng MSc MBA CEng FIET
BAE Systems (MAS)



Richard Marshall MA (Cantab) CEng FIEE FInst.P
Richard Marshall Ltd

Tim Williams
Elmac Services

Alan Warner
EMCUK Conference Director

EMCUK 2011 Training Program Practical Demonstrations

Many people come to the EMCUK training sessions to learn new tricks or re-learn old ones, or just as a refresher to keep up-to-date with EMC ideas. This year's sessions will concentrate on some specific subjects, both theoretical and practical, and demonstrations are a feature of all these presentations.

The three presenters of this year's event will include practical technical demonstrations, displayed using a multi screen process.

A combination of the power point detail of the experiments/ demonstrations along side of a live camera showing the physical changes made to demonstrations, as well as the spectral effects of either conducted or radiated emissions displayed on a spectrum analyser, the video output of which will also be displayed on one of the screens.

Tim and John will be using one of the latest Rohde & Schwarz analysers, type FSL3 with tracking generator, kindly loaned by Rohde & Schwarz for the training sessions.

Keith's demonstration will be using a low cost spectrum analyser, with simple DIY lop probes, again the detail will be displayed using the multi screen system.

The R&S®FSL is an extremely lightweight and compact spectrum analyzer for cost-conscious users who want the functionality of high-end instruments.

The analyzer is ideal for a large number of applications in development, service and production

Kindly loaned by Rohde & Schwarz.
See them on Stands 12 & 13.

The Three for All: We want your Chestnuts

Panel session with the audience, discussing any questions on EMC design, testing and compliance. As well as questions from the audience, we'll be batting around a few old chestnuts – which end of the cable screen to ground, where to connect the safety earth or split a ground plane, and so forth.

If you have a particular issue (perhaps even your own pet chestnut) which you'd like to air in open session, please send it in by email to: emcuk2011@emcuk.co.uk.

Book your place NOW at the Technical or Training sessions
www.emcuk.co.uk/conference/

Technical Forum and Training Programme

Electromagnetic Compatibility Technical Forum

Tuesday 11th October 2011

08.30 Registration

09.00-10.30 **EMC in Defence Systems**

Chairman
Ian MacDiarmid, *BAE Systems (Military Air Solutions)*

Modelling Versus Measurement in Maritime Platforms
Jonathan Burbage, *BAE Systems*

Cots Procurement for Military Systems
Ian MacDiarmid, *BAE Systems (Military Air Solutions)*

High E-Field EMC Testing in a Mini-Reverberation Chamber
Colin Lawrence, *MBDA UK Ltd*

10.30-11.00 Coffee & Visit to Exhibition Stands

11.00-12.30 Automated Comparison of EMC Datasets
Dr Chris Jones, *BAE Systems (Military Air Solutions)*

EMC & Functional Safety in Defence Standards
Peter Dorey, *TÜV SÜD Product Service Ltd*

Paper 3
TBC

12.30-14.00 Lunch & Visit to Exhibition Stands

14.00-15.30 **EMC in Buildings & Infrastructure**

Chairman
Keith Armstrong, *Cherry Clough Consultants*

Protection of Electronics and Installations
Dr Alexander van Deursen, *Department of Electrical Engineering - Electrical Energy Systems, Technical University of Eindhoven: TU/e*

High Power Electromagnetic (HPEM) Environments: Emerging Requirements and Standards for the Protection of Buildings and Infrastructure
Richard Hoad, *Electromagnetic and Environmental Services (EMES), QinetiQ*

Offshore Power Quality - A Case for Concern!
Ian C Evans, *Harmonic Solutions Co.Uk*

15.30-16.00 Tea & Visit to Exhibition Stands

15.00-17.30 EMC at ITER - the World's Largest Nuclear Fusion Generator
David Beltran, *ITER Organisation*

EMC for Theatres, Recording & Television Studios
Tony Waldron, *CADAC Electronics*

Modelling for the Protection of Facilities
Paul Duxbury, *CST UK Ltd*

17.30 Finish

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Wednesday 12th October 2011

08.30 Registration

09.00-10.30 **EMC in Transport Systems (including: Electric Vehicles)**

Chairman
Steve Hayes, *TRaC EMC & Safety Ltd*

EMC in Railway Systems (Panel Session)

Achieving EMC for the Railway - Examples from Key Projects
Ken Webb, *Mott Macdonald*

EMC Analytical and Verification Techniques used in Signalling Systems
Stuart Charles, *E-mead Consulting Ltd*

EMC & Fixed Installation in Railway Systems
Damon High, *TÜV SÜD Product Service*

10.30-11.00 Coffee & Visit to Exhibition Stands

11.00-12.30 **EMC in Electric Vehicles & their Charging Systems** (Panel Session)

Hybrid Vehicle Specs & Testing, Vehicle Directive Update
Peter Phillips, *MIRA Ltd*

EU Developments in Electromobility
Steve Hayes, *TRaC*

Electric Drives in Transport
TBC, *BAE Systems*

12.30-14.00 Lunch & Visit to Exhibition Stands

14.00-15.30 **EMC in Consumer Electronics, including Diagnostics & Smart Grid/Metering**

Chairman
Paul Duxbury, *CST UK Ltd*

Smart Grid/Metering (Panel Session)

Smart Grid/Meters, an Overview for EMC Engineers
Simon Harrison, *Engage Consulting Ltd*

PPLT & Smart Grid
Richard Marshall, *Richard Marshall Ltd*

Existing Utility Infrastructures and Smart Grid Initiatives
Mark Buckland, *Echelon*

15.30-16.00 Tea & Visit to Exhibition Stands

16.00-17.30 Radio and EMC Compliance for Smart Grid and the Connected Home
Joe Lomako, *TRaC*

EMC in Testing & Diagnostics

Innovative EMI Diagnosis with New Real-Time Spectrum Analysis
Karl-Heinz Weidner, *Rohde & Schwarz UK Ltd*

Using Noise Floor Extension to Improve Measurement Accuracy
TBC, *Agilent Technologies UK Ltd*

17.30 Finish

EMC Training Programme

Tuesday 11th October 2011

08.30 Registration

09.00 – 10.30 **Tim Williams**
ELMAC Services Ltd

Theory and live demonstration of:

- Coupling between wires, showing common impedance, mutual inductance, mutual capacitance and the effect of shielding
- The effect of a slot in a ground plane: why you should avoid it
- Mutual coupling of wire pairs: from mains cable to high-quality coax, why running signal and return together is so important

10.30 – 11.00 Coffee & Visit to Exhibition Stands

11.00 – 12.30 **Keith Armstrong**
Cherry Clough Consultants

A live demonstration of how easy it is to use a home-made loop probe – perhaps made from a paper clip – with a spectrum analyser costing less than £1000, to quickly and easily diagnose common EMC problems, such as:

- slots and seams in enclosures causing problems for shielding
- inappropriate types of cables and connectors
- assembly details that can cause problems for filtering
- inadequate filtering causing radiated emission problems above 30MHz
- inadequate shielding causing conducted emission problems below 30MHz

12.30 – 14.00 Lunch & Visit to Exhibition Stands

14.00 – 15.30 **John Davies**
EMC Goggles Ltd

Visual training with practical demonstrations of:

- Understanding EMC. A sample of the EMC Goggles training course.
- The components are everywhere! See the invisible components and use them to your advantage.
- EMC design - emissions from PCBs. Live demonstration of Good versus Bad.
- After discovering an EMC failure in the lab, some tips and tricks on how to quickly diagnose the cause and also how to implement the solution.

15.30 – 16.00 Tea & Visit to Exhibition Stands

16.00 – 17.30 **John Davies**
EMC Goggles Ltd

Continuation of above.

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Just £155+VAT per day. Includes lunch, proceedings, coffee & tea breaks

Wednesday 12th October 2011

08.30 Registration

09.00 – 10.30 **Tim Williams**
ELMAC Services Ltd

Theory and live demonstration of:

- Cable shielding and the effect of a pigtail versus a proper connection
- Self-resonance of components: the effect of parasitic inductance and capacitance, ferrite materials, and terminating impedance of filters, from SM to mains components
- Inductive coupling to a small loop: why scope probes don't always tell the truth

10.30 – 11.00 Coffee & Visit to Exhibition Stands

11.00 – 12.30 **Keith Armstrong**
Cherry Clough Consultants

Using quick, easy, low-cost close-field probing techniques to reduce financial risks in every stage of a new product's project:

- Proof of design principle
- Design, and component selection
- Development
- Fixing problems during compliance tests
- QA of EMC performance in serial manufacture
- Checking EMC effects of proposed design changes, component substitutions and software upgrades
- Helping ensure EMC of systems and installations
- Maintaining EMC despite maintenance, repair, upgrades, modifications, etc.

12.30 – 14.00 Lunch & Visit to Exhibition Stands

14.00 – 16.00 **Keith Armstrong, Tim Williams & John Davies**

Note! **The Three For All**: Panel session with the audience, discussing any questions on EMC design, testing and compliance. As well as questions from the audience, we'll be batting around a few old chestnuts – which end of the cable screen to ground, where to connect the safety earth or split a ground plane, and so forth. If you have a particular issue (perhaps even your own pet chestnut) which you'd like to air in open session, please email: **emcuk2011@emcuk.co.uk**

The presenters:

- Tim Williams is with Elmac Services, offering advice and training in all aspects of EMC design and test. He is the author of EMC for Product Designers, now in its fourth edition.
- Keith Armstrong is with Cherry Clough Consultants, and has been fixing EMC problems, providing special assistance with EMC management and design, and teaching EMC and safety training courses worldwide, on everything from cellphone PCBs to complete synchrotrons and tokamaks, since 1990. He has recently written some books on EMC design techniques.
- John Davies has over 20 years of EMC testing experience, the last 7 years as Managing Director of Blackwood Labs. He has now formed EMC Goggles, a training and consultancy company.

Banana Skins...

Editor's note: The volume of potential Banana Skins that I receive is much greater than can possibly be published in the Journal, and no doubt they are just the topmost tip of the EMI iceberg. Keep them coming! But please don't be disappointed if your contribution doesn't appear for a while, or at all. I need at least eight pages in every EMC Journal just to keep up!

644 Power supply RFI "flat earthers"

Patrick Andre, of Andre Consulting, Inc., found out what is was like to face a group of engineers who thought the Earth was flat or at least that power supplies couldn't possibly radiate at 230MHz. As usual, the story is told from the teller's perspective.

"One day I was called in by a Washington State medical instrumentation company to assist in finding the source of emissions. When I arrived I was informed that if in the next week or so, I could find the problem they were having during radiated emissions, it would save them a great deal of money. The radiated emissions were out of specification by at least 10dB at 230MHz, and about 5dB at 180MHz. They were already into a production hold, a schedule slide, and looking at circuit board turns and software changes.

I was led into a room where I met about 10 people who were involved with the problem. They included engineers flown in from the east coast, various consultants and contractors, staff engineers, and technicians. I was presented with enormous, stacks of test data, schematics, drawings, and the like. The whole thing was overwhelming. After listening to a barrage of confusing and conflicting data, I asked them if we could just go down to their EMI laboratory to see what might be going on.

I found the unit to be a roll around rack, six feet high, four feet wide, four feet deep, made up of stainless steel racks, each with filtered connectors, properly terminated coax, and high quality EMI gaskets on the lid. The lid was held down with thousands of screws, maybe more. After the lid was finally removed, the inside contained a well-designed circuit board, carefully routed cabling, and the addition of several pounds of clip on ferrites. The thing was bulletproof.

It was about this time I found out one key piece of information. The emissions only occurred when the "incubation heater" was energized. I asked where the power to the incubation circuit came from. I was shown the place on the circuit board where it was routed, and how it came from this connector on this back corner. So I asked, "The power for the incubation circuit comes from off the board?" "Oh yes", I was told, "It comes from this power supply. Mounted up here." And there sat a power supply on the top of the rack of equipment.

I asked if we could change that power supply for a linear power supply. The room fell silent. I got stares from the small crowd watching me as if I had two noses. I heard someone question my general value to the project for thinking a power supply could generate 230MHz. I said, "Humor me. Get a linear power supply and let us eliminate it as a possibility." The technician brought back a nice HP power supply, placed it in circuit and we turned on the unit. From 150MHz and higher, emissions dropped 50dB – to the noise floor of the spectrum analyzer. I spent the next hour slowly removing the several pounds of added ferrite before calling it a day."

*(Taken from "**Don't Be Silly . . . If Can't Be That!**" by Todd Robinson, Associate Editor, in the "Chapter Chatter" section of the IEEE EMC Society newsletter, Issue 218, Summer 2008, page 10, http://www.emcs.org.)*

645 Emissions limits do not protect built-in radio receivers

It has been known for some time that signals running on the LCD panel in a notebook can create EMI. This EMI not only can be an issue for FCC compliance, it also poses an even greater problem for wireless devices that are now being put in notebooks.

Some of this noise comes from video data, but some of the most serious levels of noise come from clock signals (namely pixel clock) whose harmonics can fall into radio bands. Below is an illustration of such an example. Here the 65MHz pixel clock on a commercially available notebook is causing harmonics (37th and 38th) to be generated that fall into the wireless 802.11b, g band.

Generally, the level of emissions is controlled only to the extent needed to pass FCC unintentional (part 15) emissions. However, to satisfy radio requirements, the level of interference needs to be much lower.

Figure 1 below is an example of the noise taken from a laptop with the FCC limits and wireless requirements shown. Typically, a gap of more than 45dB exists between these limits. The present FCC limits obviously are not sufficient to protect built-in radios unless manufacturers address the real radio requirements for EMI.

*(Taken from "**A Study of Platform EMI from LCD Panels – Impact on Wireless, Root Causes and Mitigation Methods**", by Jin Shi, Al Bettner and Gordon Chinn, Mobile Platforms Group, Intel Corporation, Santa Clara, CA, 95054, Kevin Slattery and Xiaopeng Dong, Corporate Technology Group, Intel Corporation, Hillsboro, OR 97124, International Symposium on EMC, Portland, OR, USA, 14-18 Aug 2006, www.emcs.org.)*

646 The battle for the airwaves

Battles of the airwaves are fought by network operators locating sources of interference, regulators countering pirate radio, and the armed forces hunting out signals from terrorists. All use radio monitoring in the field.

Private radio stations account for the majority of illegal broadcasts. They tend to operate within cities, generally on the FM radio frequencies of 87.5 to l08MHz. But interference also arises from other causes: poorly installed wireless LANS, older CB equipment and amateur radio, badly suppressed electrical equipment, or even faulty lightbulbs or thermostats.

Regulators (such as Ofcom) police radio spectrum by pinpointing sources of interfering radio signals. While interference takes many forms, regulatory authorities have a duty to act when it is caused with intent, particularly if it causes interference with the safety critical air traffic and marine bands.

Meanwhile, network operators are waging their own battle with radio interference. In response to problems such as poor voice quality; dropped calls or low data rates, network operators employ field engineers to track down and eliminate the interference. Faulty network equipment is a major source of the problem.

Interference is also more prevalent nowadays because network operators continually add voice and data services, so the licensed bands become more susceptible to it. The trend to install multiple basestations on each site has also increased interference potential.
*(Taken from "**The Signal Hunters**", by John Andrews, IET Engineering & Technology magazine, 5 Jul – 18 Jul 2008, page 78, www.theiet.org/engtechmag)*

647 Satellite broadband service delayed by interference to GPS

Until LightSquared comes up with a plan that completely protects existing GPS navigation devices from interference, LightSquared cannot operate its satellite-based broadband service.
*(Taken from "**GNSS System Congressional Committee Blocks FCC Approval of LightSquared**", GPS World, June 27, 2011, http://www.gpsworld.com/gnss-system/news/congressional-committee-blocks-fcc-approval-lightsquared-11818, reported by Interference Technology magazine on 29th June 2011, at www.interferencetechnology.com/lead-news/article/congressional-committee-blocks-fcc-approval-of-lightsquared.html.)*

648 Doomsday Plane's Immunity to Electromagnetic Pulse Determined via RS105 Testing

Metlabs admin, June 23, 2011, file under EMC, Military

With the recent news that the U.S. President's $223 million "doomsday plane" is protected from electromagnetic pulse (EMP) came the inevitable questions. What is EMP and how is it created? How can a plane with a reported 165,000 pounds of state-of-the-art electronics possibly be protected from such a sinister attack?
(The ABC News video at www.youtube.com/watch?v=FJF3Og9cCp8&feature=youtu.be shows an interesting guided tour of the President's plane, which is called "Nightwatch", and in addition to being shielded against EM Pulse also has thermal and radiation shielding to help protect it from nuclear bombs – Editor.)

EMP & Its Creation

EMP is a high amplitude, short duration, broadband pulse of electromagnetic energy which can have devastating effects on unprotected electronic equipment and systems.

The electromagnetic pulse effect was first observed during the early testing of high altitude airburst nuclear weapons. During the explosion, gamma rays (high energy photons) are rapidly released in all directions from the blast. These gamma rays interact with air molecules in the earth's atmosphere, which creates electromagnetic energy. This interaction process is called the "Compton Effect."

Energy of these pulses disperse across a broad spectrum, but the majority of pulse energy resides in the frequency spectrum of 10MHz-100MHz. For a large quantity of electronic equipment, this is the operating range and hence the greatest risk. Peak field strengths are estimated to reach into thousands of volts.

Non-nuclear EMP technologies – called "Directed Energy Weapons" – are increasingly being developed. They are capable of graduated effects on electronics ranging from disrupting operation, to permanent damage, and complete destruction. These weapons include:

- Arc Discharge EMP Generator
- Flux Compression Generator (FCG)

EMP Immunity Testing

The RS105 test method specified in MIL-STD-461F addresses the risk of radiated exposure to an EMP event. The U.S. Navy, among other military branches, requires RS105 testing for nearly every installation platform, from surface ships, submarines, and aircraft, to ground applications.

The test follows this procedure:

- Start at 10% of specified level
- Verify waveform
- Apply pulse 5 times at the rate of not more than 1 pulse per minute
- Rotate equipment under test (EUT) 90 degrees, and pulse 5 more times
- Rotate another 90 degrees and pulse 5 times
- Monitor for signs of degradation

The purpose of RS105 testing is not to damage the equipment, but to determine its immunity threshold to the electromagnetic pulse.

Hollywood's Take on EMP

Last, and most important, was the EMP attack, or "pinch," featured in the 2001 movie Ocean's Eleven possible? If you remember, George Clooney and his fellow con artists utilize a "Z-pinch" that detonates an intense electromagnetic pulse that blacks out Las Vegas' entire power grid for a few moments (in order for them to sneak into a casino vault).

No, says Sandia National Laboratories, owner of the world's most powerful Z-pinch. The super-charged electrical generator creates a rainbow spectrum of intense x-rays, but a feeble EMP.

Read more about RS105 and other military electromagnetic compatibility (EMC) tests: http://www.metlabs.com/Industries/Military/Military-EMC-Testing.aspx

Watch a 39-minute recorded webinar on RS105 testing: http://www.youtube.com/watch?v=T3OWjjDNIe0&feature=youtu.be
(Taken from Metlabs' article with the same title, at www.interferencetechnology.com/lead-news/article/doomsday-planes-immunity-to-electromagnetic-pulse-determined-via-rs105-testing.html. Also reported by Interference Technology magazine on 29th June 2011, at www.interferencetechnology.com/lead-news/article/doomsday-planes-immunity-to-electromagnetic-pulse-determined-via-rs105-testing.html.)

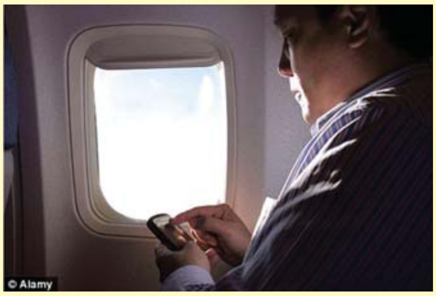
649 Confidential report reveals 75 Incidences of EMI on planes

Like most airline passengers, you probably have serious doubts about those pre-flight announcements asking you to turn off your cellphones, blackberries, iPods and anything else electronic.

The announcements are flat-out ignored by many frequent fliers, who are skeptical that so-called "personal electronic devices" pose any safety threat to airplane. Some passengers openly rebel, like New York Sen. Chuck Schumer, who cursed out one flight attendant who demanded he turn off his cellphone.

But a confidential industry study obtained by ABC News indicates there really could be serious safety issues related to cellphones and other PEDs.

A report by the International Air Transport Association, a trade group representing more 230 passenger and cargo airlines worldwide, documents 75 separate incidents of possible electronic interference that airline pilots and other crew members believed were linked to mobile phones and other electronic devices. The report covers the years 2003 to 2009 and is based on survey responses from 125 airlines that account for a quarter of the world's air traffic.



A businessman uses his mobile whilst in flight (from the Daily Mail article referenced below)

Twenty-six of the incidents in the report affected the flight controls, including the autopilot, autothrust and landing gear. Seventeen affected navigation systems, while 15 affected communication systems. Thirteen of the incidents produced electronic warnings, including "engine indications." The type of personal device most often suspected in the incidents were cell phones, linked to four out of ten.

The report, which stresses that it is not verifying that the incidents were caused by PEDs, includes a sampling of the narratives provided by pilots and crewmembers who believed they were experiencing electronic interference.

"Auto pilot was engaged," reads one. "At about 4500 ft, the autopilot disengaged by itself and the associated warnings/ indications came on. [Flight attendants] were immediately advised to look out for PAX [passengers] operating electronic devices. ... [Attendants] reported that there were 4 PAX operated electronic devices (1 handphone and 3 iPods)." The crew used the public address system to advise the passengers to shut off electronic devices "for their safety and the safety of the flight," after which the aircraft proceeded "without any further incident."

In other events described in the report, a clock spun backwards and a GPS in cabin read incorrectly while two laptops were being used nearby. During another flight, the altitude control readings changed rapidly until a crew member asked passengers to turn off their electronic devices. The readings returned to normal. "After an hour, changes were noticed again . . . Purser made a second announcement and the phenomena stopped."

Dave Carson of Boeing, the co-chair of a federal advisory committee that investigated the problem of electronic interference from portable devices, says that PEDs radiate signals that can hit and disrupt highly sensitive electronic sensors hidden in the plane's passenger area, including those for an instrument landing system used in bad weather.

"It could be you that you were to the right of the runway when in fact, you were to the left of the runway," said Carson, "or just completely wipe out the signal so that you didn't get any indication of where you are coming in."

Asked if a cellphone's signal could really be that powerful, Carson said, "It is when it goes in the right place at the right time."

To prove his point, Carson took ABC News inside Boeing's electronic test chamber in Seattle, where engineers demonstrated the hidden signals from several electronic devices that were well over what Boeing considers the acceptable limit for aircraft equipment. A Blackberry and an iPhone were both over the limit, but the worst offender was an iPad. There are still doubters, including ABC News's own aviation expert, John Nance.

"There is a lot of anecdotal evidence out there, but it's not evidence at all," said Nance, a former Air Force and commercial pilot. "It's pilots, like myself, who thought they saw something but they couldn't pin it to anything in particular. And those stories are not rampant enough, considering 32,000 flights a day over the U.S., to be convincing."

Nance thinks there are alternate explanations for the events. "If an airplane is properly hardened, in terms of the sheathing of the electronics, there's no way interference can occur."

But Boeing engineers told us that signals from PEDs could disrupt the navigation and communication frequencies on older planes, which are not as well shielded as the newer models. And anything that distracts the pilots in the cockpit is considered a true threat to safety.
*(Taken from: "**Is It Really Safe to Use a Cellphone on a Plane?**", by Brian Ross and Avni Patel, of ABC News, June 9, 2011, at: http://abcnews.go.com/Blotter/safe-cellphone-plane/story?id=13791569, kindly sent in by Doug Hughes ("The EMI Detective").*

Doug recommends viewing the actual broadcast, at: http://abcnews.go.com/WNT/video/cellphone-use-on-planes-safety-threat-13806022, and says that http://abcnews.go.com/GMA/video/danger-cell-phones-takeoff-landing-13799400 is also relevant. It is worth putting up with the introductory commercials, to see the videos of the very high levels of radiated emissions from certain very well-known types of passenger electronic devices (PEDs).

This ABC news item was also reported by Interference Technology magazine on 15th June 2011 at www.interferencetechnology.com/lead-news/article/report-unveils-75-incidences-of-electronic-interference-on-planes.html.

*The Daily Mail newspaper had their own take on this confidential report in their article "**How just ONE mobile phone can make a plane crash, leaked study reveals**", by Daniel Bates, published on the 10th June 2011, see: www.dailymail.co.uk/news/article-2001926/Your-mobile-phone-REALLY-makeplanes-crash-leaked-air-transport-study-reveals.html, which was kindly sent in by frequent contributor to Banana Skins Robert Higginson, trebornosniggih@gmail.com, on 10th June 2011)*

650 **Solar storms threaten national grids, controlled power cuts likely**

Officials in Britain and the United States are preparing to make controlled power cuts to their national electricity supplies in response to a warning of a possible powerful solar storm hitting the Earth. In an interview with The Independent, Thomas Bogdan, director of the US Space Weather Prediction Centre, said that controlled power "outages" will protect the National Electricity Grids against damage which could take months or even years to repair should a large solar storm collide with the Earth without any precautions being taken.

Dr Bogdan is in close discussions with scientists in the UK Met Office to set up a second space weather prediction centre in Britain to co-ordinate a global response to a threat viewed seriously by both the US and UK governments. One topic of discussion is how to protect national electricity grids from the immense power surges caused by the geomagnetic storms which happen when highly energetic solar particles collide with the Earth's magnetic field.

The most vulnerable parts of the grid are the hundreds of transformers connected to power lines many miles long that can experience sudden current surges during a geomagnetic solar storm, Dr Bogdan said. "It points to a potential scenario where large parts of either North America or northern Europe may be without power from between days or weeks, to perhaps months and, in extreme cases, there are estimates that it could last years," Dr Bogdan said.

The aim of the joint US-UK collaboration is to improve solar weather forecasting to a point where it is possible to warn power companies of an imminent storm. There is a feeling that if a "category 5" solar storm – the biggest of the five categories – were to be predicted, then taking the grid off-line before it is due to hit Earth and letting the storm pass would be better than trying to keep things running, he said.

In 1989, a solar geomagnetic storm knocked out the electricity grid across large parts of Canada. The loss cascaded across the United States and caused power problems as far away as California. The greatest fear is a massive storm as big as the one documented by astronomer Richard Carrington in 1859, which burnt out telegraph wires.

"The sort of storms capable of doing that are fairly rare events. We refer to them as 'black swans'," Dr Bogdan said. "If the Carrington event occurred today, and power grid operators did not take efforts to safeguard their infrastructure, then we could be facing a scenario like that."

*(Taken from: "**'Controlled' power cuts likely as Sun storm threatens national grid**" by Steve Connor, Science Editor of The Independent, in Boulder, Colorado, www.Independent.co.uk, Monday, 13 June 2011. Kindly sent in Dr Antony Anderson, also on 13 June 2011.)*

651 **Walkie-Talkie Shuts Nuke Plant Safety System**

The Davis-Besse nuclear power plant near Toledo, OH, lost the entire emergency shutdown system all because of a walkie talkie.

The scenario goes like this: A technician at the power plant used his walkie talkie in a room containing a back-up or auxiliary control panel for a system designed to automatically pump water into the reactor in the event of a catastrophic accident.

The radio wave disrupted the signal from the control panel to special pumps and emergency valves that even on stand-by are electrically alive for an instantaneous reaction.

In two bursts of conversation lasting 8 seconds and 19 seconds during a two-minute period, the technician rendered the plant's entire emergency shutdown system inoperable, the company told federal regulators.

The company posted a sign on the door to the room warning all employees not to key their radios near the sensitive control panel, said Todd Schneider, company spokesman.

The incident should have never happened, said David Lochbaum, nuclear safety engineer with the Union of Concerned Scientists. He said such incidents occurred a number of times in the early 1980s, so much that the Nuclear Regulatory Commission issued a warning bulletin in December 1983.

"This hasn't happened in decades," Lochbaum said. "Davis-Besse was warned but has failed to heed the warning."

The NRC wants to talk to that worker, said Victoria Mitlyng, spokeswoman for the NRC's regional office in Chicago. "We will definitely be looking into this."

(Taken from a LinkedIn posting with the same title, by G Hale on March 9, 2011.)

652 **EM pulse causes railcar EMI problems**

During a recent Connecticut Rail Commuter Council forum, it was revealed that hardware problems contributed to an electromagnetic pulse that caused propulsion systems on the state's new M-8 rail cars to set off track signals. The final testing hurdle is a series of simulated passenger runs in which the cars must run without substantial error for 4,000 miles. The first train of six M-8 cars will make its inaugural run carrying paying customers within weeks.

One of the Metro-North Railroad's eight new M-8 railcars.
Photo: ST, Contributed Photo / Stamford Advocate Contributed.

*(Taken from "**Electronic pulse causes railcar problems**", by IFI, http://www.ifi.com/web/html/articles/article0411_02.htm, 30 Mar 2011.)*

Banana Skins

Banana Skins are kindly compiled for us by Keith Armstrong.

If you have any interesting contributions that you would like included please send them, together with the source of the information to: keith.armstrong@cherryclough.com

Although we use a rather light hearted approach to draw attention to the column this in no way is intended to trivialise the subject. Malfunctions due to incorrect EMC procedures could be life threatening.

John Woodgate's Column

Criterion B and 'normal operation'

There is a problem with the wording of Criterion B in many if not all EMC standards that cite the criteria. The exact wording varies between standards; the wording below is from IEC/EN 6000-6-2:2007:

> **Performance criterion B:**
> **The apparatus shall continue to operate as intended after the test.** No degradation of performance or loss of function is allowed below a performance level specified by the manufacturer, when the apparatus is used as intended. The performance level may be replaced by a permissible loss of performance. During the test, degradation of performance is however allowed. **No change of actual operating state or stored data is allowed**. If the minimum performance level or the permissible performance loss is not specified by the manufacturer, either of these may be derived from the product description and documentation and what the user may reasonably expect from the apparatus if used as intended.

The first sentence is entirely correct. However, while in most cases what is 'intended' is that the equipment carries on functioning exactly as it did before the disturbance, in some cases that is not what is intended. For example, a machine may well not be intended to re-start automatically after a supply interruption, because that would at least raise operator safety issues and maybe other, operational issues, such as a need to start slowly, not at full speed. In such cases 'as intended' means whatever the manufacturer says it means, provided the words *'what the user may reasonably expect from the apparatus if used as intended'* are respected. The requirements for surviving ESD, for example, can't be evaded by stating that any ESD event is likely to damage the product beyond economical repair!

Any such special statement of what is intended to happen after a particular type of disturbance must be documented in the EMC assessment. It should, in many cases, also be explained in the user instructions.

Unfortunately, the wording goes on to say, *'No change of actual operating state or stored data is allowed'*. This might appear to mean that, whatever the manufacturer intends, the equipment must 'carry on regardless' after the disturbance, and . as explained above, that might well not be at all the behaviour that is actually necessary.. It might, however, be argued that the requirement applies 'during the disturbance' rather than 'during the whole of the test period'. But how can there be 'no change' if, for example, the disturbance is a supply interruption?

This particular sentence really over-gilds the lily. By requiring '*no change of stored data'*, it even prevents the occurrence of the disturbance being recorded in a machine's operation log! The situation can easily be remedies by changing the wording to:

'No **unintended** change of actual operating state or stored data is allowed'.

It may take quite a while for all the standards to be changed, but it can be done by means of Interpretation Sheets, which can be processed much more quickly than amendments. All it needs is the political will of the relevant committees to take action.

Conducted disturbances and immunity to them, interharmonics and 2 kHz to 150 kHz

I flagged this subject in the May 2011 issue and developments have occurred. First, CISPR has sent a questionnaire to National Committees, to be answered by 23 September:

1. Is there evidence of interference in the range 9 kHz to 150 kHz being caused by any products subject to CISPR limits or is there a strong likelihood of interference to emerging technologies using that band (e.g. Smart Metering)?

2. Is there a need to extend the frequency range of conducted emissions limits below 150 kHz and above 9 kHz for any products in the scopes of CISPR standards?

3. Should the conducted RF immunity requirements of the relevant CISPR standards be extended commensurate with the above?

However, IEC SC77A has already circulated a New Work proposal on a new Basic standard in the IEC 61000-4- series on immunity to conducted, differential mode disturbances in the 2 kHz to 150 kHz band. As a Basic standard, it will not include mandatory limits but it may recommend. The closing date for responses is 29 July, so we haven't seen the results yet. It is somewhat surprising that a two-pronged approach has been mounted, but no doubt any potential conflict will be resolved by negotiation between CISPR and SC77A officers.

In a recent meeting, SC77AWG1 has also recommended the preparation of an emission standard for 2 kHz to 9 kHz, and suggests that CISPR should deal with the range 9 kHz to 150 kHz. There is a question whether the SC77A standard should be a Basic standard (so it only applies if called up in product standards) or a Product Family standard applying to everything that connects to the public electricity supply (like IEC/EN 61000-3-2). Even if it were a Product Family standard, the EMC Directive does not require testing products unnecessarily, but it seems that manufacturers are wary of using this provision to minimise testing costs, which is a surprise.

Other new publications that have appeared recently in the low-frequency arena are:

- IEC 61000-3-12 Ed.2; this is an important emission standard and the new edition differs from the previous one in critical aspects;
- IEC 61000-4-15 Ed.2;
- IEC 61000-4-16 Ed. 1.2;
- IEC 61000-4-11 Interpretation Sheet.

SC77AWG1 also discussed the future of IEC 61000-3-9, which has not progressed since it was approved as New Work for a standard on interharmonic emissions. This is because an alternative approach was approved – measuring harmonics with a 50 Hz bandwidth so that interharmonics are included. The adverse implications of this were not realised until after it was approved, so remedial action had to be taken, appearing as clause 7 of IEC 61000-4-7, which allows the original 5 Hz bandwidth to be used. Up to now, no progress to remove this clause has been possible.

During the discussion, however, it emerged that progress **is** perhaps now possible towards removing clause 7, so the WG recommends keeping IEC 61000-3-9 as a Stage Zero project until the position with regard to clause 7 becomes clearer. WG members from the household appliance and VSD industry sectors report considerable progress in attenuating interharmonic emissions, but not all manufacturers may have implemented the techniques yet.

CISPR 'housekeeping'

CISPR is planning a 'spring clean' of its standards to improve consistency and clarity. Some would say it is long overdue, but at least it is now planned. CISPR writes to National Committees:

> It is proposed to re-establish some basic principles under which product standards should be developed and agreed across the CISPR. The proper and practical implementation of these principles should go a long way towards consistency. Consider then these principles:
>
> 1 All Radiocommunications equipment be provided with a consistent level of protection for their intended use.
>
> 2 The level of protection provided be determined:
> a. according to the ITU(R)'s assignments and protection ratios
> b. consistent with realisable and balanced objectives.
>
> 3 All equipment operating in the same environment should provide the same level of protection.
>
> 4 An increase in protection distance be used to provide equal levels of protection for harsher environments.
>
> 5 In order to meet the combination of test methods and test limits to be counted as equivalent in a standard, each would need to be shown to offer similar protection.
>
> 6 Where this is not the case, a precedence should be set or a single test method selected.
>
> 7 In keeping with item 3 above the selection of limit classes should be similar in standards applying in similar environments.
>
> With these principles agreed these should be implemented by a review of (and necessary amendments to) existing standards when they are maintained or when amendments are made. A plan should be developed showing how this alignment will be realised and this should be tracked at the annual CISPR plenary meetings so that progress can be seen.
>
> Further discussion will be held at the CISPR plenary in Seoul, Korea on 18 October 2011.

Comments on this plan can be submitted to BSI committee GEL210 before 23 August.

CISPR also plans full revisions of CISPR14-1 and 14-2. Also under consideration are radiated emission limits below 30 MHz. Methods of measurement for magnetic fields exist, but there seems to be a need for electric field measurements as well, which may raise serious repeatability issues.

PLT (you didn't think it wouldn't be mentioned, did you?)

A number of private individuals have communicated their concerns to BSI about the draft EN 50561-1. A special BSI meeting has been called to consider the matter yet again, but it can't solve the problem. The **only** way to solve it is to adopt a transmission protocol that reduces the emissions to an acceptable level. It can be done, by reducing effective data transmission speed, and for many possible applications of PLT, that wouldn't be a killer. But the chances of it happening are remote indeed.

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Know Your Standards

Recap

Over the last two issues, we looked at the standards-making bodies and their characteristics, how one can obtain standards economically, **what to do with them when you have them (most important!)** and how one can participate in standards work (masochism is not essential, but it helps).

Types of standards publication

There is a problem with terms, because the word 'standard' is used, even by standards-making bodies, to mean various sorts of publication, only one of which is a 'standard' as normally understood, i.e. a prescriptive document, using 'shall' as the verb for its provisions. Not so many years ago, the then edition of BS 0 ('A standard for standards') listed ten types of publication, and used 'specification' to mean the prescriptive type, which nevertheless are called 'standards'. Furthermore, the terms differ between standards bodies.

IEC and ISO publications

These publications are numbered as IEC [prefix] NNNNN-nn-nnn, ISO [prefix] NNNNN-nn-nnn or ISO/IEC NNNNN-nn-nnn. The '-nn-nnn' refer to Parts and Sections of multipart standards and are absent from single standards. At one time, especially in IEC, the first N was 6, but now other numbers appear in that position for standards on different major topics.

- Standards (no prefix) – prescriptive documents;
- Technical reports (TR) – usually descriptive documents, may give recommendations, using 'should', but definitely not prescriptive;
- Technical specifications (TS) – 'wannabe' standards - NOT to be regarded as standards but they use prescriptive language. May be turned into standards after experience has been gained of their use or they may continue to exist as a 'halfway house';
- Guides (numbered in their own series); in spite of the name, many of them are prescriptive; they concern the content of standards, their relations with other standards and how they are to be developed.
- Publicly-available specifications (PAS) – documents originated elsewhere that are candidates for adoption as standards after experience has been gained of their use.

CISPR

Although CISPR is part of IEC, it has its own Constitution and its own numbering system. Publications are numbered in the form CISPR [prefix] NN-nn-nn. The only prefix is TR for Technical Report, like an IEC TR. Generic EMC standards produced by CISPR are numbered in the IEC 61000-6 series.

CEN and CENELEC

These publications are numbered as EN (or TR) NNNNN-nn-nnn, but in CEN, the number of Ns may be fewer. ENs are 'European Standards', **not** 'Euronorms' which are quite different publications, from a different source.

- Standards (EN) – prescriptive documents;
- Technical reports (TR) – usually descriptive documents, may give recommendations, using 'should', but are definitely not prescriptive;
- Technical specifications (TS) – 'wannabe' standards - NOT to be regarded as standards but they use prescriptive language. May be turned into standards after experience has been gained of their use or they may continue to exist as a 'halfway house';
- Harmonized documents (numbered in their own series HD NNNNN-n-nnn) – prescriptive documents adopted when due to different legal or other circumstances in EC member states, an EN could not be implemented verbatim in all states. The number of Ns is variable. Examples are standards for cables and those for electrical installations, such as BS 7671, which is the British implementation of HD 60364;
- Guides (numbered in their own series); these are **not** the same as IEC or ISO Guides and are usually not prescriptive.

In CENELEC, the first two Ns indicate the origin and nature of the standard:

- EN 50NNN-nn-nnn – a standard prepared and published by CENELEC;
- EN 55NNN-nn-nnn – a standard adopted from CISPR, therefore an EMC standard. The last two Ns and any ns are taken from the CISPR number;
- EN 6NNNN-nn-nnn – a standard adopted from IEC; the 6 may be replaced by another digit except 5;

EN 55NNN and EN 6NNNN standards are **very similar** to the original CISPR or IEC standards but are **never** identical; the difference may be trivial or very significant, and that varies from case to case. A difference may be trivial to others but profoundly affect your product.

These standards adopted from IEC or CISPR may include 'Common Modifications', which apply across Europe, and Special National Conditions, which apply only in the states which request them. A few standards still include 'A deviations', which are necessitated by legal provisions or infrastructure conditions that cannot be readily or reasonably changed. The Normative References are replaced by references to ENs and HDs if they exist, and EMC standards include an Annex that details how the standard matches the provisions of the Directive. There may be other differences between the EN and the standard from which it was derived.

Harmonized

There is another terminology problem with this word. Originally, all ENs and HDs were 'harmonized' – meaning 'implemented in all EU states'. But the Commission hi-jacked the term (probably inadvertently and no-one bothered to challenge it) to mean **only** those standards listed in the Official Journal, conformity with which conveys *prima facie* evidence of compliance with a Directive.

Implementation

IEC and ISO standards are recommended to the organizations' members – the national standards bodies – for adoption nationally. **They are not 'recommendations' in the sense of**

being only advisory. Problems have been caused by some National Committees implementing standards that are referred to in legislation, such as safety and EMC standards, immediately on publication by IEC or ISO. A case occurred some years ago where products were legal when put in a ship but illegal when taken out of it in a far country! IEC and ISO do not specify 'transition periods' but call the attention of National Committees in the Forewords of such standards that transition periods may be required at national level so that industry has time to manufacture products conforming to the new standard.

In CEN and CENELEC the procedure is more detailed. National Committees **must** implement published ENs, even if they voted against them. There is a sequence of critical dates, some of which are listed in the actual publication:

date of ratification (dor)

date when the Technical Board notes the approval of an EN (and HD for CENELEC), from which time the standard may be said to be approved

date of availability (dav)

date when the definitive text in the official language versions of an approved CEN/CENELEC publication is distributed by the Central Secretariat

date of announcement (doa)
latest date by which the existence of an EN (and HD for CENELEC), a TS or a CWA has to be announced at national level

date of publication (dop)

latest date by which an EN has to be implemented at national level by publication of an identical national standard or by endorsement

date of withdrawal (dow)

latest date by which national standards conflicting with an EN (and HD for CENELEC) have to be withdrawn

All these are determined by CEN or CENELEC, but there is also another one, of very high importance, that is determined by the Commission. This is the fabulous beast **'docopocoss'** – the (BIG breath!) date of cessation of presumption of conformity of the superseded standard. This is listed against each standard notified in the Official Journal as providing *prima facie* evidence of conformity with a Directive. A newly-listed standard **can** be used immediately, but industry has a transition period, usually of three years, before the former standard reaches the docopocoss and may no longer be referred to in Declarations of Conformity.

The docopocoss is normally the same as the dow, but the Commission reserves the right to set a different date, and occasionally exercises that right.

FAQ

FAQs used to be all the rage but they seem to have fallen out of favour over recent years. Even so, I do get many questions over and over again, so I wonder if a 'standards FAQ' on the Compliance Club web site would be useful. If you think so, I recommend that you email the Kindly Editor (and copy me) with your views.

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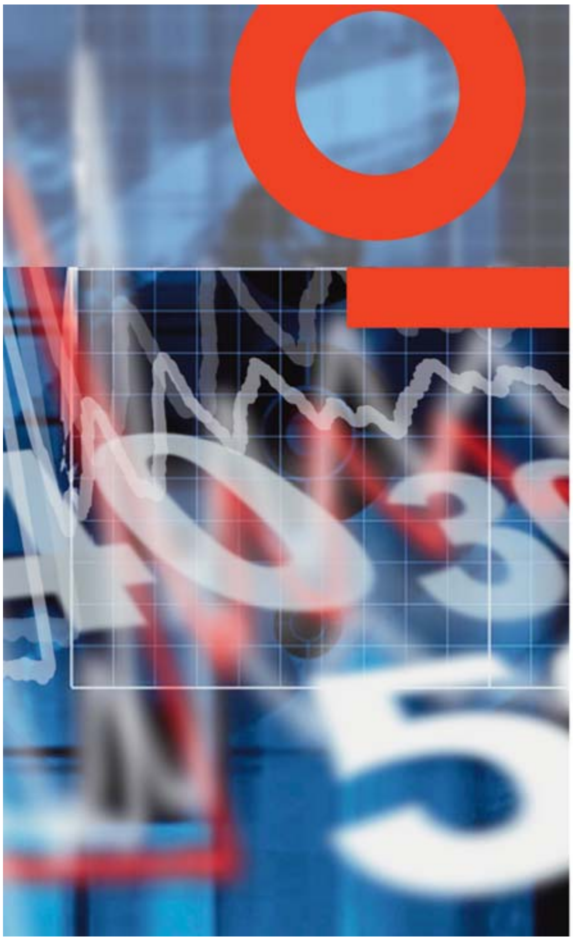

PRODUCT GALLERY

Install, maintain and analyze ATSC Mobile DTV networks efficiently with the R&S ETL TV analyzer

Rohde & Schwarz is enhancing its R&S ETL TV analyzer with a set of comprehensive functions developed for ATSC Mobile DTV (ATSC MDTV). The new capabilities make the R&S ETL the first analyzer that can perform all required measurements for installing, commissioning and maintaining ATSC MDTV networks using a single instrument. Even broadcast drive tests are now possible. Moreover, the TV analyzer is an ideal solution for optimizing ATSC MDTV single-frequency networks (SFNs). Users will profit from its patented time-saving measurement method.

Some years ago, the Advanced Television Systems Committee (ATSC) established a digital TV broadcasting standard for North America and South Korea. The

ATSC MDTV extension to the standard allows digital television to be received on smartphones and other handhelds. Suitable networks are currently being set up by network operators as quickly as possible. To test these networks, TV transmitter manufacturers, network operators and regulatory authorities need T&M instruments such as the R&S ETL. Using the R&S ETL-K320 software option, the TV analyzer determines whether transmitters function in conformance with the ATSC MDTV specifications and whether network coverage is complete. For coverage measurements in the field, Rohde & Schwarz also offers the R&S BCDRIVE software. Data measured at a number of stations can be analyzed in detail and displayed in straightforward fashion using the software.

ATSC MDTV networks can also be set up as single-frequency networks. SFNs provide more stable broadcasting reception, since all transmitters in a network broadcast signals on only one frequency. Better coverage of the broadcast area is achieved with multiple powerful transmitters, each operating on a different frequency. To optimize SFNs, Rohde & Schwarz has developed and patented a unique measurement method: The R&S ETL equipped with the R&S ETL-K321 software option allows users to precisely determine the frequency offsets of all transmitters in a network with a single measurement. First, the R&S ETL defines a reference transmitter. At a central point in the SFN, it then measures the frequency offset between the other transmitters and the reference. Users immediately get all the information they need to align the transmitters. This differs from today's conventional methods, where each transmitter must first be measured individually on site before the transmitters can be aligned with each other in a subsequent step.

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www.rohde-schwarz.co.uk

Conductive coatings combine high shielding performance and ease of application to allow use of plastic enclosures for sensitive electronics equipment

Chomerics Europe - a division of Parker Hannifin, has introduced two new electrically conductive acrylic coatings that are designed for application onto plastic housings to provide EMI/RFI shielding. CHO-SHIELD® 2040 is silver-filled material that provides superior shielding performance of > 75 dB and CHO-SHIELD® 2044 uses a nickel filler to achieve > 60 dB shielding effectiveness (both between 80 MHz and 10 GHz).

CHO-SHIELD 2040 and 2044 are durable and provide high levels of abrasion resistance making them suitable for use in equipment that is likely to be operated in harsh environments. Able to provide EMI/EFI shielding, anti-static protection and surface grounding, the coatings facilitate the design of a wide range of electronic products and equipment in ABS, PC/ABS & many other types of plastic enclosures.

Both materials have a robust formulation that allows them to be applied using either low or high volume paint application processes using conventional paint spraying equipment. The coatings have good adhesion properties and are tack-free 30 minutes after application and fully dry after 24 hours helping to minimise production bottle-necks; elevated temperatures (65ºC) allow full drying times to be reduced to around just one hour. Continuous operating temperature range for the new coatings is -40ºC to +85ºC.

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emcia Member

New from AR

Completely automated Radiated Immunity Test System for MIL-STD 461 Testing

AR RF/Microwave Instrumentation has introduced its latest automated system for conducting radiated susceptibility testing. The AS18027 AR System has been specifically designed to perform automated testing for MIL-STD 461 requirements. The system will produce fields up to 50V/m at 1 meter distance from 1-18 GHz.

The system is comprised of a variety of components including one of AR's new dual-band, solid state amplifiers; signal generation and control equipment. The equipment is housed in a compact, EMI-shielded rack designed to be kept inside the chamber, minimizing cable losses. Capabilities for safety interlock have been integrated into the AS18027 system allowing a single switch to be monitored and to disable all RF generation inside the chamber. Also included in the system are frequency matched and dedicated antennas and other auxiliary equipment. AR's SW1007 EMC test software is provided and allows for complete automation of the system.

This is just one example of AR's system capabilities. Whether you chose one of our standard test systems or have one built to your specifications, AR can deliver a solution that integrates all your testing needs.

"Smart" Electric Field Probe

AR RF/Microwave Instrumentation has upgraded its line of laser-powered star probes with a new electric field probe, that replaces the previous model FL7018. The new model, FL7218, is a smart, fast, extremely accurate electric field probe that contains an internal microprocessor to provide linearization, temperature compensation, control, & communication functions. The probe's noise reduction and temperature compensation allow accurate measurements down to 2 V/m without zero adjustment. Microprocessor based linearization technology provides a 54 dB dynamic range. When rotated about its critical angle mount, the probe provides typical isotropic response of +/-1.5 dB to 18 GHz.

The FL7218 is laser-powered to allow for continuous operation without recharging or battery replacement.

The FL7218 star probe joins other AR field probes to create what AR describes as the most advanced, most complete, & most rugged line of EMC field probes in the industry.

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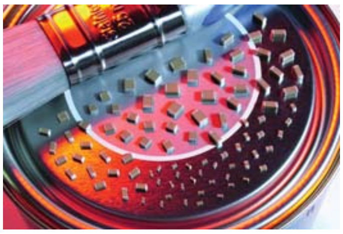
When size is important and stability matters

Selecting the best multilayer chip capacitor (MLCC) for the application can involve difficult trade offs involving stability, capacitance and cost. European passive component manufacturer, **Syfer Technology**, has introduced a range of devices that increases the choice and reduces compromise.



For applications that require maximum stability, then chip capacitors based on the C0G/NP0 dielectric are the obvious choice as capacitance does not vary with applied voltage. But what if you want higher capacitance values than the few nF maximum typically available in C0G?

X7R capacitors deliver higher capacitance, as they have a dielectric constant in the region of 2000-4000. With more capacitance per unit volume, they are generally smaller for the comparable capacitance values, and are typically much lower cost than C0G. However, their capacitance variation with temperature can be as much as ±15% over the temperature range from -55°C to +125°C with no voltage applied. In fact no limit at all is specified for X7R with applied voltage, and so significant capacitance loss can occur. This effect is magnified for less stable dielectrics.

But now X7R dielectric MLCCs are available from Syfer with a defined capacitance variation under applied DC voltage, across the full operating temperature range. Derating or using a higher voltage rating can reduce the capacitance drop but where an application requires more stable performance with minimal voltage derating then these parts are particularly suitable.

The advantage of devices with a clearly specified limit for the fluctuation is that they give designers the data they need to make an informed choice for their application.

Syfer's TCC/VCC range of X7R MLCCs is available in two versions. The "B" code dielectric conforms to MIL STD BX dielectric and IECQ-CECC 2X1 standards, while the "R" code dielectric (conforms to MIL STD BZ dielectric and IECQ-CECC 2C1 standards.) The 2X1 (BX) devices, for example, are the most voltage stable of the X7R versions, at +15 to –25% capacitance charge with full rated DC voltage applied across the full temperature range. The 2C1(BZ) offer +20 to -30% capacitance charge.

The 2X1 (BX) range includes devices rated at 50V, 100V and 200V, and with capacitance ranges from 100pF to 4.7nF (50V, 0603), through 2.7nF to 180nF (50V, 1808) up to 15nF to 1µF (50V, 2225). Comparable devices in the 2C1 (BZ) range are 100pF to 5.6nF (50V, 0603), 2.7nF to 220nF (50V 1808), and 15nF to 1.5µF (50V, 2225).

These X7R dielectric MLCC ranges are eminently suitable for use in a wide range of coupling and power supply bypassing applications, while the higher voltage types are particularly sought after in switching power supplies, dc-dc converters, automotive and aerospace equipment.

The devices are available with FlexiCap™ terminations using Syfer's proprietary flexible termination material, which make them considerably more resistant to damage through bending or flexing, and when under stress and temperature cycling extremes. Alternative terminations are also available.

The surface mount capacitors are already in production and available immediately on an 8 week lead-time from Syfer's Norwich, UK manufacturing facility. The devices are fully RoHS compliant. Price is dependent on type and quantity.

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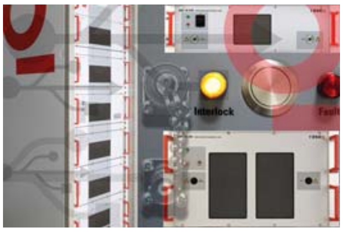
New USB Interface on all Teseq RF Amplifiers simplifies operation



Teseq, a leading developer and provider of instrumentation and systems for EMC emission and immunity testing, now offers an integrated USB port on its complete range of CBA series, solid-state, class-A power amplifiers that offer frequency and power ratings specifically for EMC immunity test applications.

Teseq's CBA series, offering frequency ranges from 10 KHz to 6 GHz and power levels from 12W to 1,000W, are robust and dependable amplifiers that ensure complete reliability at low operating costs. When fitted with the new USB port, the amplifiers can be switched on remotely from standby to operation mode and be controlled by Teseq's Compliance 5 test software to monitor status, local lockout, interlock & fault conditions. The interface comes with a dynamic link library file that enables control by other test software packages as well as a simple program that provides direct control of the amplifiers via a PC.

Teseq's Compliance 5 is the leading software for RF EMC testing. It is used in test laboratories worldwide to deliver fully-compliant, fast, efficient and repeatable testing in military and aerospace applications, reverberation chambers, commercial/consumer products and the automotive industry. The software features standard drivers that interface with the amplifiers.

Teseq offers a full range of broadband power amplifiers that feature the new USB interface. Each is covered by a three-year warranty.

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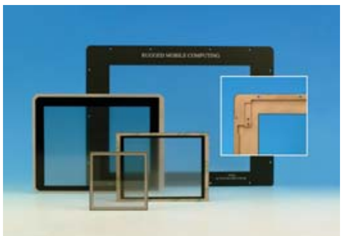
Shielded windows support EMI compliance in growing number of products with high graphical content

Chomerics Europe - a division of Parker Hannifin is able to offer a complete range of shielded and non-shielded glass and plastic windows for use in a wide range of product in both portable and fixed location equipment. Typical applications can be found in markets that include military, medical, public information display and test and measurement equipment.



Glass windows offer the best optical clarity and transmission along with good scratch resistance. Non-glass windows meanwhile, use either polycarbonate or acrylic material and are selected for their lightweight, impact and shatter resistant characteristics, operating temperature ranges up to 100 ºC and the high degree of design flexibility they allow.

Chomerics windows offer excellent physical properties combined with outstanding shielding performance & optical clarity. Features such as enhanced optical filters, hybrid laminated glass and plastic filters with an integrated metal mesh for EMI shielding, hydrophobic, oliophobic, anti-reflective and anti-fogging coatings can all be included to meet the requirements of specific applications.

The use of large screen sizes as well as the high graphical content of modern equipment applications has made compliance with EMI regulations and ensuring reliable performance an increasingly significant challenge for design engineers. Fitting a shielded window over a display aperture can restore the EMI-blocking property of an otherwise conductive enclosure.

Chomerics provides expert design and technical support for all materials in its comprehensive range of shielded and non-shielded optical products. An online selection guide is also available to help designers choose the most appropriate material for their application.

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The National Register of RF Workers

Ian Litchfield, Institute of Occupational and Environmental Medicine, University of Birmingham

Introduction

Radiofrequency (RF) has been present in the working environment since the introduction of radio broadcasting in the 1930's. These days it is used across a range of industries, for example: heating and welding in the ceramics and plastics industries; health care; telecommunications; broadcasting; navigation; and now, in the wireless office.

However, the last twenty years in particular have seen a marked increase in the prevalence of RF radiation. The advent of 24-hour broadcasting, and the roll-out of analogue and digital mobile telephony systems, means our reliance upon and demand for RF technology is at an unprecedented level. Concerns over the health effects of RF radiation have also risen, in line with the visible proliferation of RF technology. Though the health effects resulting from heating and RF are well documented and explored here, much of the science concerning other health effects is inconclusive. This uncertainty has created an atmosphere where alarmist if well-intentioned reporting in the media can lead to misperceptions amongst both the working and broader population of the impact of RF on human health. Here we offer some clarification of what remains a complex issue. We begin by discussing the mechanism of the thermal effect and the potential impact on health of both and acute and long-term exposure. We discuss the origins and role of the Register in the context of the current evidence base and discuss the initial follow-up study to utilise the Register database. Finally we provide information on participating in the Register and details of the Register Annual Meeting 2011.

Existing evidence of adverse health effects from occupational RF exposure?

A number of reviews of the health effects of occupational exposure to RF radiation have been undertaken. The earliest dates back nearly 30 years, and considered claims made in Russia and Eastern Europe that long-term exposure to low-level RF radiation caused physiological and psychological problems, albeit of a reversible nature. Since then, an increasing number of health effects have been reported resulting from both acute, and long-term exposure. The only currently recognised mechanism for causing adverse health outcomes is the thermal effect.

The heating or thermal effect is observed when the energy deposited by oscillating electric fields causes an increase in temperature due to the agitation of the mobile ions contained in the body. This causes an electric current, the resistance of which by body tissue leads to heating. The exact nature of this effect is dependent upon the frequency of the signal as this determines the depth to which the RF radiation penetrates the tissue which in turn impacts on whether the temperature receptors in the skin are stimulated, receptors that play an important role in local and whole body thermo-regulation.

The exposure standards for RF are based on the assumption that the primary route of energy absorption is via heat deposition. All current occupational guidelines are devised on this basis. Heat absorption is affected by the following factors; frequency of the radiation, body position relative to the wave direction, distance between body and source (RF energy generally decreases with the inverse of the square of the distance form the energy source), exposure environment (electro magnetic fields are known to be affected by the topography of their environment and objects can reflect, resonate or modify incident waves), and electrical properties of the tissue i.e. its conductivity and its dielectric constant. The dielectric constant measures the ratio of the amount of the current that will flow in a specific medium compared to that which will flow in a vacuum. The electrical properties of tissue are a constant and depend on water content. Tissue such as brain, muscle and skin has a higher constant than bone or fat. Boundaries between tissues can reflect the energy waves differently resulting in hot spots that can cause localized injury.

Long-term occupational exposure

The evidence of the effects of long-term occupational exposure is less consistent. On a cellular level the majority of literature published on *in vitro* research demonstrates that, in cells – heated or otherwise – RF radiation does not induce DNA strand breaks, chromosome aberrations, or transformation.

Though haematological changes have been observed in radar operators, any effects of RF radiation on the pituitary, adrenocortical, growth and thyroid hormone so far identified have been caused by heating. An effect on the production of melatonin by the pineal gland has been suggested, but never reliably established. Current research indicates that in general, if tissue is not heated during exposure, then current flow is necessary in order for any effect to be observed.

A known hazard of RF heating is injury to the eyes, which can be especially damaging at frequencies above 800 MHz. Since the lens of the eye does not have an adequate vascular system for the exchange of heat, even a slight rise in temperature can cause protein coagulation, and opacities may form in the lens. This may be defined as a cataract. However, in clinical practice the term cataract is normally not used unless the opacity has progressed so much as to interfere with visual acuity.

A number of reported reproductive outcomes have been explored in the literature, including semen density and motility, fertility and gender, all of which were inconclusive. In the 1980's concern emerged that there was an association between Visual Display Units and low birth weight though subsequent studies were flawed and no causal effect has been reliably demonstrated.

Recent reports suggest that the use of handheld mobile phones may be linked to the occurrence of malignant disease, especially brain cancer and, to a lesser extent, leukaemia. Other tumours, such as acoustic neuroma that occur in the head and neck have also been investigated.

By far the largest existing body of evidence concerns the occurrence of cancer at a number of different sites. The majority of these studies showed that occupational exposure to RF showed no increased risk. Though isolated studies have shown some potential areas of concern, for example an increased risk for breast cancer in radio operators, research is ongoing and to date remains inconclusive.

IARC: Recent advice on RF exposures:

In May, the International Agency for Research into Cancer (IARC) convened a meeting of global experts in the subject to review the existing literature and classify the carcinogenic properties of RF. They concluded that the evidence suggested there RF was a possible carcinogen however the evidence of increased risk of cancer from occupational exposures was judged 'inadequate'. See Table 1 for further details.

Table 1: IARC classifications

Group 1 Carcinogenic to Humans	Group 2A Probably Carcinogenic to Humans	Group 2B Possibly Carcinogenic to Humans	Group 3 Not Classifiable	Group 4 Probably not Carcinogenic to Humans
Evidence that an agent is "proven" to be associated with human cancer	Limited evidence of an association with cancer in humans, but sufficient evidence of cancer in experimental animals	Limited evidence of an association with cancer in humans, but insufficient evidence of cancer in experimental animals	Evidence indicates that it is not possible to classify an agent based on the available information	Evidence to prove agent is "not associated" with human cancer

A list of previous classifications can be found at: http://monographs.iarc.fr/ENG/Classification/index.php

The origins and role of the Register

In response to public concerns that began to emerge in the mid 1990's that still exist today the British Government called on the head of, what is now, the Radiation Protection Division of the Health Protection Agency (HPA), to form the Independent Expert Group on Mobile Phones (IEGMP). Chaired by Sir William Stewart, Chairman of the HPA, this group embarked on a broad programme of consultation across the UK and abroad. Meeting with scientists, network operators, broadcasters, pressure groups and members of the public they also assessed peer-reviewed literature and other scientific writings. After two years they produced their first report which concluded there was no evidence to suggest that exposures to radiofrequency (RF) radiation below the international guidelines cause adverse health effects. However, it was acknowledged that there may be biological effects occurring at exposures below these guidelines, so a precautionary approach was adopted and the implications of this approach were reflected in the recommendations made by the group. One of these recommendations was that a register of occupationally exposed workers be established enabling a long-term follow-up study of cancer risks and mortality, amongst those occupationally exposed at relatively high levels. This Register will then be used to explore specific health concerns that emerge in the coming years. Ultimately, if adverse effects of exposure to RF radiation are identified, then the Health and Safety Executive of the UK (HSE) would establish a system of health surveillance of the affected groups.

Named the National Register of RF Workers, the database initially consisted primarily of those whose work brings them in close proximity to transmitting antennas on telecommunication, broadcasting masts and similar structures. In 2010, the decision was made to extend the Register to include those exposed to RF in bench-top or laboratory type settings including RF testing laboratories and microelectronics manufacturing.

Role of the University of Birmingham

The SG contracted the Institute of Occupational and Environmental Medicine (IOEM) at the University of Birmingham to administer the Register. Led by Tom Sorahan Professor of Occupational Epidemiology the responsibilities of the University team include the administration and secure storage of the database, recruitment of individuals and the management of the initial follow-up study exploring incidence of cancer and mortality within the Register cohort and is discussed in more detail later.

Recruiting Participants

Key to the success of the Register is recruitment of individuals in sufficient numbers to allow for robust research to be undertaken in the future. Professor Sorahan of IOEM confirms "…we need to ensure that all individuals eligible to join are aware of the Register and have made an informed decision on whether to participate….it is important that as many of the relevant individuals as possible join the Register as the greater the number of participants the greater the confidence we can have in any findings".

The numbers enrolled have continued to increase as the majority of workers within the telecom and broadcasting sectors have become aware of the study. In 2010 the Steering Group made the decision to expand recruitment to include those who are potentially exposed to RF in laboratory and manufacturing environments.

Collaboration with other research bodies

The Register has close links with the Mobile Telephone and Health Research programme (MTHR) in the UK, a programme co-funded by the government and industry. The current chair of the Register Steering Group Julia Clark welcomes the relationship between the two organisations and is "…delighted that the MTHR recognise the importance of our work and acknowledge the benefits such research provides, both to employees and employers".

But it is not only the MTHR that recognise the value of the Register. Sir William Stewart, Chairman of the Health Protection Agency recently commented that his organisation "….welcomes the establishment of the Register by the Institute of Occupational and Environmental Medicine at the University of Birmingham. This should facilitate the determination of whether, occupationally, there are health effects from exposure to RF fields not observed in the general public." Going forward the Steering Group plan to collaborate with other organisations undertaking similar research across Europe and the rest of the world to the mutual benefit of all those working with RF radiation.

The initial follow-up study: Exploring the link between occupational RF exposure and cancer

The first study utilising the Register to explore potentially adverse health effects of RF began a last year and is looking at cancer incidence amongst individuals enrolled on the Register. The mortality experience of the cohort will be compared with that which might have been expected to occur if rates of mortality for the general population of England and Wales had been operating on the study cohort, taking into account sex, age, and calendar year.

Studies of this type are called a 'prospective cohort' studies. The relevant information is collected on a current group or cohort which is then followed prospectively forwards through time. This study design is one of the stronger as it means the data gathered is more accurate and free of much of the bias than can be found in retrospective studies that rely on historical data and personal recall. Cohort and further defined in Box 1.

BOX 1

Cohort study

A cohort study identifies a group of people and follows them over a period of time to see how their exposures affect their outcomes. This type of study is normally used to look at the effect of suspected risk factors that cannot be controlled experimentally, for example the effect of smoking on lung cancer.

Prospective study

A prospective study asks a specific study question (usually about how a particular exposure affects an outcome), recruits appropriate participants and looks at the exposures and outcomes of interest in these people over the following months or years.

The study population will comprise over 2,500 employees. In order to account for variation in exposure between different occupationally exposed jobs, participants supply their job title. This is then placed in one of eight job categories. The IOEM will receive follow-up particulars (copies of death certificates and cancer registration (incidence) details from the National Health Service Information Centre (IC) according to the tenth revision of the International Classification of Diseases.

How to get involved?

If you would like to know more about the Register, or would like to request electronic or hard-copies of joining forms, then please contact us using the details below. Participation is free and all individuals enrolled by December 2011 gain automatic entry to the Register prize-draw and a chance of a £250 activity day of the winner's choosing.

The Register Annual Meeting

This year's meeting will be hosted by the University of Birmingham in October. Guest speakers include Dr Simon Mann from the HPA, the sole UK representative at the recent IARC meeting will be joined by Arwel Barrett of the HSE who will discuss the implications of the IARC conclusions on policy and provide an update on the EU physical agent's directive (EMF). If you are interested in attending then again, please contact us using the details below.

Further reading

WHO website
http://www.who.int/peh-emf/research/agenda/en/

ICNIRP's guidelines, Update
http://www.icnirp.de/documents/statgdl.pdf

HSE Website- non-ionising radiation
http://www.hse.gov.uk/radiation/nonionising/index.htm

Mobile Telephone Health Research website
http://www.mthr.org.uk/

IARC website
http://www.iarc.fr/

Independent Expert Group on Mobile Phones; Mobile Phones and Health
http://www.iegmp.org.uk/report/text.htm

National Register of RF Workers
http://www.hse.gov.uk/radiation/nonionising/electro.htm

Watching the Directives:
Occupational exposure to electromagnetic fields: paving the way for a future EU initiative
http://osha.europa.eu/en/news/SE_Occupational_exposure_electromagnetic_fields

Physical agents (electro-magnetic fields) Directive – HSE
http://www.hse.gov.uk/aboutus/meetings/hseboard/2009/251109/pnovb09110.pdf

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GTEMs - An In Depth Analysis

Jonathan Hamilton – Megger Limited & Chairman of the GTEM User Group
Howard Chetwin – Measurement Technology Ltd & Secretary of the GTEM User Group

Figure 1. The GTEM. Gigahertz Transverse Electro Magnetic Test Chamber

Correlation between GTEM and Open Area Test Sites

In the last article – 2 issues ago, we outlined the basic principle of the GTEM (Gigahertz Transverse ElectroMagnetic) Cell. This concluded that the main benefit of the GTEM when it was launched in the 1990's was its relative low cost compared to a traditional test chamber. This enabled medium sized enterprises to conduct their own in-house testing and self-certify to the EMC directive.

It is indeed true that a properly calibrated GTEM is perfectly suitable for radiated immunity testing. A 4 point calibration is usually adequate for most cells, with a 9 point setup necessary for only the largest GTEMs. However, there is not a straightforward translation from using a GTEM cell for radiated immunity testing to using the same cell for radiated emissions.

The reason for this is cables. Any product which uses cables for its operation will by its very nature emit EMI from these cables at some level during its operation. It is the very purpose of the emissions test to find the true level of these signals and determine if they are acceptably low. In an 'ideal' environment – there would be only free space and nothing to interfere with the measurement and hence a perfect capture could be made of the state of the EUT. However a GTEM's size means that it is often so close to the EUT that it interferes with the near-field produced by the cables. The signals radiated from the product's cables are reflected around the cell and as a result are distorted and often magnified. In the worst case, a particular emission can have a quarter (or other multiple) wavelength equal to the length of one of the cables. The resulting resonance and reflections play havoc with the measurement and the result is far from a true representation of the product in the real world.

When an EUT is taken to an open area test site (OATS), the results are usually the closest possible to a true free-space reading. Typical objections to this theory are local radio and mobile phone-based interference. However, in practise, test engineers at OATS sites are so well practised at performing the tests that they already know exactly where such unintended interference lies. Care should be taken though on inclement days, since standing rain water also causes extreme reflections and can completely invalidate a set of results. It is because an OATS is as close as possible to true free space, that the relevant EMC standards (61000-4-3) clearly prefer radiated emissions testing to be performed at such sites.

The real point for any company purchasing and using a GTEM is of course to save money on testing fees and to speed up development time. This can still be achieved, even with the limitations imposed by the physics of the GTEM's construction. As previously described, the GTEM is perfectly acceptable for radiated immunity testing since the field is uniformly generated inside the cell and has been checked and calibrated to be identical to that generated inside a 3m chamber. The GTEM is also useful for shielding the world-at-large from the inevitable results of a conducted immunity (CI) test. Often the signals injected onto EUT cables by the CI test cause substantial transmission to result as the Dover coastguard was able to robustly confirm following a CI test many years ago at a popular Dover test laboratory.

It is possible to achieve as close a match as possible between the GTEM and an OATS. This requires a separate calibration to that performed for radiated immunity. Such a calibration gives as high as possible level of confidence that the radiated emissions results are a true representation of what would be seen on an OATS. It is not perfect and cannot be used as a true certification against the EMC directive, but it is very useful for development purposes. With experience, a competent EMC engineer can identify if a scan result from a GTEM test which looks like a fail will actually turn into a pass on an OATS. This reduction in emissions results is not a 'fix' it is simply the case that an OATS will be more realistic because of it's lack of reflections and resonances. It is much more difficult to predict the opposite though – a pass in the GTEM becoming a fail at OATS. Whist unusual, this does happen, and is again a result of reflections and resonances masking the real problem.

To calibrate a GTEM to be as near as possible to an OATS is a specialist task and involves using a low-level white RF noise generator on an OATS and taking the results and correlating with the results of the same test inside a GTEM. The resulting difference file can be used as a calibration of the GTEM. Whilst this method of calibration will reduce the effect of reflections from the geometry of the GTEM, no calibration can remove the effect of resonances.

To conclude, the GTEM is a very useful piece of kit and still a worthy investment for medium sized companies. Time to market can be significantly reduced by using the GTEM for radiated immunity and conducted immunity full-compliance tests. With practise, the GTEM can also be used to design for compliance with radiated emissions tests, a final 1 day test at an OATS is a must though for full confidence .

Methods of positioning the EUT and its cables

When performing radiated emissions and immunity testing in a test house, there are clear rules and guidelines to be followed: 1m of exposed cable where possible etc. However, there are a wide range of GTEM sizes and in most such rules cannot be applied because of physical limitations. Furthermore, it is extremely rare to come across a GTEM with a turntable – a feature that is common to most well equipped test houses.

GTEM users cope with this limitation resourcefully. The true purpose of any EMC test is to replicate real-world conditions in a controlled EMC environment. True to this philosophy, some users choose to lay their cables out literally at random – exactly as they would be in the 'real world'. The counter argument to this approach is that no 2 setups will be the same, and hence repeatability is poor. An alternative method of running the cables around a pre-formed jig is typically adopted by many GTEM users. This gives repeatability and hence a more controlled test. Whilst this is the favoured method for most GTEM operators, one of the authors has found from experience that a random approach is in many ways more useful because of the real-world nature of the test results.

Physical and cost limitations usually mean that it is not practical to install physical manipulators such as turntables inside GTEM cells. Therefore the majority of users tend to manipulate the EUT by hand. The traditional approach is to perform radiated tests in three orthogonal positions such that each plane is exposed. There are some users who go further and test radiated immunity in 4 or even 6 rotated positions to give a higher level of confidence in the integrity of the equipment. The author used to adopt this approach, but found from experience that products which passed in three planes, never failed in one of the additional orientations (reverse plane).

Equipment required to instrument immunity testing rigs, providing automation

The process of Radiated Immunity testing to EN 61000-4-3 involves a number of repetitive processes, and the requirement to monitor the equipment under test (EUT) to look for deviations in performance against specification. The purpose of applying automation to this process, is to help it be completed as rapidly as possible, with the minimum of user intervention, and to provide test results that can be easily presented in an EMC test report. The use of a computer and one of the commercially available programs to control a signal generator and take measurements with a power meter is assumed.

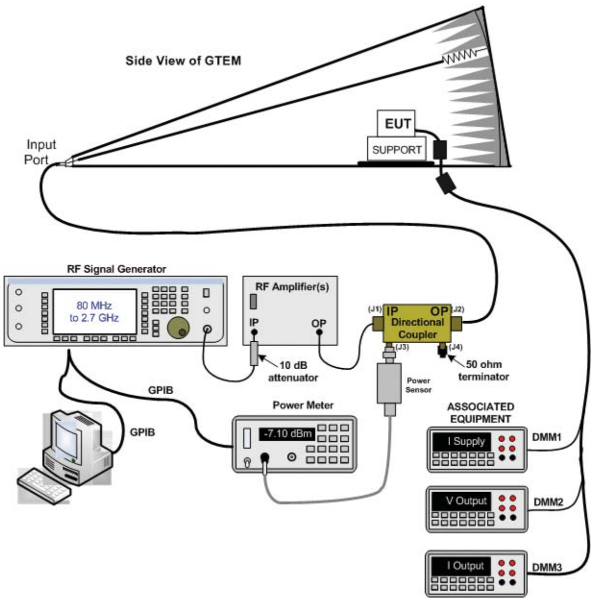


Figure 2. Basic radiated immunity setup with a PC

Processes that could be automated include:-

- EUT positioning
- Amplifier switching
- Data Collection
- Report Generation

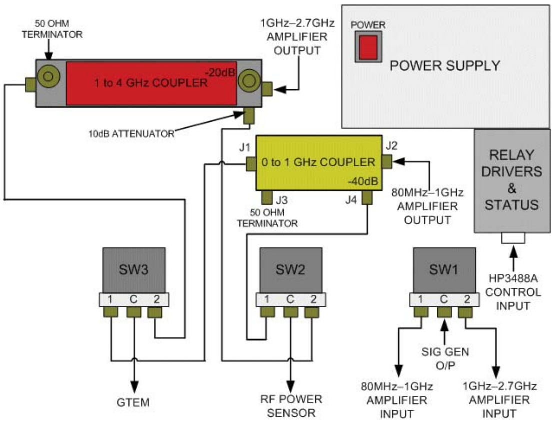
Automation of any one of these processes can significantly reduce the time taken to validate a product, and minimise uncertainties due to inconsistent methods. Which processes can be automated will depend upon the dimensions available in the test volume, and the nature of the parameters to be monitored on the EUT. It is important that all of the processes being automated are placed under the full control of the one Radiated Immunity test program, running on the local computer. Only in this way can the state of the EUT, and its resulting behaviour remain in synchronism with each stage of the test process.

EUT positioning

The equipment under test must be exposed to the electromagnetic field on various faces / orientations to simulate interference arriving from any direction. Manipulators exist to perform this function, and it is possible these may be controlled from the Radiated Immunity test software program itself. This is likely to be most useful with a large test facility with plenty of space around the EUT. Manipulators are made for GTEMs as small as the GTEM750, but for this size it may be easier to fabricate a number of RF transparent jigs to support the EUT, and its cables. The jigs can be made of such dimensions as to support the EUT at the correct height when it is rotated through the three orthogonal axes.

Amplifier switching

It is unlikely that a single amplifier could cover the entire frequency range required for the radiated immunity test. For example, to cover the range 80MHz to 2.7GHz is likely to require two amplifiers, one covering 80MHz to 1GHz, and another to cover the range 1GHz to 2.7GHz. Some facilities use three amplifiers to cover the range. The trouble with manual amplifier switching is that the changeover requires someone to be present to do it, and the duration of each test segment is likely to be different. Also the connectors and cables are likely to wear out. RF switches are available suited to this purpose, i.e. with 50 ohm impedance, and capable of passing from d.c. to 18GHz. A power supply is required to operate the 28 volt relay coils, logic may be required to send power to appropriate relay coils, and a computer controlled switch to allow the control program to signal the changes. An example of a two amplifier system is shown here.



Automatic control of amplifiers

Figure 3. Two amplifier switching system designed by an OEM for product testing

This system uses one signal generator, one power meter, and an HP 3488A GPIB controlled relay multiplexer. The RF switches shown have one common port ‘C’ that is routed to either port ‘1’ or ‘2’. When energised the relays changeover to port ‘2’. In this arrangement all three coils are switched together, and the HP 3488A only requires one relay signal ‘on’ or ‘off’ to command this. The immunity control software will require a driver for the switch control unit. The choice of components is quite critical, and requires some explanation.

Directional Couplers

The Directional Couplers must be tailored for the frequency range, power meter sensitivity, and power level involved. A very wide range of couplers is available from a number of manufacturers. The purpose is to tap off a small fraction of the rf signal for the power meter, with minimal loss from the main feed, and with a flat frequency response. The power meter is connected to the port coupled to the forward power (the one nearest to the power input). When using dual directional couplers as shown in the diagram, the reflected power port should be fitted with a 50 ohm termination. Couplers are available with coupled powers of -10, -20, -30, -40 and -50dB. The power sensor will only operate over a finite range of power levels, and you need to consider the possibility of testing over a range of power levels to attain field strengths according to the severity of the testing being done. The system above suited a GTEM with septum height of 0.75m, and a power sensor with range -30 to +20dB. The accuracy of the coupled fraction is probably not critical, as the system calibration process will use the same system components, and therefore any small frequency deviation can be accommodated. Couplers with smaller attenuation tend to have more variation in the frequency response, and greater power lost to the coupled port. An attenuation of -20dB was found to work well, although repeatable amplitude variations of +/- 1dB occur over the specified frequency range. For this range a -30dB attenuation was required, so the extra 10dB loss was introduced with a precision d.c. to 18GHz attenuator fitted to the coupled port. Couplers used were Narda 3022-20 and AR DC3001. Directional Couplers are impressive and useful pieces of technology, and provided the cables and connectors are selected well, and mated securely, should give no trouble at all. Significant power flows through the couplers, and a loose connector may result in a loss of power to the load, and a very hot coupler.

RF switches

The switch that routes the signal generator to the power amplifiers must terminate the deselected port with 50 ohms. The type designation will include the letter ‘T’ to denote this. The deselected amplifier then has its input terminated with 50 ohms to ground so that although switched on, it will not pickup any spurious signal. A system with more than two amplifiers will require switches with the appropriate number of ways. Four and six way rf switches are available. These have one coil per way, and some logic may be necessary to decode the required states, dependent on the control possible from the software driver in the immunity test software. RF switches are not 100% guaranteed to pull in when energised, and relays are available with additional contacts that can be used for status monitoring. The system illustrated has these additional contacts operate indicator lamps. Switches used are Narda SEM123DN for the power meter and GTEM, and SEM123DT for the signal generator.

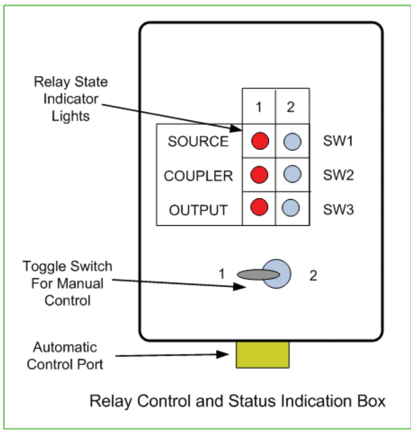


Figure 4.

This system was originally manually controlled by the toggle switch. When it was automated the logic circuit was arranged to detect the automatic control connector being plugged in, and so disabled the toggle switch.

Potential suppliers of rf switches include Narda, JFW Industries, Charter Engineering inc, Hewlett Packard, Dow-Key Microwave, and many more.

Any method of control for the relays that can be accepted by the radiated immunity software may be acceptable. The HP 3488A was chosen because of its compatible GPIB interface, already in use on the basic immunity system, and low cost on the second hand market in the USA. It requires a plug-in card to operate, and one ‘44471 general purpose relay’ plug in is suitable, together with the essential rear wiring connector associated with this card.

Data Collection

Many of the radiated immunity software programmes include support for collecting data from associated equipment that can be used to monitor the performance of the EUT during the test run. A standard test run consists of applying a pre-calibrated rf stress to the EUT at a series of frequencies, each spaced 1% higher than the last until the scan has covered the interval from the start to the stop frequency. At each frequency step the system will apply carrier only to establish the demanded stress, then apply 1kHz amplitude modulation for a duration equal to the dwell time. The time data needs to be collected is immediately prior to the expiry of the dwell time. Any attempt to perform data collection manually will fail to achieve any correspondence between the time the modulated stress is applied, and the time the reading is taken, so that if deviations are taking place, their amplitude is undefined. It is inevitable that distractions would arise during a human-monitored test run, so some frequency steps might go unrecorded.

Automation both provides the required correspondence between applied stress and measurement timing, and records every step. The data will be saved into a file, along with the frequency value, and this can be imported into a spreadsheet program to produce a graph for the test report.

The requirements of the software include:

- EUT monitoring function
- Driver for the associated equipment to be used
- Data output to file in format acceptable to a spreadsheet program
- Sufficient channels for the number of points to be monitored

Not all EUT can be monitored in this way, but many of those with cables can, e.g. power supplies, or equipment with analogue or digital output functions. It is understood that one manufacturer has designed a vision system to monitor instrument displays for changes, and has the intelligence to grade the severity of the change.

It is possible that numerous parameters need to be measured, so the immunity software needs to provide a sufficient number of monitoring channels. A measuring instrument is required for each channel. Fortunately the GPIB interface is ideally suited to the communication task, and the one GPIB port will control both the basic immunity system components, and perhaps up to 8 monitoring channels. The monitoring instrument needs an electrically robust and versatile input, and a GPIB port. Bench DMMs with 6½ digit resolution fit this task well, and can measure d.c. and a.c. voltage, d.c. and a.c. current, ohms, frequency, dB as the main variables. For example, alarm relay contacts can be monitored with the ohms function.

Referring back to the diagram showing 'Basic radiated immunity setup with a PC', the only item to be added is a number of GPIB cables to link up the DMMs to the PC. The DMMs stand nicely in a stack protected by their rubber bumpers, and can be interlinked with (n-1) 0.5 metre GPIB cables, where n is the number of meters.

It is worth installing an SPDT GPIB manual selector unit to switch the control PC GPIB interface between 'Emissions' and 'Immunity'. This isolates the single spectrum analyser from the 11 or so GPIB devices on the immunity rig. The spectrum analyser has a massive amount of data to transfer, and its bus should be as lightly loaded as possible.

Report Generation

Many emissions and immunity test programmes offer report generation whereby the outcome of the test is recorded along with details of the EUT, the standard being applied, and any numerical or graphical data that may have been collected. All of the details need to be entered if not automatically collected, so a complete report is not going to be available before this is done. The desire for this automation will depend very much on the user, who may be happy to be prompted to input this data whilst it is current, or who may prefer to collect the data when ready to do so. One thing is true, if the test person fails to record the details of the test/equipment used/environmental conditions/ etc at the appropriate time, it is amazingly difficult to recall them a week or so later when some of the test equipment has gone out for calibration, the environmental conditions have changed, or the EUT has been mixed up with other similar ones.

Methods for GTEM Performance Verification

The GTEM consists of a myriad of large components, all of which must be in good condition, and assembled correctly to give any chance of good performance. Even then, it will be necessary to have the various adjustments set up to optimise the system. This article refers to an actual test setup and the various measurements that were performed in order to verify the integrity of the GTEM.

A number of techniques are considered for verifying the suitability of the performance for test work. Only one technique is considered in full, the others are listed for completeness, and could form the basis for future papers.

- Comparison noise emitter
- Time Domain Reflectometry
- VSWR measurement
- Forward power required for a given field strength

Comparison Noise Emitter

These produce a defined pattern of broadband noise, useful over a specific range, typically 30 MHz to 1 GHz. The purpose is to evoke a linear response from a given receiving transducer, and to compare this response against the emission pattern the CNE is known to provide. Without a certificate such a device is merely a go / no go detector. The device really becomes useful if it is stable, and is accompanied by a detailed calibration record of the actual response. The spectral distribution for this emission pattern varies from one make to another. The type with which we have become familiar provides line spectra at 2MHz intervals from 30 MHz to 1 GHz. This is called a comb generator, and calibration data is available for the Horizontal and Vertical emissions referred to a 3 metre separation from the antenna. A comb generator with a 2 MHz interval provides 486 data points for each of horizontal and vertical calibrations. The GTEM is sensitised for a vertical field, therefore it is only the vertical calibration data that is required. To be able to use the supplied calibration data to verify the performance of the GTEM a fair amount of data manipulation is required, and this will be described after some preparatory work.

Preparatory work with the CNE

A couple of tests need to be done before relying on the measurements taken with the CNE:-

1. It is necessary to ensure the signal level received from the CNE neither overloads the receiving device, nor is so weak that the signal to noise ratio is poor.

2. The location of the CNE will surely be in the optimum calibrated position in the GTEM, but one should get a feel for the variation in the results if the CNE is moved into the extreme positions that we allow our EUT and cables to occupy during regular testing.

Test 1 is done with the CNE in the optimum position, and no preamplifier or attenuator between the GTEM and the spectrum analyser. A scan of the emissions from 30 to 1000 MHz is performed, and the results saved. A second scan is done with a 20dB attenuator fitted in line with the signal. The two scan results are then plotted on the same graph.

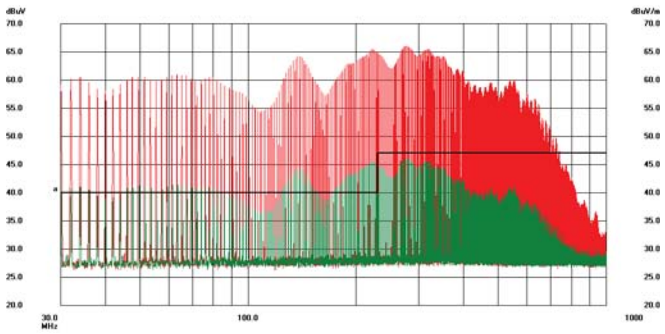


Figure 5. Spectrum Analyser compression test

Look for a constant difference of 20dB between the two curves. If this is met, then the receiver is neither being overloaded, nor operated near to its noise floor. The plot illustrated shows a constant difference of 20dB up to 600 MHz, reducing above 600 MHz as the more attenuated signals fell towards the noise floor on the analyser.

This plot indicates that:-
1. No compression was taking place where the CNE output is at a maximum.
2. The attenuator is not wanted, as it drops the level below the noise floor when the CNE output level is falling away at the upper frequencies.

Test 2 is done with the CNE in 5 positions in a horizontal plane:-

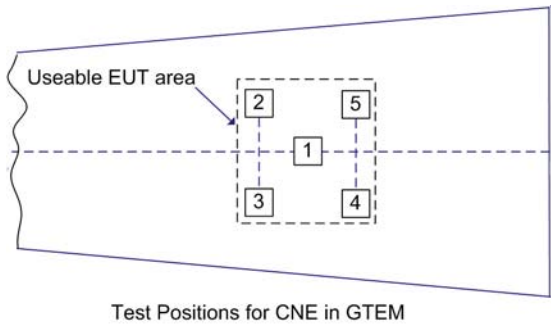


Figure 6

The scans are overlaid using the graphical presentation facilities of the Radiated Emissions test software. It was found that position 1 always had the highest data. Position 2 was the closest match, being lower at 65-100MHz, 300-350MHz, 550MHz, 850-950MHz.

Position 3 had -3dB variations in many places.
Position 4 had -4dB variations in many places.
Position 5 had -4dB variations in many places.

In conclusion, position 1 will be used, and neither preamplifier nor attenuator required.

The CNE verification process

When performing emissions measurements we use a spectrum analyser with a receiving bandwidth of 120 kHz. It would be possible to capture a full 30 MHz to 1000 MHz spectrum on a single spectrum analyser screen in Max Hold mode, but it was thought this might not provide the required accuracy. A single analyser 'screen' has a finite number of data points, perhaps in the range 500 to 1000 samples. These samples are unlikely to align with the comb spectral components satisfactorily, indeed aliasing is likely to occur. To overcome this, the spectrum analyser is used to scan the emissions in the same way as we would for a regular Radiated Emissions test run, therefore the results will be most comparable between the verification, and actual Radiated Emissions product testing. The spectrum analyser is stepped through the full frequency spectrum at 60 KHz intervals. Why such a close spacing ? Figure 7 shows the analyser response with a 120 kHz bandwidth.

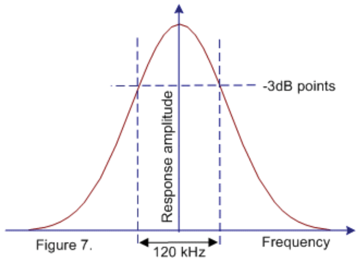


Figure 7

Figure 8 shows two such response curves spaced 120 kHz apart. It can be seen that if a comb frequency component fell anywhere in the frequency range, its recorded amplitude could suffer a 3dB peak to peak variation.

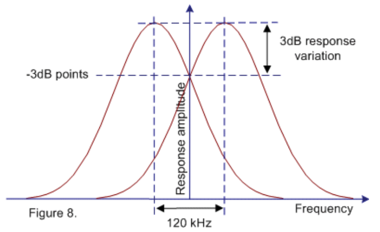


Figure 8

By comparison, if the response curves are spaced 60 kHz apart as shown in Figure 9, the peak to peak variation is reduced to a value less than 1dB.

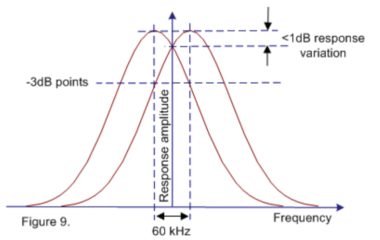


Figure 9

A 60 kHz sample spacing for the interval 30 MHz to 1000 MHz results in 16,167 samples. This is a very large number, but by using a spreadsheet program, it can be reduced to the required 486 data points corresponding to the maxima in the 16167 numeric series. We found the spectrum analyser neither required a preamplifier, nor an attenuator to optimise the received signal level. This is ideal, as both of these components are frequency conscious, and we need to avoid all unnecessary variables in the process.

Spreadsheet reduction method

The data recovered from the emissions scan contains data pairs of frequency and emission strength from 30 to 1000 MHz in steps of 60 kHz. This is 'Y-axis' data, and we do not wish to introduce either X-axis or Z-axis data sets to correlate it against. This is because we wish to compare the result against the CNE 'Vertical' calibration data. However the Y-axis data must be correlated before it can be analysed. One option would be to correlate 3 identical sets of Y-axis data. An easier option is to use a factor file. The Radiated Emissions software used allows the application of factor files, therefore we have created a factor file (2Ghzgtem.amp) for this purpose that is equivalent to correlating 3 sets of the same data. It increases the level of high frequencies , and reduces the level of low frequencies, and has neutral effect at 192 MHz. The slope is 20dB per decade.

Frequency, MHz	Correction, dB
25	-17.3
30	-15.8
40	-13.3
50	-11.5
60	-9.9
70	-8.6
80	-7.5
90	-6.5
100	-5.6
192	0
200	0.3
300	3.8
400	6.4
500	8.4
600	10.1
700	11.5
800	12.7
900	13.8
1000	14.8
2000	21.5

Table 1 – Contents of factor file 2Ghzgtem.amp used for 'correlating' a single set of data

The correlated data is imported to a spreadsheet, frequency to column A, emission dB to column C.

Columns B and D are populated with formulae for the full 16167 rows.
Column B computes the theoretical nearest comb centre frequency for this frequency step. For example, in the range 31 to 33 MHz the value would be 32 MHz.
Column D computes the maximum emission value seen over this 2MHz range.

Column E is empty, and used as a visual separator.

Columns F, G and H hold the smaller output table of 486 points.
Column F is populated with the theoretical comb centre frequency, e.g. 30, 32, 34 MHz etc.
Column G is the maximum emission value picked out from that frequency range.
Column H is the imported calibration data file provided with the CNE unit.

The method chosen for this process uses formulae in columns B, D and G to condition the data, however it would be equally possible to create macros to process the data, and populate the columns with the results.

Plot CNE vertical cal data on same graph as scaled response data

A graph may be plotted using the output table of 486 points with two lines:-

a) The amplitude of the peak emission points scanned.
b) The CNE vertical calibration data.

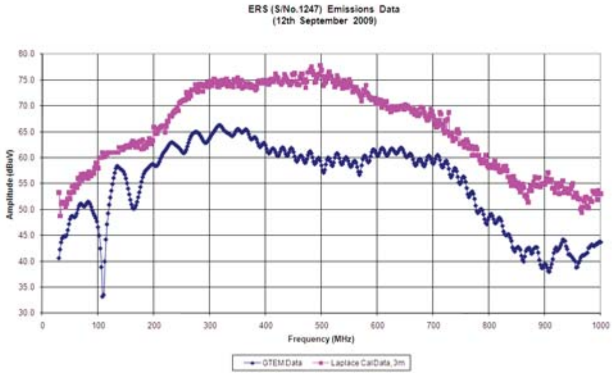


Figure 10

Scale data to same distances (it may be measured based on 3 metre distance

It may be found these lines are quite separate. The reason is probably that the CNE calibration data is based on a 3 metre distance, whereas the GTEM data is based on a 10 metre distance. If that is the case, the CNE calibration data may be corrected by subtracting 10.46 dB. This is calculated as 20 x LOG_{10} (10 / 3). Hopefully the two data curves should now appear on top of each other. If they are consistently spaced by a significant amount, it may be due to some numerical offset inadvertently included. This must be resolved. The more likely situation is that the two lines will match over some frequency ranges, and fail to match in others. The plot on the next page shows the result of correcting the scaling to 10 metres.

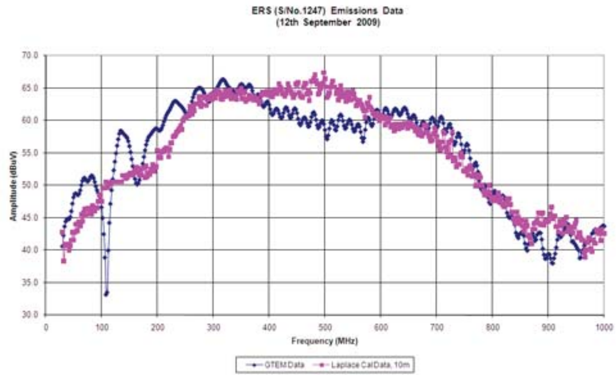


Figure 11

The difference represents the sum of the comb generator calibration errors, plus the imperfection of the receiver system. We have noticed up to 4 dB variation in comb generator calibrations between different CNE units, and the same unit used 2 years apart. This is quite a large uncertainty, but the first job the CNE was given was to reveal a gross deviation in our GTEM's response (20 dB), so was easily able to do this. The plot above shows problems at 107 MHz and 900 MHz.

The CNE calibration data may itself be in error by several dB, as it is generated in a two stage process itself. The CNE manufacturer submits a master CNE for characterisation at NPL. The master CNE is then returned to the manufacturer who issues dates when customer calibrations may be obtained. On these dates customers' CNE units are compared one by one against the master CNE in the manufacturer’s own anechoic chamber. In this way the calibration data is produced.

Conclusion

The calibration comparison described above was performed with the CNE in the optimum position:- central between floor and septum, central between GTEM sides, and at the marked calibration distance from the apex of the GTEM.

This method has pinpointed some particular flaws in the GTEM response that needed to be fixed, and provided real time feedback whilst the necessary adjustments were made.

When the adjustments are as good as they are going to get, the next step would be to create a factor file with the difference between the GTEM response to the CNE, and the CNE data itself. The idea of using the factor file is to correct the GTEM data to the ideal response when performing product testing. Such a factor file with 26 points had been successfully been used, providing a useful decision making tool when emission results are close to the limit.

Time Domain Reflectometry

The GTEM is intended to possess a 50 ohm impedance all the way from the rf amplifier to the termination, and this pathway is a transmission line. Electromagnetic energy flows down the transmission line, and on its way samples the impedance at every point. Where the impedance varies at any point, the discontinuity creates a reflected wave that travels back to the source, and affects the amplitude of the continuing wave. This effect can be used to pinpoint impedance discontinuities, and inform their severity.

The equipment required is a source of fast risetime pulses, and a fast digital oscilloscope. It may be possible to demonstrate the technique with existing test equipment, but to provide the sensitivity and accuracy to dare to adjust the septum, specialist equipment is required, and it is better to leave this to the professionals.

As an example a pulse generator and wide bandwidth Oscilloscope is used to reveal the impedance in the GTEM between the apex and the termination.

An Agilent 81130A Pulse/Pattern Generator issued fast risetime pulses at a repetition rate of 1kHz. These were monitored at the pulse generator output connector by an AP020 Active Probe connected to the LeCroy LC564A 1GHz Oscilloscope. The usual RG213 cable was used to connect to the GTEM apex connection point.

Figure 12

It was found the voltage level reached by the pulse after the original low to high transition was a good indication of impedance along the route of the transmission line. For example, when an RG213 (50 ohm) cable was connected to a 60 ohm termination at the far end, the voltage level rose about 10%. The formula for VSWR is (1+Ro)/(1-Ro), times the nominal impedance. This confirms the value as 60 ohms. The plot here shows the result when the RG213 cable was reconnected to the GTEM. The first cursor is positioned at the time where the pulse transfers from the cable to the GTEM. The second cursor is positioned where the septum connects to the resistor boards. The trace appears level for the cable and the septum, but shows a marked discontinuity along the resistor boards. The peak of the bump appears to rise 14.8% above the 50 ohm level. This converts to 67.5 ohms.

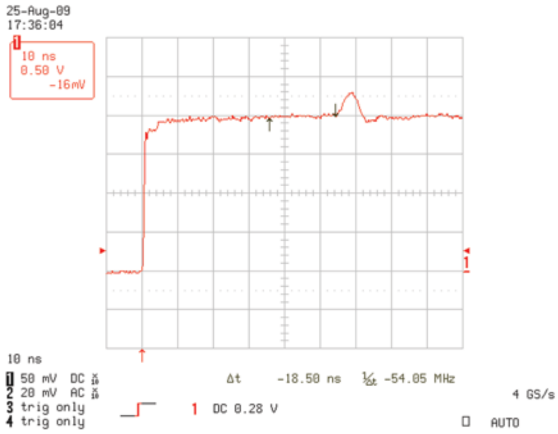


Figure 13

As stated, do not attempt to adjust your GTEM on the basis of such a setup, leave this to the professionals.

VSWR measurement

VSWR stands for Voltage Standing Wave Ratio, and is derived from the measurement of RF power supplied by the amplifier (forward power), compared to the power reflected back to the amplifier (reflected power). The reflected power is created by the impedance bump resulting from a mismatch between the GTEM and it’s rf input cable. The Return Loss, VSWR (voltage standing wave ratio) or VRC (voltage reflection coefficient) are all terms used to describe the matching of the load impedance to a transmission-line, and they are used interchangeably. The reflection coefficient magnitude, $|\Gamma|$ or ρ, is the ratio of the amplitude of the reflected wave to the amplitude of the incident wave at the junction of a transmission line and the terminating impedance. $|\Gamma|$ has a value between 0 and 1. A $|\Gamma|$ of 0 means the line is perfectly matched, and a value of 1 means that the line is either shorted or open-circuit. The Return Loss, RL, is the magnitude of the reflection coefficient expressed in dB.

$$R_L = 20 \log_{10} |\Gamma| \text{ dB.}$$

Here a return loss of 0 dB means the line is either shorted, or, open-circuit, and a value of $-\infty$ dB means the line is perfectly matched

$$VSWR = (1+|\Gamma|)/(1 - |\Gamma|)$$

The VSWR of a GTEM can be measured by adding a second power meter to the system shown in ‘Basic radiated immunity setup with a PC’. The second power sensor should be attached to J4 on the directional coupler after removal of the 50 ohm terminator fitted there. This will measure the reflected power. The difference between the two power measurements is the return loss.

e.g. a return loss of 20 dB is expressed as -20 dB.
Divide by 20 to get -1.
Take the antilog to get 0.1. This is $|\Gamma|$
Calculate VSWR = $(1+|\Gamma|)/(1-|\Gamma|)$: $(1+0.1)/(1-0.1) = 1.22$.

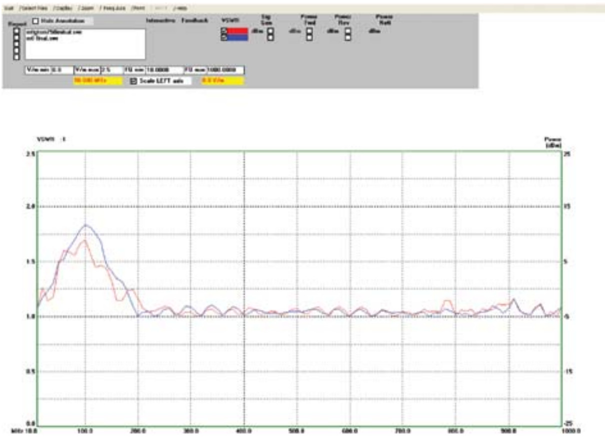


Figure 14. VSWR plots taken for a GTEM

The plot shows two VSWR measurements for one GTEM performed at different times. The red curve shows a peak VSWR level of 1.6, and the blue curve a peak level of 1.8, both at 100 MHz. The resolution of the samples was 10 MHz. Subsequent investigation of this GTEM using a CNE with 2MHz comb emissions spacing showed more detailed deviations, and led to the eventual solution of the problem.

Forward power required for a given field strength

When a GTEM calibration run is performed, one of the data outputs recorded is the forward power applied to the GTEM to provide a constant field strength. If the impedance match of the GTEM is flat over the frequency range, the forward power measurement would be a fixed figure. In practise there are noticeable variations in the forward power at certain frequencies. These variations may be due to a resonance internal to the GTEM. The magnitude of the variations will affect the power output required from the amplifier system to achieve a particular field strength. Clearly this could have a cost implication if a more powerful amplifier has to be purchased, but more significantly a variation may suggest that the GTEM requires adjustment. A peak to peak variation of greater than 6dB should be investigated.

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EMC design of high-frequency power "switchers" and "choppers"

Design techniques for HF isolating transformers

One of a number of "Stand Alone" articles on the EMC design of switch-mode and PWM power converters of all types

By Keith Armstrong, Cherry Clough Consultants Ltd, www.cherryclough.com

Issues 93 and 94 of The EMC Journal carried the first two of these "Stand Alone" articles [13] [42] on the EMC design of switch-mode and PWM power converters – my attempt to cover the entire field including DC/DC and AC/DC converters, DC/AC and AC/AC inverters, from milliwatts (mW) to tens of Megawatts (MW).

In this series I aim to address _all_ power converter applications, including: consumer, household, commercial, computer, telecommunication, radiocommunication, aerospace, automotive, marine, medical, military, industrial, power generation and distribution, in products, systems or installations. And I will also cover hybrid & electric automobiles, electric propulsion/traction; "green power" (e.g. LED lighting); and power converters for solar (PV), wind, deep-ocean thermal, tidal, etc.

This Stand Alone article addresses the circuit design issues associated with the high-frequency (HF) isolating transformers. I generally won't repeat material already published in the EMC Journal [14], or in my recently-published books based on those articles [15], so that you don't get bored by repetition. But I will provide the appropriate references.

Before I make a start on the title subject of this article, I must return to Section 2.2 in Part 2 [42], which very briefly mentioned Ćuk converter topologies by simply referencing [23].

[23] is a Wikipedia page that only describes the non-isolated Ćuk topology, and doesn't do justice to the very wide range of Dr Ćuk's resonant-mode converter topologies. However, [23] partially redeems itself by referring to what I have listed below as [43] – a page in the website of www.boostbuck.com dedicated to showing how easy it is to use the Ćuk topologies to beat the pants off all other DC-DC converter topologies.

I can do no better than to copy the words on the www.boostbuck.com homepage:

> "The purpose of this web site is to show Power Electronics Engineers how to design the Boostbuck (Ćuk) Converter easily and painlessly.
>
> "The motivation is to encourage general use of this Optimum Topology to improve performance of industry designs. To that end, the optimality of this family of 4 converters is shown plainly vis. a vis. many of the other common topologies currently in use.
>
> "Along the way, a number of very sweeping generalizations are made to simplify the design process. These are each justified in turn, and save the engineer much time spent chasing after popular, but unfruitful, design approaches."

I should also mention here that one of the strong points of Ćuk converter topologies is their ability to combine the input and output inductors into one smaller component whilst simultaneously reducing noise emissions and ripple voltage, thus also reducing the size of the filter and DC storage capacitors.

Isolating Ćuk converters can combine *all three* magnetic components: the input and output inductors *plus* the isolating transformer; into a single smaller component – whilst also reducing noise emissions from the input and the voltage ripple at the output.

It seems that the reason that most people don't use Ćuk topologies is the difficulty they have in designing the integrated magnetic components, but www.boostbuck.com has a web page that claims to make this an easy task.

What made me revisit the issue of Ćuk converters, prompting me to sing their praises here, is an article by the good Dr Ćuk himself in the latest edition of Power Electronics Europe magazine [44].

This article extends his DC-DC converter topologies into AC-DC converters that do not require an input rectifier – thereby reducing the typical AC-DC converter's fourteen switching devices (transistors and rectifiers) and three magnetic components, to just four switching devices and one magnetic component, as shown in Figure 3A.

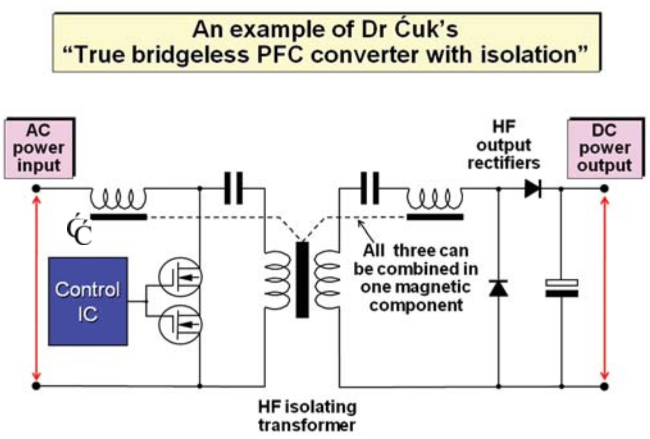

Figure 3A. Example of Dr Ćuk's new converter topology

[44] also describes how using three such converters on a three-phase AC supply can eliminate the need for any energy storage/smoothing capacitance, saving even more cost and weight.

All single-phase AC-DC converters deliver pulsating DC power (a full-wave rectified sinewave) at 100Hz (or 120Hz in the US and other "60Hz" countries) because a single-phase AC mains supply provides a 50/60Hz sinewave with an unavoidably pulsating AC power. As a result, they need a lot of energy storage or "smoothing" to provide the load with a DC output that has acceptable levels of voltage ripple.

However, a three-phase mains power supply actually provides a continuous, constant AC power, but using a three-phase bridge rectifier sums three individual 100/120Hz full-wave-rectified sinewaves, each shifted 120° in phase. The result is a DC voltage, right enough, but one with a considerable level of AC ripple consisting of half sinewaves at 300/360Hz.

So, providing the load with a DC voltage that has an acceptable level of voltage ripple again needs an energy storage or "smoothing" capacitor – although it does not need to be nearly as large, for a given value of ripple voltage, as if the same load power was being delivered from a single-phase mains supply.

However, the three-phase Ćuk converter described in [44] has no bridge rectifiers and needs no energy storage/smoothing capacitors, thereby reducing cost, weight and size even further. Constant three-phase mains power in, constant DC power out.

A downside of this approach may be that because there is no "hold-up" energy provided by large energy storage/smoothing capacitors, the usual dips, dropouts and imbalances in the three-phase public mains electricity supply can harm the DC output's power quality. But where the three-phase supply has a high enough quality (e.g. when powered from a dedicated generator, such as an aircraft's jet engine's 110Vac generator) this might not be important.

I understand that Dr Ćuk's converters were used on the Space Shuttle (may it Rest In Peace) because of their high efficiency and small size and weight, so maybe aerospace applications are a good application for using this new three-phase AC-DC converter topology without energy storage/smoothing capacitance.

4 EMC design of HF isolating transformers

4.1 Introduction to the example

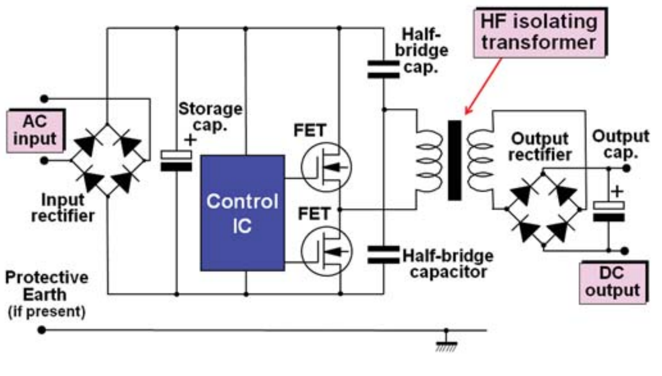

Figure 3B. Example of an AC-DC SMPSU converter

Figure B shows the (very) basic circuit schematic that will be used in the discussions below, and in several later articles in this series.

It is an isolated half-bridge Pulse Width Modulated (PWM) converter (a "chopper") – because I had to draw *something* to use as a practical example. There are many other types of power converter, and the EMC design principles discussed below apply to them all (except where noted).

Figure 3C shows the example I will use for the 2-layer printed circuit board (PCB) layout of the converter in Figure 3B, and Figure 3D shows a sketch of this example's complete assembly.

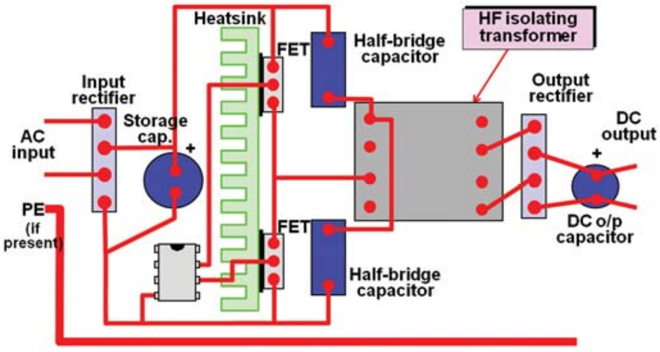

Figure 3C. The basic PCB layout for the example SMPSU converter

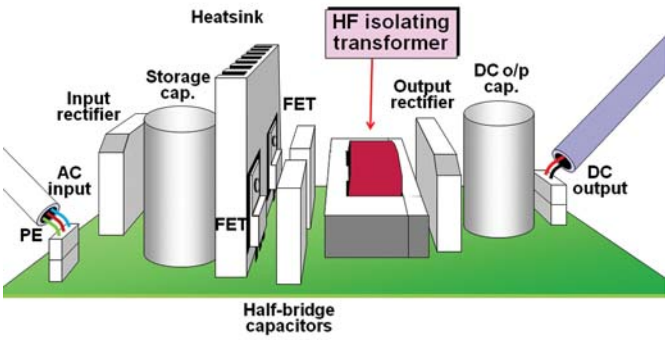

Figure 3D. The basic PCB assembly for the example SMPSU converter

The following sections describe a number of good EMC design and construction practices relating to isolating transformers, with the aim of reducing the reliance on EMC mitigation methods such as filtering and shielding to a minimum, to save cost, size, weight, and time-to-market.

There are other methods than transformers for transferring electrical power across an isolation barrier, for example the "flying capacitor" method. However, isolating transformers are the most common method used, and no other methods are discussed in this article.

Reducing emissions by a few dBs *here* by applying one low-cost transformer design and construction technique, then reducing a few more dBs *there* by applying another, and so on, pretty soon adds up to a significant reduction in emissions with the lowest overall cost of manufacture, in the shortest time.

But reductions in time-to-market will not be achieved unless these good EMC design techniques are all taken into account *from the start of the project*.

I'm not saying they must all be done, only that they should all be considered individually and each one should only not be used if there is a fixed technical constraint that makes it inappropriate. In such cases, an alternative should be employed. If EMC design is ignored until the end of a project, then *when* (not *if*) the product fails its EMC tests the timescales are usually so desperate that the bill of material (BOM) cost targets are forgotten as costly filtering and shielding "fixes" are thrown at the product until some combination of them allows it to pass, eventually. Many EMC engineers worldwide are fully employed in doing just this, on product after product. But the eventual cost and the time it takes are unpredictable, so it represents a very significant financial risk.

If only Design and EMC engineers learned to speak the financial language of their managers (it's very easy, really, but it's not an engineering discipline) they would soon be able to persuade them that designing using good EMC techniques from the start of a project would significantly reduce financial risks. A worked example is given in Chapter 1 of [5].

4.2 How the interwinding capacitance causes emissions

Isolating transformers have interwinding capacitance (C_{STRAY}) between each isolated winding. In this example I will consider the C_{STRAY} between a primary and a secondary, although similar principles apply to any pair of windings. Figure 3E shows where this C_{STRAY} arises.

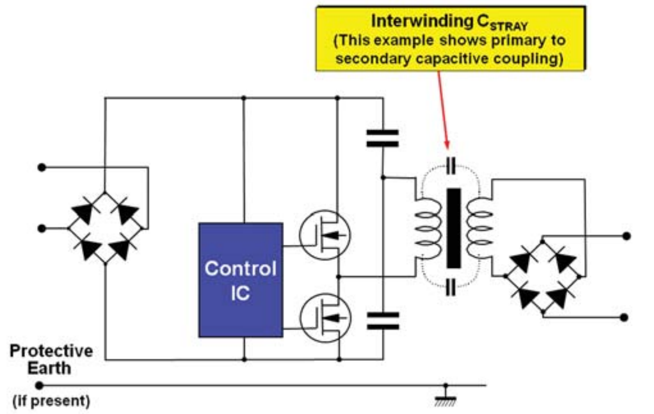

Figure 3E. The stray interwinding capacitance (C_{STRAY}) in the HF isolating transformer

This C_{STRAY} injects primary switcher noises into the DC output circuit, as common-mode (CM) noises that flow in the DC output circuit and its loads. It also injects the DC output's HF rectifier's switching noises as CM noises into the primary switcher circuit, which then flow into the power supply lead and power distribution network in the building or vehicle.

As was already mentioned in an earlier part of this series (section 2.5 of [42]) ***all*** currents – including stray currents – always *always always* flow in closed loops. For more on this natural phenomenon see [4], or chapter 2 of [5] (which copies the text of [4]).

[45] and [46] describe the consequences of this law of physics/nature for any/all types of electronic design at any scale (including the fact that "earthing" or "grounding" or connecting to "chassis" *cannot* make unwanted noise vanish as if the "earth", "ground" or "chassis" was some sort of infinite sink for electrical current).

[4], [45] and [46] also show that any current loop naturally takes the path with least impedance, hence naturally creating the most compact pattern of electric (E) and magnetic (H) fields, automatically giving the best EMC (for emissions and immunity) that is possible from a given design and its physical construction.

When we understand this fundamental EMC principle, we can see that instead of trying to suppress stray CM currents with costly mitigation techniques such as filtering and shielding, we can save cost and time (and make our EMC lives much easier) by simply creating lower-impedance paths – with their even more compact E and H fields – available to all of the noise currents.

These lower-impedance paths must be very local to the noise source (always a semiconductor device), because the dominant constituent of the impedance of any current path is generally its inductance, which is directly related to the area of the current loop.

EMC textbooks and guides have for years been saying words to the effect of "keep all current loops small", because keeping the wanted, differential-mode (DM) current loops small reduces their generation of stray CM noise. We now see that keeping the stray CM current loops small is also important, by reducing the extent of their stray CM E and H fields and thus reducing emissions and improving immunity.

Effectively, this important approach manages the shapes and extents of both wanted and stray E and H fields, so that the noisy switcher circuits experience less coupling with their external electromagnetic environment.

Where a current (whether wanted or stray) has a choice of loops to flow in, it will naturally divide amongst them in the inverse ratio of their impedances – the loop with the lowest impedance will automatically carry more current than the others. So a key EMC design technique is to identify where stray capacitive coupling is occurring and – in each case – provide a local current loop with a small area and low impedance.

So let's now apply these basic principles to the interwinding CM noises in our example half-bridge PWM chopper!

Figure 3F attempts to show the paths of the two stray CM noise currents being considered here, from the noise generator (a switching device) through the interwinding C_{STRAY} and the circuit on the other side of the isolation transformer, eventually coupling back to form closed loops through stray conducted and radiated currents in the world outside of our example circuit.

What this means in practice is that primary switcher noise that flows through the transformer's C_{STRAY} and flows in the DC output, will loop back through the air and other conductors outside of the product and eventually return mostly via the power supply lead and be measured as conducted emissions. This is why shielding and/or filtering the DC output circuits and their loads can often reduce the conducted noise that is measured on the power supply cable.

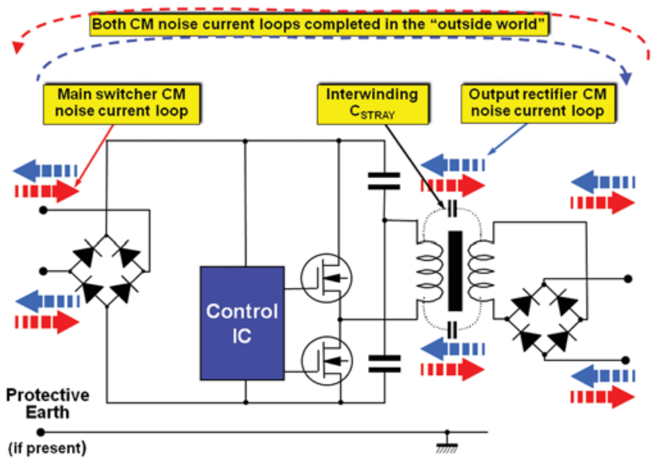

Figure 3F. The CM current paths that flow through the transformer's C_{STRAY}

These stray conducted and radiated currents in the outside world are, of course, the conducted and radiated emissions measured by EMC tests, which for Regulatory Compliance we need to keep below the limit lines in the relevant test standards over the operational lifetime of the power converter.

However, we might need to ensure emissions are much lower than the standards' limits to prevent actual interference with other parts of the product that uses the power converter, or nearby equipment that is especially sensitive. My story below about powering an analogue professional audio mixing desk from a switch-mode power supply is relevant here.

That shielding and/or filtering DC circuits and their loads can reduce power supply-borne noise is not comprehensible unless one understands that all currents, even stray noise ones, have to flow in closed loops.

But how does the LISN (or AMN, AN, etc.) used to measure conducted noise in the power supply cable even detect a noise current that is coming from the power supply side? Surely it filters out all noise coming from the "wrong side"?

This confusion is all my fault, for describing currents as if the wanted signal (or unwanted noise) starts off at the source and travels all the way around the current loop before eventually returning to its source and completing the loop. This is a low-frequency circuit designer's way of looking at the issues, and I find that it helps me to visualise where the stray currents are actually flowing in a given physical construction. *But it is not what actually happens!*

All electrical currents (wanted, or noise) are real energy, so the Law of Conservation of Energy applies. What actually happens is that as the source emits its current, it also emits an antiphase return current. At each step forward in time the send and return currents progress a little further around their loop, maintaining a total energy of zero (Conservation of Energy means we can't create it, so our total energy must always be zero). Eventually, the positive and negative phase currents meet at the furthest end of the loop from the source, and cancel out.

"Proper" EMC engineers with good mathematical skills, and electromagnetic (EM) field solvers, analyse all electronic circuits as a huge number of very, very tiny dipoles – each one emitting EM waves in one direction whilst at the same time emitting identical *antiphase* EM waves in the opposite direction.

Tim William's excellent textbook [47] gives the basic equations for vanishingly small electric dipoles (also known as "current filaments" or "Hertzian dipoles"), and for magnetic dipoles (i.e. current loops) in its Appendix D, section D.3.8 on page 461. If you want to get into more depth, read chapter 7.1 of [48].

I tend to focus more on the practical implications for product and system design, which led me to write [45] and [46]. If your interest is more in visualising EM wave propagation (which, after all, is what all electricity really is, whether used as power, signals, data or noise), these two references should be more to your taste.

All circuit analysis is taught using "circuit theory" that is a gross simplification of real EM propagation (i.e. electricity), but this is never explained. Consequently, concepts based on circuit theory (including all circuit simulators) can lead us badly astray when we try to understand how best to design for EMC, and for that we have to blame our University lecturers for not providing us with a complete understanding of electricity.

It's not surprising, really, that generations of circuit designers have resorted to getting a circuit functional and then – to comply with EMC requirements – stuffing it all into a costly and heavy shielded box that is fitted with costly and heavy shielded and/or filtered cable connections, then fiddling about with the shielding and filtering for as long as it took to get a design that passed all the EMC tests. We can do so much better than that, saving huge amounts of cost, time, weight, and mental anguish, when we understand what is really going on with EMC.

So, let's get back to the question of why it is that primary switcher C_{STRAY} noise currents that are emitted from our DC output and its loads and then (using an approach based on flawed circuit theory) "circle back" into the building or vehicle's power supply to complete their current loops, along the way being measured as conducted noise emissions on the power supply.

What is really happening is that our power converter is acting like a radiating dipole antenna, and as primary switcher C_{STRAY} noise current flows *out* of the converter's DC output, an exact antiphase replica of it simultaneously flows *out* of the power supply lead, into the test LISN (AMN, AN,etc.) and so gets measured as part of the converter's conducted emissions.

Whenever our grossly simplified analysis shows CM noise currents entering a LISN by its (filtered) power supply terminals to complete their loop in accordance with Maxwell's equations, what is really happening is that noise currents are entering the LISN from its product terminals.

This same "dipole effect" also means that sometimes conducted emissions measured on the power supply lead can be reduced by reducing radiated emissions (e.g. by shielding).

Figure 3G attempts to visualise the "near fields" around the converter's PCB assembly and its cables, as the stray CM currents complete their loops by flowing as conducted and radiated currents into and out of various components and cables.

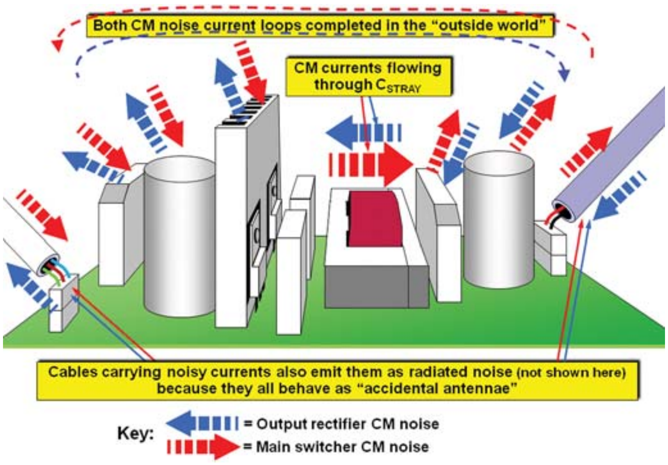

Figure 3G. Visualising the CM current noise loops flowing around the converter's assembly

Because these CM noises are injected across an isolation barrier, their current loops are completed by external circuits (e.g. power source, load) and also by stray electric fields between the conductors and components on either side of the transformer, all behaving as accidental antennas, creating high levels of conducted and radiated emissions in the outside world.

The main culprits for creating emissions are the input and output cables, because conducted noises are measured directly on the power supply input cable, and because cable lengths make them very efficient "accidental antennas" for emitting radiated fields. (The unavoidable "accidental antenna" behaviour associated with any type of conductors is described in detail in [4] and Chapter 2 of [5].)

The radiated emissions from components acting as accidental antennas couples currents through E fields in the air (i.e. stray capacitances) into the power supply cable and so can increase conducted emissions. This is especially a problem for switching device heatsinks, and appropriate design solutions were discussed in Section 2.5 of [42].

CM noise via the HF transformer interwinding C_{STRAY} is difficult to filter at frequencies below 10MHz, because the stray interwinding capacitance presents a high source impedance at such frequencies.

As Chapter 5 of [5] shows, with a high noise source impedance we can't achieve much attenuation by using series CM chokes, as they work best when the noise source impedance is *much lower* than their series CM impedance.

Because the noise is CM, and is galvanically isolated by the transformer from its origin, capacitors across inputs or outputs have no effect (they only work on DM noise). Capacitors from inputs or outputs to the chassis or protective earth/ground *might* help, but adds a new accidental antenna and so might cause more problems than they solve (see 4.9 below). Remember – "earth", "ground", "chassis" or whatever *cannot* act as some sort of infinite sink for noise currents.

These CM noise currents flowing through the high impedance of C_{STRAY} create CM noise voltages between the primary and secondary circuits, which can upset voltage control feedback circuits and often make it necessary to use optoisolators (or other galvanic isolation signal techniques) with high *dV/dt* ratings, in the feedback signal's path.

It is best to reduce noise generation at source by keeping *dV/dt* and *dI/dt* low at every instant throughout the switching cycle, ideally by using a 'benign' type of resonant-mode power switching topology (see section 2.2. in [42], and the additional comments on Ćuk converters above) and also by using more "benign" HF output rectification techniques, which will be covered in a later "Stand Alone" article.

If further suppression of conducted or radiated emissions is required, it is best to apply the techniques described below as they might reduce (possibly even eliminate) the need to apply the more costly usual mitigation techniques: filtering and shielding.

4.3 Reducing emissions with an interwinding shield (or two, or more)

To reduce the CM noise currents flowing through an HF isolating transformer's interwinding C_{STRAY} from primary to secondary, or vice-versa, we can add one or more interwinding shields.

An electrostatic shield (usually a wide copper foil) that is wound next to a primary winding and connected to the associated primary circuit's RF Reference (one of its voltage rails), reduces that primary's CM noise current injection into the other windings, by providing the stray noise currents with a more local current loop with a much smaller area, that they will "prefer" to take. Figure 38 of [49] provides some detailed guidance on constructing a primary shield.

And a shield that is wound next to a secondary winding and connected to the associated secondary circuit's RF Reference (usually its 0V rail) reduces that secondary's HF rectifier noise CM current injection into the primary (and any other windings), also providing the stray noise currents with a more local current loop with a much smaller area.

A practical tip: split all such shields so they don't act as shorted-turns! We only want them to shield the electrostatic fields (i.e. C_{STRAY}) – not the magnetic fields that create the transformer action.

Figure 3H shows an example of using an interwinding shield to reduce the CM noise created by the primary switching circuit and flows through C_{STRAY}.

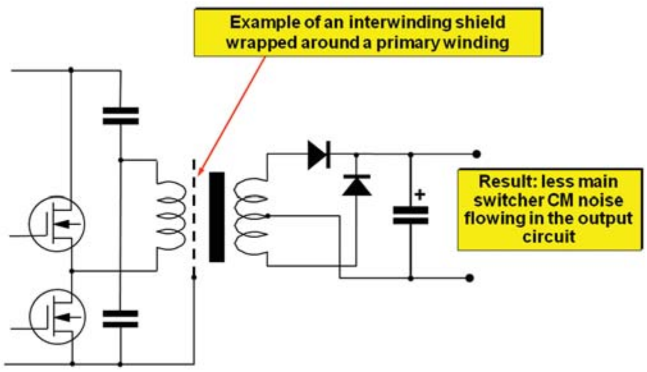

Figure 3H. Example of shielding a primary winding

Interwinding shields tend to increase the primary-secondary leakage inductance, and so could increase the problems of overshoot and ringing of the switching waveforms, requiring more snubbing (see section 2.4 in [42]). It is possible that this extra snubbing might reduce the conversion efficiency a little.

Also, if a transformer has been designed without shields it might have no room to add them, and a larger core size might be required. Discovering this at a late stage in a project can cause all sorts of knock-on redesign of PCBs and mechanical housings to fit the larger transformer, so it is always a good idea to initially design prototype isolating transformers with two or more interwinding shields.

If the shields turn out not to be required after all, they can be left unconnected, or removed from production units. If removing the shields allows a smaller core size, this can be a cost-saving modification the next time the product is changed.

Another reason for possibly having to use a larger core size when adding interwinding shields, is that the shields can have a negative impact on the thermal properties of a transformer – the windings might be running too hot for their insulation ratings.

I am told that it is possible to use additional single-layer windings as interwinding shields, and that they shield better than foil. But I haven't experienced this type of interwinding shield yet, and wonder if the series inductance of such a "shield coil" would limit its effectiveness at high frequencies.

"Planar" transformers can easily add any number of shields at a late stage in a project without causing significant knock-on redesign issues, because each new shield simply requires an additional PCB layer.

I have found in my training courses that not everyone is familiar with planar transformers, so have included Figures 3J and 3K to show that their magnetic cores pass through holes cut in the PCB, and the PCB traces provide the windings.

Figure 3J. Example of the use of planar isolating transformers in power converters

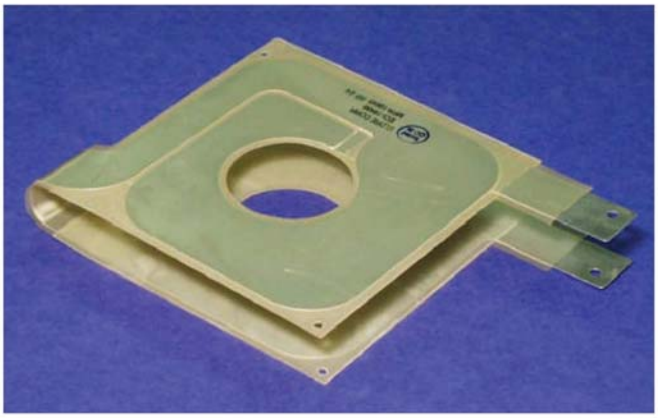

Figure 3K. Example of a secondary winding for a planar isolating transformer for an electric vehicle's mains charger

For better suppression, add two or more interwinding shields, connecting the shields to the correct circuit nodes to return the various capacitively-injected stray currents to their sources via the smallest-area and therefore lowest-impedance paths.

I was the first person (as far as I am aware) to use a commercial switch-mode AC-DC power supply to drive an all-analogue professional audio mixing console, way back in 1981. The analogue audio circuits were the quietest we knew how to make at the time, but were so sensitive to noise on their split-rail DC power supplies that the huge custom-made and very costly mixing desks we were making for music, TV and film studios, all required very large, heavy racks of linear power supplies (e.g. ±18V at 100A), achieving 50% efficiency if we were very lucky.

A switch-mode power converter with the same output rating was much smaller, lighter, more efficient and less costly, but nobody had ever managed to find one that didn't completely destroy the very high signal-to-noise ratios of our mixers, regardless of whatever filters were fitted to their power supply inputs and/or DC outputs.

But in 1981 I borrowed a "low-noise" switching power supply (from Advance Ltd, if memory serves) that, with the addition of a little bit of filtering on the DC side, was just perfect! So we used that instead. When I asked how they had made it so quiet, I was told that its safety isolating transformer used five (5!) interwinding shields – each one connected to a different part of its circuit.

In those days we didn't have to meet EMC emissions standards, but if we had we would have found that the "audio-quiet" switch-mode power converter had much lower emissions than all of the others.

So we shouldn't be shy about adding interwinding shields in our prototypes. They cost less and take up less space than filtering and shielding, and we can always take them out later on if we find they are not needed to pass the emissions tests.

Transformer cores also have C_{STRAY} to their windings, and since the types of ferrites used in switch-mode magnetic components are conductive, transformer cores will suffer from stray capacitive noise currents, and since they are "floating" they have a high impedance relative to the RF Reference and so experience a *dV/dt* and emit E fields that add to the product's emissions.

This is a similar problem to heatsink emissions (see 2.5 of [42]), with similar solutions: either connect the transformer core to the appropriate power rail (taking care of any and all safety issues), or wrap a shield around the core and connect that to the appropriate power rail instead. (As before, split the foil shield so that it doesn't create a shorted-turn!)

4.4 Reducing emissions with primary-secondary capacitors

Connecting a capacitor between reference voltages for the primary and secondary circuits, provides a low-impedance local loop current return path for the C_{STRAY} noises that have coupled across the galvanic isolation barrier from primary to secondary, and vice-versa.

Important Safety Note: Capacitors connected between primary and secondary are almost always safety-critical! See section 4.6 below.

The stray CM currents "prefer" to flow through this capacitor with its low-impedance current loop, rather than flow in the much larger loops available from the various components and cables and their E fields that I tried to visualise in Figures 3F and 3G.

Of course, nothing is ever perfect, and so because we can never truly create 0Ω current paths for the stray currents there is always *some* stray CM noise current flowing in the larger loops shown in Figures 3F and 3G, that get measured as conducted and/or radiated emissions.

For example, when using a primary interwinding shield, there will still be *some* C_{STRAY} noise that couples from primary to secondary, so providing a primary-secondary capacitor gives it a second lower-impedance loop and reduces the stray current flowing in the (high-impedance) external loops even more.

Because the C_{STRAY} noises flowing through the transformer generally have a high source impedance (due to the small values of interwinding capacitance), the low impedance of the primary-secondary capacitor makes it very effective as a filter (Chapter 5 of [5]).

Also, the low impedance of the primary-secondary capacitor has the beneficial effect of reducing the source impedances of the remaining C_{STRAY} noises that are still stubbornly flowing in the larger loops, making it possible to obtain much better suppression on the power supply input and/or DC output conductors by using series-connected CM choke filters.

Very large isolating transformers (e.g. MW ratings) have large values of C_{STRAY}, but MW-rated converters switch at lower frequencies with lower *dV/dt*, so their C_{STRAY} noise source impedance is still high. Very high-frequency converters (such as Analog Devices' "isoPower" devices, see 4.5) use very small isolating transformers that have very small values of C_{STRAY}, so despite their very high frequency operation the source impedance of the C_{STRAY} noise is still high.

Figure 3L shows my example half-bridge chopper fitted with two interwinding shields (one to reduce emissions of primary switcher C_{STRAY} noise, the other to reduce emissions of HF rectifier C_{STRAY} noise) and a primary-secondary capacitor.

It has some curved arrows that are my attempt to visualise how these techniques ensure that almost all C_{STRAY} noises flow locally, so that they don't contribute significantly to the measured emissions. The broad red and blue arrows try to show the paths followed by the majority of the C_{STRAY} noise currents through the interwinding shields, while the dashed red and blue arrows try to show that most of the noise currents that managed to escape capture by the shields are rounded up and herded back to their sources via the primary-secondary capacitor.

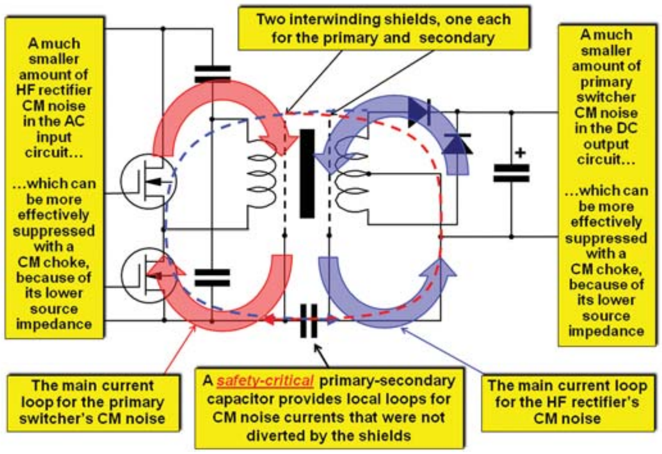

Figure 3L. Example of adding a capacitor from primary to secondary circuits (also shows two interwinding shields)

If not using a benign, resonant-mode switching topology, and using an isolating transformer, it makes good sense to allow for at least two interwinding shields plus a primary-to-secondary capacitor as shown in Figure 3L.

When testing emissions, we might find that we only need one of the shields and the capacitor, or just the capacitor, or just one or more shields – but because we made provision for them we are not going to delay the project by wrestling for days or weeks with costly and expensive filtering and shielding.

It is sometimes possible to use the good EMC design techniques described in this "Stand Alone" series to completely eliminate the need for a power supply filter. But it is more likely that some power supply filtering will be needed, in which case using these good EMC practices will reduce its complexity, size, weight and cost – and also make its design much easier.

These good EMC design practices may be able to make shielding totally unnecessary as long as rise and fall times of the switching waveforms are no less than about 10ns.

4.5 Using "buried" PCB capacitance for frequencies above 100MHz

Generally, mains suppression capacitors (e.g. Class X or Y types) perform well up to 10MHz or more, and higher frequencies may be possible by using types with polypropylene or ceramic dielectrics. But their self-inductance plus the series inductance of the wire leads or PCB traces used to connect them into the circuit (see 4.7 below) begins to dominate their impedance above a few MHz, rendering them pretty much useless at frequencies above about 100MHz.

However, we can easily create "buried capacitors" inside a PCB's layer structure, by overlapping areas of copper plane on adjacent layers. These have such low series inductances that they are effective at providing low-impedance current loops for frequencies well-above 100MHz.

To keep the noise loop area as small as possible (hence as low-impedance as possible), the overlapping plane areas should be placed underneath – and symmetrical with – the semiconductor whose CM noise emissions are to be provided with a low impedance, local current loop.

To date, we have not often had to deal with CM noise emissions above 100MHz, because of the switching speeds (and resulting harmonics, see Figure 2A of [42]) of typical power converters. However, some low-power isolating DC/DC converters operate at very high frequencies indeed, with high levels of interwinding C_{STRAY} emissions at those frequencies, and I have recently met University researchers attempting to design 200W AC-DC converters that switch at frequencies of 30MHz or more.

The Analog Devices "isoPower" ADuM5xxx product family is an example of a tiny isolating DC/DC converter that can transfer nearly a Watt of power across a 4kV isolation barrier by running its switchers at between 180 and 300MHz.

It apparently uses a resonant-mode topology that produces sinewave voltages and currents with minimal levels of harmonics. No discrete capacitors have sufficiently low series inductance (see 4.7) to be able to successfully provide a low-enough-impedance local current loop for the C_{STRAY} emissions at such high switching frequencies, and [50] recommends creating a buried capacitor within the PCB.

The common PCB material FR4 has a nominal relative dielectric constant (ε_r) of about 4.3, between 1MHz and 1GHz, which means that between overlapping areas of copper planes we create a $C_{overlap}$ of about 35/d nF per square metre, where d = the overlapping planes' dielectric spacing in millimetres.

For a noise current loop that provides any significant benefits we generally need a total loop impedance of less than 1Ω (much less would be much better). For 1Ω at 180MHz we need just under 1nF, and we can create 1nF with a 10 sq cm plane overlap with a 0.3mm (7.5 thousandths of an inch) FR4 layer between the two copper plane areas.

Chapter 5.3.15 of [37] discusses techniques for achieving much greater buried capacitance.

Figure 3M sketches the general concept of the idea, using the example of an isolating DC/DC converter that bridges between a PCB's 0V plane and a galvanically isolated area of 0V plane. It is a common experience to suffer excessive conducted and radiated emissions from such PCB constructions, which is why Figure 3M shows a row of discrete capacitors spread all around the circumference of the 0V plane split.

Spacing these capacitors apart by less than one-tenth of a wavelength (λ) at the highest frequency to be controlled (for emissions or immunity) helps prevent resonances that could create huge problems for EMC. (For more on the use of the "<λ/10 spacing" approach to prevent unwanted resonances in PCBs and other electronic product design aspects, see [5] and [37]).

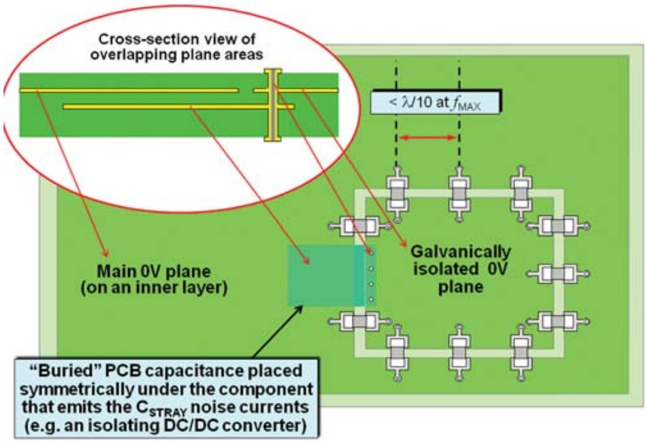

Figure 3M. Creating buried PCB capacitance to control C_{STRAY} noise at 100MHz or more

Figure 3M shows a row of via holes being used all along one edge of the buried plane area, to connect it to the galvanically-isolated 0V plane. Via holes suffer inductance at the rate of about 1nH per mm of length, so the 0.3mm length of via hole we are using has an inductance of about 0.3nH, which has an impedance of about 0.34Ω at 180MHz. This series impedance would add significantly to the <1Ω loop impedance we are trying to create for the C_{STRAY} CM noise currents, so Figure 3M shows the use of four vias in parallel, spread uniformly along one edge of the buried plane area, to reduce this stray series inductance to less than 0.1Ω at 180MHz.

For frequencies above 1GHz, the inductance of four 0.3mm long via holes connected in parallel as shown in Figure 3M would be 0.85Ω. Clearly, if we ever want to provide local loops for C_{STRAY} currents at such high frequencies – as we no doubt will have to one day soon – we will have to be cleverer.

4.6 Safety issues for capacitors that cross galvanic isolation barriers

Capacitors connected between the mains power input (primary) circuit and any —

- Protective conductor; safety ground; protective earth; chassis; enclosure, etc.
- Safety-isolated output circuit(s)

— must all be chosen with safety foremost. They will be "Y rated" according to the relevant standard (IEC 60384-14) for the nominal mains voltage, and their values will be chosen on the basis of the maximum permissible ground leakage current specified by the relevant safety standard listed under the appropriate EU Safety Directive.

(Some commonly used safety standards are: IEC/EN 60950; IEC/EN 61010, and IEC/EN 60335. Medical devices use IEC/EN 60601-1, which for patient-connected equipment can limit leakage currents to 10µA – making it virtually impossible to use any primary-secondary capacitors, or connect Y-rated mains filter capacitors to the protective earth or safety ground.)

I always recommend that the only capacitors that are used in any safety-critical applications (such as the primary-secondary capacitor discussed in section 4.4 above) are types that have been approved by a 3rd-party Safety Approval Body such as SEMKO, DEMKO, NEMKO, UL, VDE, BSI, TUV, etc.

But it is not sufficient to take the supplier's word for this, because the manufacturer who incorporates a component into their product assumes full responsibility under the law for any resulting safety defects. "Buying in good faith" is not a legal defence. So all safety-critical capacitors' safety approval certificates should be obtained from their vendors, and carefully checked to make sure the capacitors are rated correctly for what is required for the safety compliance of the final product.

It is commonplace to see a VDE (or other Safety Approval Body's) logo printed on a capacitor along with its ratings – let's assume for the sake of argument "230VAC, Class Y1".

But it should never be assumed that the presence of their logo means that Safety Approval Body has actually approved that capacitor as "230VAC, Class Y1".

The capacitor manufacturer might rate his part at 230VAC Class Y1 but the Safety Approval Body whose logo is proudly printed on the component might only have approved it as 120VAC Class Y2, or worse.

I have even heard of Class Y safety capacitors marked with the VDE logo, for which the logo had only been awarded for the quality of the tin-plating on its leads!

Because some capacitor manufacturers have been known to forge their 3rd-party Safety Approval documents, I also always recommend that the Safety Approval certificates obtained from the capacitor suppliers are checked – with the 3rd-party Safety Approval Body named on the certificate – as being valid.

Whenever I have done this, I have always found the Safety Approval Body's personnel to be most helpful and kind – which I suppose is not surprising because it is helping them police their market against fraud and protecting their good reputation.

Similar precautions are recommended for any/all safety-critical parts, not least the safety isolating transformer itself.

I also recommend carefully reading through all Safety Approval certificates for any "conditions of use". I have seen a US-made UL-Approved mains power supply module that included in its Approval certificate a brief statement that under fault conditions it could emit a jet of flame 12 inches long, and so must be enclosed in a fireproof enclosure when used in a final product.

Nobody had actually read the approval document. It had simply been obtained from the supplier and filed away on the assumption that because the unit was UL approved, it must therefore be perfectly safe. As a result, the power supply module was being used in the manufacturer's product with no flame protection at all, creating a serious fire hazard he was not aware of when he declared the product to be compliant with the Low Voltage Directive and affixed the CE marking to it.

Where a buried PCB capacitor (see 4.5) is used across a safety-related galvanic isolation barrier, the relevant safety standard will provide the "creepage and clearance" rules to be followed to ensure the capacitor is safe enough. For the dielectric between the plates, most (maybe all) safety standards simply require that it passes the withstand voltage tests that it specifies for "reinforced insulation". These generally apply 3kV rms at 50 or 60Hz, or 4.25kV DC, for one minute, and check that no significant current flows.

When FR4 is dry it will withstand about 40kV per mm [51], so a 0.3mm thickness of it should easily cope with the reinforced insulation test voltages. However, FR4 tends to absorb water, depending on the humidity and temperature of its environment, which can lead to it becoming conductive, and in the presence of high voltages (say, over 50V) cause "tracking" to occur – the dendritic growth of conductive metal salts – *inside* the PCB.

Safety standards are well-used to dealing with tracking on the *surfaces* of PCBs, in mains-powered areas, because with inadequate PCB layout it can quite quickly lead to electric shock and fire hazards. However, the safety standards all ignore the possibility of *internal* tracking, so I recommend that PCBs with buried safety-critical capacitance should be subjected to simulated lifetime testing with maximum humidity and temperatures that result in the PCB absorbing the most moisture, whilst the reinforced insulation voltage withstand test is continually applied to the buried capacitor to check that it doesn't fail.

Air has a much lower breakdown voltage than FR4, and with a spacing of 0.3mm (say) it will spark-over at about 340V. So it is important to ensure that the PCB dielectrics used in boards with buried safety-critical capacitors are "void free" – something for the Purchasing and Quality Control Departments to deal with.

But there is also a design-related concern – overheating a PCB can make it delaminate and/or carbonise (char), which can open up voids inside the PCB and/or convert the material from a slightly damp insulator to quite a good conductor. So it is important to ensure that any safety-critical buried capacitors are not exposed to heat sources that could cause any damage to their dielectrics over the lifetime of the product, even in the hottest anticipated environment.

4.7 Connecting to interwinding shields, cores, and primary-secondary capacitors

Connections to interwinding shields and primary-secondary capacitors all suffer from series inductance, which limits their effectiveness at providing low-impedance current loops, especially at higher frequencies.

So it is important to keep all shield and capacitor connections as short as practical, whether they use PCB traces, leads or wires, or busbars.

It might help to reduce the inductance of a shield connection by using two connections in parallel, to opposite sides of an interwinding shield (although to avoid creating a shorted turn they should both be on the same side of the transformer core).

Every electrical/electronic structure has resonances, due to their stray capacitances interacting with their stray inductances (this is a low-frequency view, see Chapter 3 of [4] or Chapter 2.5 of [5] for more detail). "Series resonant modes" provide current loop impedances that are as low as the series resistance (often just a few milliΩ), regardless of loop area. "Parallel resonant modes" provide current loop impedances that are very high indeed, possibly several tens of kΩ.

So it can be possible to "tune" a circuit's series resonances to make noise currents more likely to follow desirable loops, and/or to tune parallel resonances to make noise currents less likely to follow undesirable loops.

For example, if the CM C_{STRAY} noise currents caused by interwinding capacitance cause just one emissions frequency to be above the limit line, adding a primary-secondary capacitor that is series-resonated with the total inductance of its current loop (including the self-inductance of the capacitor) at that exact emissions frequency will have the maximum effect at that frequency – but will probably be less effective at other frequencies.

I don't generally recommend "resonant tuning" EMC techniques, because a small design change later on can make them completely ineffective. If the change is not being done by the original "tuner" (and he/she has remembered that they "tuned" the design!), people can be unpleasantly surprised by how a small change could cause the emissions to increase by such a large amount.

Many manufacturers do not bother to redo their EMC tests when making a "small" change (e.g. a component substitution), so can be caught out badly when an entire batch of products is returned under warranty because they cause interference or don't function reliably enough. As I have often pointed out in articles and books, the real reason we do EMC engineering and comply with EMC standards is to control financial risk. Complying with the EMC Directive is a very secondary issue, by comparison, for all that it is legally required in the EU.

4.8 Everything resonates

When the stray capacitances and stray inductances associated with a local noise current loop that we have designed cause it to resonate in "parallel" ("shunt") mode, the local loop can have an impedance of several tens of kΩ, possibly even more – making it ineffective at reducing emissions at the parallel resonant frequencies.

We normally consider a wire or cable to have an impedance that increases the longer it is or the more loop area it encloses, but when it resonates – either due to stray capacitance or because of transmission-line effects – it can have a very low impedance, maybe less than an Ohm.

So a building's or vehicle's power distribution and protective earthing (safety grounding) networks can have very low-impedances at certain resonant frequencies, effectively "sucking" our converter's noise currents away from the local loops we have created for the CM noise and increasing measured emissions at those frequencies.

This is a big problem for the design of power supply filters, and sometimes it is necessary to fit an "earth-line choke", and/or a 50/60Hz isolating mains transformer, to help prevent noises being "sucked" into the building or vehicle's earth or ground structure.

Consequently, it is very important to be in control of all "accidental" resonances, if we are to cost-effectively achieve good EMC characteristics in a timely and low-risk manner, as our managers would like us to do.

Understanding resonances in sufficient detail to control them effectively during design is beyond the scope of this article, but is covered in [4], [5] and [37].

4.9 Connecting interwinding shields, cores, and primary-secondary capacitors to earth/ground/chassis/frame/etc.

The astute reader will have noticed that I have not suggested connecting anything to "earth", "ground", "chassis", "frame", or any of the other words people use to describe a protective earth or safety ground connection, or some mythical infinite sink for electrical noises.

Protective earths or safety grounds in buildings or vehicles can only provide additional "accidental antenna" effects for noise currents that were created by switching devices. These noise currents must (by the laws of physics) flow in closed loops, but the conductive structure of a building or vehicle's earth or ground is not a suitable low-impedance loop for it to flow in, because it is outside the converter.

I recently heard a very wise and experienced EMC engineer describe a site's protective earthing (safety grounding) wiring structure as an "interference distribution network" – a very true and telling observation that I wish I had made.

As for any of the other words people might use to mean an infinite sink for electrical noise – no such thing can ever exist.

Connecting a part that is carrying noisy CM currents (such as a switching device's heatsink, interwinding shield, ferrite transformer core, etc.) to the protective earth (safety ground) connection simply allows its noise currents to flow in all sorts of additional paths, most/all of which will increase emissions.

However, where costly high-performance filtering and shielding is used, it can be designed to be very effective at returning the internally-generated noise currents back to their sources – completing their current loops entirely within the product's shielded enclosure, and therefore passing emissions tests.

Very many switch-mode power converters (or products using them) have been made in the past by using such "brute force" EMC mitigation techniques. Typically, they add around 25% to the BOM cost, and to the product's volume and weight, and they can add 50% to 100% to the design timescales.

When using such a brute-force EMC-mitigated filtered and shielded construction, the internal earth/ground structure can be conveniently used to provide all the noise currents with closed loops inside the product enclosure.

Unfortunately, this has helped to perpetuate the myth that "earthing" or "grounding" ***in itself*** provides magical benefits for EMC. Which it doesn't.

Military and government projects use taxpayer's money so still tend to use brute-force EMC mitigation techniques, (except where the resulting large size and weight cause problems.). However, the rest of us have to be much more cost-and-time effective – which is why in this article I have not suggested closing any noise current loops that use any conductive structures that are connected to the safety ground or protective earth (or to the chassis, frame, or whatever).

Without high-performance, large, costly, weighty filtering (on all unshielded cables) and shielding of the enclosure and unfiltered cables, using earth or ground conductors inside the products as part of noise current loops encourages the noise currents to escape and flow widely outside of the product – increasing its emissions.

I am not saying never to use an "earth" or "ground", "chassis", "frame" or whatever as part of a low-impedance local noise current loop, as this is not always practicable.

What I am saying, is that every time we use an "earth", "ground", "chassis", "frame", etc., as part of a stray noise current's loop, we tend to increase the specification required for the product's filtering and shielding – and hence increase its cost, size and weight and the difficulty of designing them to control emissions.

4.10 Construction of the isolating transformer

[52] and [49] provide EMC design advice on constructing isolating HF transformers for flyback converters. Some of their recommendations are specific to flyback topologies, whilst others are relevant to isolating HF transformers in general.

They tell us that the primary leakage inductance should be high to decrease the *dI/dt* of the primary switching current, thereby decreasing the harmonic content of the switching noise. The downside – increased flyback voltages at switch-off – must be dissipated as heat in snubbers or overvoltage protection circuits.

A lower intrawinding (i.e. turn-to-turn) capacitance in the primary winding results in smaller current spike at the turn-on of the switching transistor and a smaller stored energy in the resonant circuit. This can be achieved by increasing the distance between its turns.

To efficiently demagnetize the air gap and transformer core on each cycle of operation, the secondary leakage inductance must be low and the mutual inductance with the core must be high.

The interwinding capacitance C_{STRAY} causes stray high-frequency CM currents (see 4.2), which can be reduced by reducing the value of C_{STRAY}, for example by spacing the primary and secondary windings further apart. However, this decreases their mutual inductance and increases their leakage inductance so might increase H field emissions and/or may affect the resonance/ringing frequencies.

However, the CM C_{STRAY} currents can be reduced without reducing the value of C_{STRAY}, by arranging any multilayer windings so that the layers that are "closer" to connections to quieter circuit nodes (i.e. have lower *dV/dt*) are the closest winding layers to the other windings and/or to the core.

For example, in Figure 3L, the capacitor side of the half-bridge primary switcher has a very much lower *dV/dt* than the switched side, so – if the primary winding has two or more layers – the layer that is connected to the capacitors should be the one that is closest to the secondary winding in the transformer's "layer stack" (if the aim is to reduce the stray CM current flowing in the secondary).

Alternatively, if the aim is to reduce the stray CM current flowing in the core, that primary layer should be the one closest to the core.

To avoid suffering from increased emissions at the transformer's resonant frequency, it is possible to design so that its fundamental resonance frequency lies in-between any two of the switcher's emissions frequencies (the switching frequency and its harmonics).

This transformer resonance design trick can be a neat and clever way of reducing certain emissions by 20dB or more, but like all "tuning" techniques it is vulnerable to causing unexpectedly large increases in certain emissions frequencies (by 20dB or more) in the future, often resulting from what was thought to be a small design change that was not significant for EMC.

It is especially important to use a magnetic core that has its only air gap in a central limb (so, no "C-core" types). With this construction, the magnetic leakage flux from the air gap is shielded to some extent by the outer limbs of the core, with circular types (e.g. pot cores) providing better shielding than rectangular cores (e.g. H-core types).

A shorted-turn (i.e. complete loop) of wide copper tape around the *outside* of the complete transformer also helps reduce the stray H field emissions from its air gap(s). It might help to electrically connect this "stray flux band" to both halves of the transformer's ferrite core. The orientation of this stray flux band with respect to the air gap may be significant, too.

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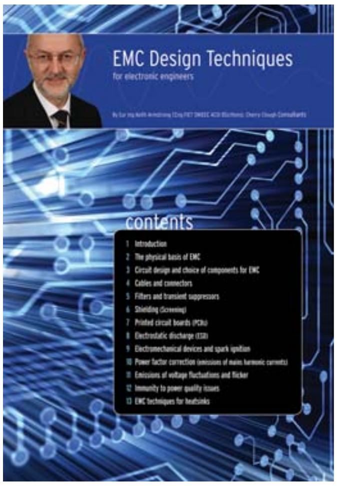

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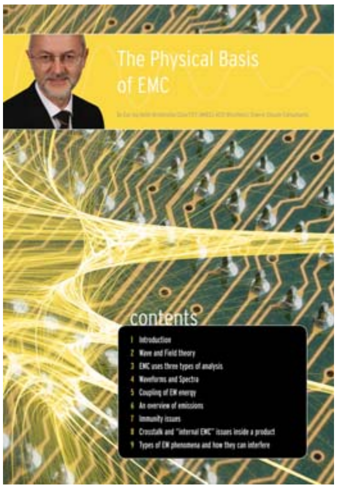

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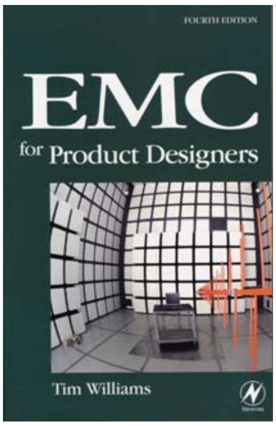

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