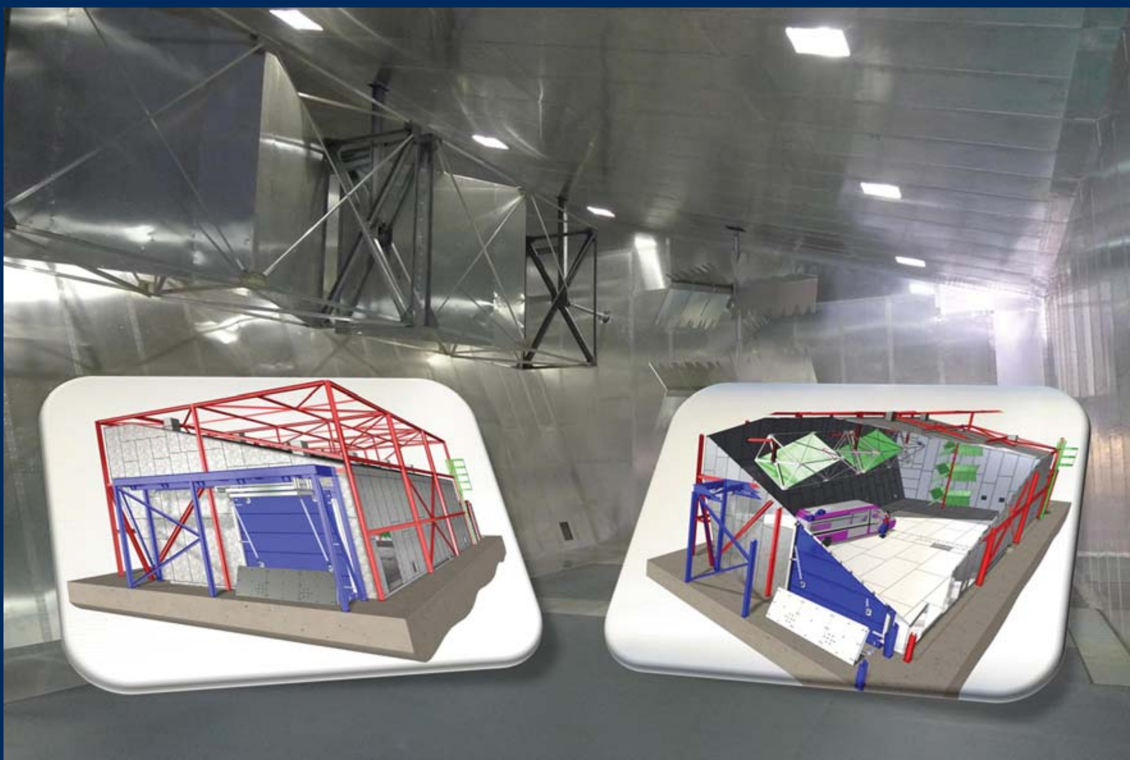
the emc journal

Issue 101 July 2012



ISSN 1748-9253

EMC design of high-frequency power "switchers" & "choppers"
By Keith Armstrong
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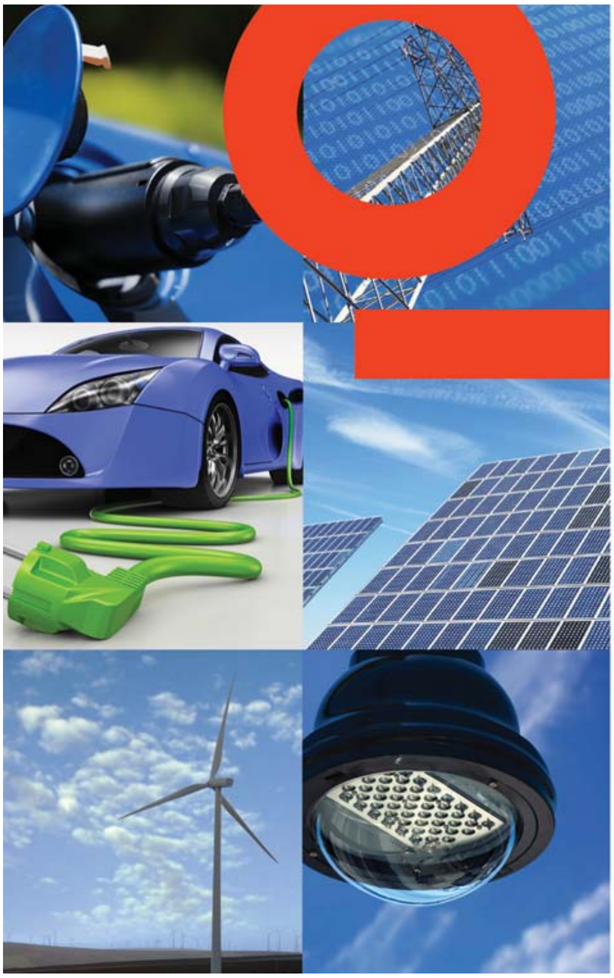
EMCUK 2012
9 & 10 October
www.emcuk.co.uk
See pages 8-11

EMC UK 2012

What's In This Issue

www.theemcjournal.com www.emcia.org www.emcuk.co.uk www.emcacademy.org


Intelligent 4-Quadrant Power Supply
4-quadrant (bipolar) operation concept diagram
Voltage
+V
Quadrant 2
Quadrant 1
current
−I
+I
Quadrant 3
Quadrant 4
−V
: Voltage and current directions are the same (source)
: Voltage and current directions are opposite (sink)
Power fluctuation test for automotive electronic components
Car navigation systems, others
Rechargeable battery charge/ discharge test
Various rechargeable batteries
Simulated battery charge/ discharge test
Digital cameras, cellular phones, and others
Constant current source for pulse plating
HDD, others
TELONIC
KIKUSUI
www.telonic.co.uk info@telonic.co.uk
Tel : 01189 786 911 Fax : 01189 792 338



Rainford EMC Systems appoints new European Sales and Marketing Manager

Rainford EMC Systems, the leading UK based global supplier of anechoic and shielded chamber solutions, is pleased to announce the appointment of Paul Duxbury to the position of European Sales and Marketing Manager. In his new role, Paul will be responsible for working with customers and distributors, developing and growing the business in the UK and across Europe.

Paul joins REMC from CST (Computer Simulation Technology) where he was involved in the sales and support of electromagnetic modelling software with an emphasis on EMC/EMI applications. Prior to this he worked in EMC test and measurement at NPL, BSI and IFR (now Aeroflex) before joining Flomerics where his responsibilities included leading the technical support, consultancy and other engineering activities for the EM products within the UK, Europe and Asia/Pacific.

He has, and continues to be involved with many industry groups, including the IEEE EMC Society which he chaired in the UK in 2009/10, the EMCIA of which he was

President from 2010-2012 and the IET EM Technical Professional Network for which he is currently vice-Chair. Paul is also a member of the EMCUK Steering Committee.

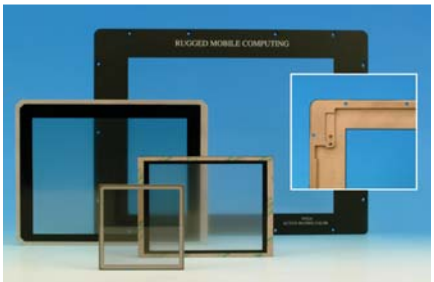
Commenting on the appointment, John Noonan, REMC Managing Director, says that “Paul is a fantastic appointment for us. He joins us with a wealth of knowledge and experience of the EMC industry, not only in the UK but also further afield. His experience will be key as we continue to develop and grow the business in the coming years.”

Sales and Marketing Director, John White, backs this up saying that “Paul is very experienced, well known and respected in the EMC sector and we are very pleased to have him on board. He also has a good knowledge of the RF, microwave and antenna industry. In the few weeks he has been with us, Paul has already made a positive contribution to the business.”

From their UK headquarters, Rainford EMC is a global leader in the design, manufacture, installation and testing of Anechoic and Shielded Chamber solutions for EMC, RF, microwave and antenna applications. With representation in over 25 countries across Europe, Asia and America, they are ideally placed to serve the global market. REMC supply chambers for use in many industries, including aerospace, defence, consumer electronics, automotive and telecoms and, their solutions, both standard and bespoke, have been installed at many global and independent test houses, as well as numerous in-house facilities.

For further information, please visit **www.rainfordemc.com** or contact **sales@rainfordemc.com**

Chomerics Europe starts production at its advanced shielded cast window manufacturing cell



Chomerics Europe - a division of Parker Hannifin, has set-up and begun production at a new manufacturing cell at its facility in Grantham, UK. The specialist cell provides a unique and advanced resource to support the manufacture of shielded cast windows. These are required to provide crucial EMI protection and help ensure compliance with EMC regulations in a wide range of equipment in sectors including military / aerospace, instrumentation & control and life sciences.

Chomerics’ cast windows manufactured in the new cell utilise advanced proprietary techniques and processes so that they provide an application specific combination of shielding effectiveness, optical transmission and mechanical and environmental performance. Chomerics’ Grantham facility for optical windows has been established for over 10 years. Over that time the company has developed significant expertise in both the design and manufacture of these specialised products.

Commenting on the commissioning of the new cast window production cell, Billy Sheedy, General Manager, Parker Chomerics Division Europe, said: “With an increasing demand for equipment to be designed for portability and use in uncontrolled environments, along with more stringent regulations in terms of EMC compliance, we are seeing greater demand for the shielded optical products designed and manufactured at our facility in Grantham. The establishment of an advanced, dedicated cell for cast windows will enable us to further advance the quality of our products for this important market.” **www.parker.com/chomerics**

Front Cover

Hero image, Rainford EMC Systems
Circle top, Rohde & Schwarz, page 20
Circle middle, Teseq, page 20
Circle bottom, AR, page 21

Secretariat for EMCIA

emcia
Electromagnetic Compatibility Industry Association

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

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News and Information

EMCTLA celebrates 20 years

On Saturday 30th June, the EMCTLA celebrated its 20th anniversary with a gala event. Over 80 people attended including current members, past members as well as several honoured guests.

The event was held in a marquee in the gardens of the home of Phil Carter near Swindon. EMCTLA stalwarts Tony Maddocks and Dave Imeson were presented with Lifetime Honorary Memberships in recognition of their extraordinary contribution to the EMCTLA over so many years.

Dave Imeson & Tony Maddocks having been presented with their awards by EMCTLA Secretary John Davies

Several artists performed throughout the night, including someone familiar to the EMC community; Vic Clements, who along with his singing partner, Roxy, of 'Ballad and Swing' rounded off the night in glorious style. Secretary, John Davies, said, "It was an opportunity, not only to celebrate 20 years of the EMCTLA, but to meet with our members in a social environment and also to catch up with old friends. It was a fantastic evening, full of entertainment and memorable moments. I would like to express my thanks to Phil Carter and his family for their generosity and all the preparation work they put into hosting this event."

TEGAM, Inc appoints AR UK as their new distributor in the UK and Ireland

AR UK is pleased to announce we have recently signed a distribution contract with TEGAM, Inc. Their range of test & measurement and calibration equipment compliments the existing products, systems and services offered by AR UK.

TEGAM is recognised for its Power Sensor Calibration Systems, RF attenuation measurement systems, resistance standards, ratio standards and micro Ohm meters. The recently introduced 1830A RF Power Meter is at the heart of the new PM Series of Power Sensor Calibrations Systems operating up to 50GHz.

The TEGAM product range includes:

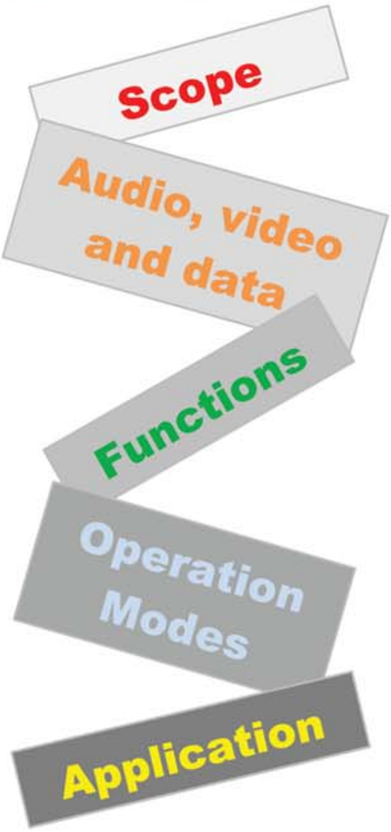
- RF Power sensor calibration systems
- RF Power meters
- RF attenuation measurement systems
- Arbitrary waveform generators
- Safety voltmeters
- Micro Ohm meters
- Ratio standards

For more information on TEGAM or any of the products offered by AR UK please do not hesitate to contact a member of our sales team or visit our new website: **www.arukltd.co.uk T: 01908 282766, E: aruksales@arworld.us** emc goggles

training and consultancy

with John Davies

The birth of the Multimedia Emissions standard.



Few would disagree that CISPR 22 has been the mother of all EMC standards for many decades. Earlier this year, born out of CISPR 22 and CISPR 13, came the baby, CISPR 32.
Ten years since the conception is quite a long gestation period, and many would argue that it is long overdue.
John Davies, of EMC Goggles, has been one of the many mid-wives in CISPR Sub-Cimmittee I working hard on its delivery.
So EN 55032 came along as the European cousin of CISPR 32 and its in Europe where this standard will be utilised the most.

This baby is in its infancy now but it is widely expected to outgrow its parents.
So what is it all about? What is this function based approach? How will CISPR 32 / EN 55032 be applied?
Don't forget we have it's sister on her way, CISPR 35 the Multimedia Immunity standard.

John Davies is putting together a training course for equipment manufacturers and EMC engineers who will be required to apply the Multimedia standards.

To register your interest in learning more, contact EMC Goggles:

info@emcgoggles.com +44(0)7506015791

EMCUK 2012

The Racecourse, Newbury
9 & 10 October 2012

Companies who have already Booked for 2012

Agilent Technologies UK Ltd
ANSYS UK
AQL-EMC Ltd
AR UK
BAE SYSTEMS (Rochester)
BAE SYSTEMS (Warton)
Blackwood Compliance Laboratories
Castle Microwave Ltd
Cove Industrial Enterprises Ltd
CST - Computer Simulation Technology AG
Dexter Magnetic Technologies Europe Ltd
DM Systems & Test Ltd
Easby Electronics Ltd
Electronic Test & Calibration Ltd
EMC Hire Ltd
EMC Industry Association
EMC Partner UK Ltd
ETS-Lindgren Ltd
F. C. Lane Electronics Ltd
Frequensys Ltd
Global EMC UK Ltd
HTT (UK) Ltd
Hursley EMC Services Ltd
Hypertac Ltd
Kemtron Ltd
Laplace Instruments Ltd
MBDA UK Ltd
MDL Technologies Ltd
Midas Components Ltd
MILMEGA Ltd
MIRA Ltd
MPE Ltd
MS Testing
Panashield (UK) Ltd
PPM Pulse Power & Measurement Ltd
Q Par Angus Ltd
Rainford EMC Systems Ltd
Rohde & Schwarz UK Ltd
Roxburgh EMC
Syfer Technology Ltd
Telonic Instruments Ltd
Teseq Ltd
TMD Technologies Ltd
TRaC
UKRF Ltd
Ultra Electronics
Uvox Ltd
Wurth Electronics UK Ltd

There are just a few stands left - Don't Miss Out!
Contact Lynne Rowland on +44 (0)1208 851530 or email: lynne@theemcjournal.co.uk

Technical Forum and Training Programme

Electromagnetic Compatibility Technical Forum

Tuesday 9th October 2012

08.30 Registration

09.30-11.00 **EMC in Equipment & Specifications Day**

Specifications & Standards

Chairman
Peter Kerry, *CISPR*

CE Marking is not enough for EMC
Keith Armstrong, *Cherry Clough Consultants Ltd*

Rationale supporting the introduction of unbalanced CDN/LISN/AMN networks for mains cables
Richard Marshall, *Richard Marshall Ltd*

Administrative Compliance - your Achilles Heel
Nick Wainwright, *York EMC Services Ltd*

11.00-11.30 Coffee & Visit to Exhibition Stands

11.30-12.30 **Keynote Speaker on Specification/Standards**

Why are there so many Product Standards
Stephen Colclough, *Samsung Electronics (UK) Ltd*

12.30-14.00 Lunch & Visit to Exhibition Stands

14.00-15.30 **EMC in Equipment**

Chairman
Paul Duxbury, *Rainford EMC Systems Ltd*

Panel Session on EMC & Reliability

In Situ Filter Testing for Increased Safety & Reliability on Vehicles
Alex Matos, *Ultra Electronics Precision Air & Land Systems*

Practical Reliability of Power Filters in Critical Applications
Will Turner, *MPE Ltd*

The Circles of Reliability Related to EMC
John Terry, *Hitek Electronics Materials Ltd*

15.30-16.00 Tea & Visit to Exhibition Stands

16.00-17.00 A Journey Through the EMC of Integrated Circuits - A Round Trip ticket
Allan Diamond, *Wolfson Microelectronics plc*

Transistor Technology Choice for 80 - 1000MHz Amplifiers
Dave Andrews, *Vectawave Technology Ltd*

17.00 Finish

Wednesday 10th October 2012

08.30 Registration

09.30-11.00 **EMC in Platforms, Vehicles & Installations**

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

Marine Platforms
Jonathan Burbidge, *BAE Systems*

Automotive EMC - An update on progress of the EMC requirements for Electric Vehicles and their Charging Systems
Steve Hayes, *TRaC Global*

Simulation-based Investigation of Possible Impact of Vehicle Bodyshell on low Frequency Magnetic Fields due to Power Cable Currents
Dr Alastair R Ruddle, *MIRA Ltd*

11.00-11.30 Coffee & Visit to Exhibition Stands

11.30-12.30 **Keynote Speaker on Environmental Effects on EMC**

Space Weather a Natural Source of EMI
Dr Mike Hapgood, *STFC Rutherford Appleton Laboratory*

12.30-14.00 Lunch & Visit to Exhibition Stands

14.00-16.00 **EMC in Installations**

Chairman
Richard Marshall, *Richard Marshall Ltd*

A Large HF Antenna for Whole Aircraft Testing
Tim Hague, *AR (UK) Ltd*

Challenges for ensuring compliance of Grid Connected Power Conditioners - an insight to the background and work for the future edition of CISPR 11
Steve Hayes, *TRaC Global*

Alien Earths; experiences in problem-solving on a large industrial site
Howard Chetwin, *Measurement Technology Ltd*

Smart Meters/Grid Security (Paper TBC)
Speaker TBC

16.00 Finish. Tea & Visit to Exhibition Stands

Register online for the Conference and Exhibition Visitor Tickets at www.emcuk.co.uk/visitors/registration.asp

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EMC Training Programme

Tuesday 9th October 2012

08.30 Registration

09.30–11.00 **John Davies**
EMC Goggles Ltd
Presentation

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.

11.00–11.30 Coffee & Visit to Exhibition Stands

11.30–12.30 **John Davies**
EMC Goggles Ltd
Live Demo

12.30–14.00 Lunch & Visit to Exhibition Stands

14.00–15.30 **Keith Armstrong**
Cherry Clough Consultants
Presentation and Live Demo

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

15.30–16.00 Tea & Visit to Exhibition Stands

16.00–17.00 **Tim Williams**
ELMAC Services Ltd
Presentation and Live Demo

Theory and live demonstration of:

- Coupling between wires, showing common impedance, mutual inductance, mutual capacitance and the effect of shielding
- The horror of heatsinks: why it is that where and how you connect your processor or switchmode supply's heatsink is so important

Wednesday 10th October 2012

08.30 Registration

09.30-11.00 **Tim Williams**
ELMAC Services Ltd
Presentation and Live Demo

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

11.00–11.30 Coffee & Visit to Exhibition Stands

11.30–12.30 **Keith Armstrong**
Cherry Clough Consultants
Presentation

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**

The Three For All: Panel session with the audience, discussing any questions on EMC design, testing and compliance.

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.

Register online for the Conference and Exhibition Visitor Tickets at www.emcuk.co.uk/visitors/registration.asp

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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. Even using four pages in every EMC Journal I can't keep up!

708 Error message! How mobile phones distort measurements

The awareness that the interference resistance of measuring systems is very dependent on the configuration and the installation on site has not been sufficiently taken into account in the normative requirements.

This discrepancy is based on the fact that the European testing requirements worked out several years ago do not sufficiently take into account the actual present-day disturbance source situation due to the spread of radio receivers and mobile phones.

Due to this technical requirement and also the possible political consequences, a revision of the respective standards was initiated in which PTB is participating. For the determination of new normative limiting values and for the assessment of the interference resistance of measuring devices on site by the verification authorities, metrologically traceable EMC tests on site are necessary, for which there has not been a measuring device available up to now.

(Taken from: PTB (Physikalisch-Technische Bundesanstalt), 17 September 2008. www.ptb.de/en/aktuelles/archiv/presseinfos/pi2008/pitext/pi080917.html)

709 How cellphones can interfere with low-frequency electronics such as ECGs

EMI or RFI sources continue to become more prevalent in our world. This type of noise can invade even the low frequency analog circuits. The source of this radiated noise interference can be found wherever electric or magnetic fields exist.

The proliferation of intentional and unintentional EMI radiators can wreak havoc on your circuits. The signals from these radiators are not out to contaminate your circuits, but you may want to keep your low-noise systems out of harm's way. Imagine a doctor using an ECG (electrocardiogram) diagnostic tool to get a good look at your heart. This high precision measurement is also low-frequency, so the electronics don't extend past 1MHz. However, if you are connected to an ECG tool with a poor EMI design and your physician answers his cell phone during the test, you may have cause for concern.

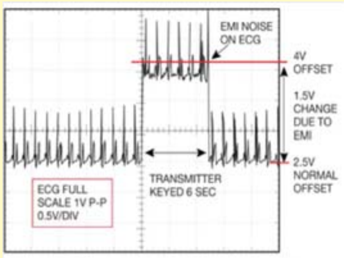

***Figure 1** EMI from a cell phone can cause a 1.5V change from normal on an ECG. The ECG diagnostic tool senses a heart while a 0.5W, 470MHz transmitter turns on and off just one and a half feet away.*

Figure 2 An engineer's precision, low-level ECG cardiotachometer board took the measurements for Figure 1.

The heart's input signal to the system is approximately 0.25 mV p-p. This small signal requires an instrumentation amplifier's gain of approximately 6000V/V. The good news is that the results in Figure 1 do not represent the performance of a doctor's office ECG-measurement tool. This measurement was actually taken in an engineer's lab from the board in Figure 2.

Don't fall into this EMI trap. Take care to create boards and use components that are EMI-resilient, regardless of your analog or digital circuit's bandwidth. When an EMI source is present in the vicinity of your application circuit, it may create a response to the radiating source.

How did the radiated noise from the phone get into the measurement with such a low-frequency board? In EMI terms, three elements are at work with this type of problem: a radiation source, a coupling path for the radiation signal to travel through, and a receptor. The radiation source in this example is the cell phone. The EMI signals may come through the air or be conducted across your PCB and originate from unexpected sources. EMI, or RFI, surrounds a receptor either by direct conduction or through fields. These fields couple directly into the circuit's connecting wires and PCB traces, where they are converted to conducted RFI.

Acknowledgment: Special thanks to John Brown for the ECG board and data.

*(Taken from: "EMI problems? Just the facts, please", by Bonnie Baker, in EDN, February 16, 2012, www.edn.com/article/520893-EMI_problems_Just_the_facts_please.php?cid=NL_UBM+Electronics. **Editor's note:** Unfortunately, Ms Baker doesn't mention how it can happen that RFI at frequencies very much higher than a circuit's operating bandwidth, can result in signal errors within its bandwidth. The reason is demodulation in the non-linearities naturally present in the PN junctions in the circuit's semiconductors – the very same principle that has been used for over 100 years now to receive radio, TV and radar signals. Essentially, every low-frequency analogue circuit can be regarded as a number of radio receivers connected to PCB traces and cables that act as antennas for the local E and H fields.)*

710 Uncontrolled Acceleration of Light Vehicle when 2-Way Radio was used

Queensland Government Natural Resources and Mines

Mine Type: All Mine Types.
Incident: A recently introduced 4 x 4 vehicle accelerated when the button on the vehicle's 2-way radio was depressed. This was subsequently repeated several times and confirmed the incident.

While using the radio to transmit at the same time as the vehicle was engine braking down a slope, the vehicle slowed still further.

Again, after using the radio several times to transmit, the vehicle emergency engine

management mode automatically initiated, resulting in a top speed of approximately 15 kph.
Equipment: Equipment involved included both the fitted VHF mine compliant radio and a hand held radio.
Hazard: A light vehicle exhibited uncontrolled movements while the onboard 2-way radio was being used.
Cause: Preliminary investigations have been conducted by the vehicle sales technical services manager. The problem appears to be related to electromagnetic interference with the electronic throttle positioning sensor. Similar issues have been found on certain aftermarket cruise control components.
Comments: Additional information will be released as it becomes available during the investigation.
Recommendations: All mine sites should audit their vehicle fleets to determine if the problem exists, and if so, formulate procedures to reduce the risk to an acceptable level.

Chris Skelding, Manager, Safety and Health – Central
Contact: Kevin Clough, District Inspector of Mines, +61 7 4967 0869

Please ensure all relevant people in your organisation receive a copy of this Safety alert. Any such advice supplied to site should reach those who require it, and it should also be placed on the mine notice boards.

See more Safety alerts and Safety bulletins at http://mines.industry.qld.gov.au/mining/safety-alerts-bulletins.htm *(**Editor's note**: this is the latest URL, 9 July 2012, not the one originally used).*
(This is a copy of Mines Inspectorate Safety Alert 213, "Uncontrolled Acceleration of Light Vehicle when 2-Way Radio was used", originally published 28 November 2008, by the Queensland government, Australia www.dme.qld.gov.au, kindly sent in on the 30th May 2012 by our regular contributor Chris Zombolas of EMC Technology Pty Ltd, www.emctech.com.au.)

711 RFID frequently interferes with other medical technologies

Regardless of the foregoing arguments about RFID as supportive or disruptive innovation in various applications in healthcare settings, there is one consideration that opens up the possibility for new entrants to introduce disruptive innovation. Current RFID technology frequently interferes with other medical technologies.

A 2008 study conducted in The Netherlands was the first to consider the problem of electromagnetic interference by RFID tags on other medical devices [47]. After testing 2 different RFID systems against 41 different medical devices, the researchers found 34 incidents of interference in 123 tests.

Despite limitations inherent in the study, the U. S. Food and Drug Administration, manufacturers, and healthcare providers are investigating the problem further [9]….

[9] DiConsiglio, John, 2008. "Much ado about RFID", Materials Management in Health Care 17:11, pp. 28-30, www.matmanmag.com/matmanmag_app/jsp/articledisplay.jsp?dcrpath=MATMANMAG/Article/data/11NOV2008/0811MMH_FEA_Technology& domain=MATMANMAG

[47] van der Togt, Remko, Erik Jan van Lieshout, Reinout Hensbrock, E. Beinat, J. M. Binnekade, and P. J. M. Bakker, 2008. "Electromagnetic Interference From Radio Frequency Identification Inducing Potentially Hazardous Incidents in Critical Care Medical Equipment", JAMA: Journal of the American Medical Association 299, pp. 2884-2890, www.ncbi.nlm.nih.gov/pubmed/18577733)
*(Taken from pages 171-2 of "RFID Technology as Sustaining or Disruptive Innovation: Applications in the Healthcare Industry" by Karen Crooker, Dirk Baldwin and Suresh Chalasani, in the European Journal of Scientific Research, ISSN 1450-216X Vol.37 No.1 (2009), pp.160-178, www.eurojournals.com/ejsr.htm. **Editor's note:** In their document: "The Importance of Using Wireless Engineers Who Understand Patient Care and RFID Technology", www.infologix.com/pdf/infologix-rfid-jama-response.pdfInfologix rubbished [47] claiming, amongst other things, that it took no consideration of the way wireless devices are used in healthcare premises. However, I have to say that their arguments do not take into account reasonably foreseeable misuse, as required by IEC 61508 and its many 'daughter' standards, and (more specifically) as required by Clause 4 of ISO 14971 "Medical devices — Application of risk management to medical devices". Their arguments also do not take into account the very rapidly increasing use of medical devices outside of the traditional healthcare premises, for instance: at work; shopping; travelling, etc., where RFID devices are increasingly likely to be used by people who are not medically trained and who are probably also unaware of the possibility that medical devices may be in close proximity.)*

712 First Product Completes Medical Device RFID Susceptibility Testing

MET Labs has completed testing on the first product to be submitted to the Medical Device RFID Susceptibility Program. The Program – co-developed by MET Labs and the U.S. Food and Drug Administration (FDA) under the auspices of AIM Healthcare Initiative (HCI) – is designed to determine potential adverse events of radio frequency identification (RFID) emissions on electronic medical devices.

The patient-worn battery-operated vital sign monitoring device was tested at MET's Santa Clara, California laboratory. It passed six of seven tests, demonstrating a hard fault when subjected to 860-960 MHz frequency RFID at 54 V/m, as specified in ISO/IEC 18000-6 Type C. Testing was performed with the RF parameters that emit the minimum and maximum occupied band-width. The testing ranged from 134.2 kHz at 160 A/m to 2.45 GHz at 54 V/m.

Interested medical device manufacturers that have not expressed interest in the past are still eligible for participation in the program. For more information about MET Laboratories, please visit www.METLabs.com.
(Taken from Business News, on page 64 of IN Compliance magazine, April 2012, http://www.incompliancemag.com/DigEd/inc1204/offline/download.pdf)

713 Fears of TV interference from 4G cellphone roll-out

Thousands of television viewers in Shropshire could suffer problems with their digital reception if the Government pushes through plans for a more hi-tech mobile phone network, Freeview bosses have warned.

According to the company, an estimated 202,218 homes in the Central region, which includes Shropshire, could be at risk of interference with their viewing from the planned new 4G mobile phone network.

Ofcom is proposing that 4G coverage should be rolled out to cover at least 98 per cent of the population to deal with increased demand as smartphone and mobile data broadband use continues to rise. But Freeview bosses claim that the new network could lead to 'deterioration of signal, a loss of channels, or blank screens' for viewers.

The company, the UK's biggest digital TV provider, has warned that Government plans to set up a £180 million fund to help counter the effects does not go far enough. Officials said that based on figures calculated by Deloitte for the Ofcom consultation, industry estimates put the total cost of providing and installing filters to mitigate interference on main and second sets at almost double the amount.

The company is now asking for the Government to revise its plans for the rollout so that mobile operators are responsible for the full costs associated with protecting television services.

Ilse Howling, managing director of Freeview, said: "We strongly believe that Freeview homes in the Midlands should not be subject to further inconvenience and additional cost to make way for mobile broadband. The Government has committed to recouping the cost of protecting viewers from interference, using proceeds from the 4G mobile auction. However, this will still leave viewers to bear a substantial proportion of the cost.

(From: www.shropshirestar.com/news/2012/06/14/fears-new-phones-network-will-hit-shropshire-tv-reception, Thursday 14th June 2012, 10:59AM BST. Also see a similar story about TVI from the 4G roll-out in the Westcountry: www.thisiscornwall.co.uk/New-phone-networks-hit-TV-reception/story-16446342-detail/story.html.)

714 CFL lamps interfere with broadcasting receivers

The Crosstalk America broadcast as a phone-in current-affairs show, often hosted by veteran broadcaster Vic Eliason, now in his mid seventies. It is produced in the main studio complex of the VCY America network, in Milwaukee, Wisconsin. On 3rd February 2012, Vic digressed while talking to studio guest Larry Pratt.

Vic – "Now we have an interesting story here. Here at the studios yesterday we had a test done." Vic explained that this was due to new regulations requiring energy-efficient lighting to replace the old fluorescent fittings.

"And so we found out that to re-do our building here, and our broadcast buildings, would be in excess of $38,000. Over 400 light fixtures here in this one building. Well, at any rate, what came out of this is that we said, "Well, bring in a test unit." And they brought in this test unit, and we – in that studio - turned on a receiver that would be used in the field of news-gathering, and found that 21 places on the dial were being obscured by the fixtures, by the r.f. signal that was going out, literally interfering with our ability to use a news-gathering radio."

Vic – "If we have 400 light fixtures, that's 800 of those little transmitters in a building that is sensitive to broadcast equipment. And you can't do it."

After a comment from Larry about having stockpiled the old-style lamps, Vic joked about lighting for the studios which would not cause interference. "Well, I think we're going to go out and get some kerosene lanterns. I did my homework in high-school up to eleventh grade in kerosene lights. So we may be running our studios with kerosene lights."

(Kindly sent in by our regular contributor Robert Higginson, on 11 Feb 2012)

715 LED Lighting tested with MIL STD 461F to prevent MRI Scanner EMI

Incandescent Lighting: A Solution Based On Compromise

Since AC-powered luminaires and dimming systems are known to generate Electromagnetic Interference (EMI), DC-powered, fixed-output incandescent luminaires became the lighting systems of preference within magnetic resonance imaging (MRI) suites.

Although this is an effective technique for mitigating EMI, it negatively impacts such important factors as power consumption, lumen output, lamp life and occurrences of sudden lamp failure – all of which increase both operation and maintenance costs and the MRI's operational downtime. In addition, the use of fixed-output severely restricts staff control of illumination levels.

LED Lighting: The Superior Alternative

Today's solid-state, DC-powered LED sources solve the EMI issues that make fluorescent lamps unsuitable for MRI area use. Recent advances in LED technology make this source a superior alternative to incandescent lamps as well. When compared to a typical150-watt incandescent installation with a 750-hour rated lamp life, white LED systems average 50,000 hours – or 66 times – more life than incandescents.

LEDs even exceed the rated life of both compact and most linear fluorescents. LEDs are also far more energy efficient than incandescents and gradually lose their efficacy (unlike heated-filament counterparts) preventing the interruption of MRI usage for lamp replacement.

Finally, Kenall's LED fixtures are dimmable, giving the MRI suite technicians the ability to tailor illumination levels to both preference and the specific function being performed at any given time.

EMI Transmission

One of the most problematic areas of lighting MRI suites has historically been EMI. Not only are MRI systems highly sensitive to EMI emissions from lighting fixtures and other electrical devices, MRI scanners themselves emit RF pulses that can negatively affect the operational performance of lighting equipment and the lifespan of certain light sources.

When EMI from light fixtures, AC voltage, or dimming systems is present, it can adversely affect the performance of the MRI system, rendering its output unusable. On the other hand, when the MRI scanner emits its own RF pulses they can create EMI that defeats the operational integrity of traditional light sources by causing unwanted lamp flicker and premature source burnout.

It is for reasons such as these that fluorescent sources and AC power are rarely installed in MRI suites, having been replaced in most cases by low voltage DC incandescent. While this change by itself has been successful in mitigating some EMI related issues, it has not solved all problems. In order to achieve an appropriately lit MRI environment free of problematic EMI, all potential sources of interference must be either successfully controlled or eliminated altogether.

Dimming

Dimming is an important feature for both operational safety and patient comfort in MRI suites. When scanning is performed, low light levels are appropriate as they create a more relaxed and comfortable ambience for patients. Conversely, higher light levels are needed for maintenance and other staff functions. Despite this need, even DC-powered dimming is often omitted from MRI suites due to potential EMI issues caused by voltage changes, as well as lamp flicker caused by MRI-originated EMI.

Kenall engineers have successfully solved these problems by designing and integrating special shielding systems inside the luminaires, allowing a problem-free, 0-10 volt full-range dimming capability on any system such as the Lutron Graphik Eye®, or other scene controllers, when installed per our instructions.

RFI Susceptibility and Compatibility

Unlike the European Community (EC), the U.S. has no government standards for RF compatibility between MRI systems and other electrical devices, nor do we have government-based programs for testing the susceptibility of one device to the RF of another. It is therefore up to the lighting manufacturer to determine the RFI potential between the luminaires and the MRI system being used. Not only must the effect of the luminaire(s) on the MRI be identified, the effect of the MRI's RF transmissions on the lighting systems must be identified as well.

To minimize the luminaire's potential effect on the MRI and vice-versa, the first step is to shield the fixture's interior to keep potential RF from escaping while also preventing the MRI's RF from affecting the luminaire. Step two is to pragmatically determine how the MRI and luminaire perform together.

Only with the combination of expert design and empirical knowledge can the specifier and user be assured of compatibility between the devices. Kenall MRI fixtures not only have the most effective shielding developed to date, they've been field-verified as compatible with systems from the world's foremost MRI systems manufacturers.

EMI Test Procedure: MIL-STD-461F NSF

To ensure Kenall luminaires for MRI/ imaging suites are not producing EMI emission levels that could jeopardize the integrity of MRI images, refer to MIL STD-461F as a guideline, specifically RE102. RE102 is a radiated emissions test that covers the frequency ranges of interest. The RE102 test procedure is also suited for this application due to the set-up commonality it shares with existing MRI rooms. The test measures emissions one meter away from the luminaire in units of dB microvolts per meter.

Immunity/Susceptibility:

Another consideration is the immunity or susceptibility of a device. Ensuring our luminaires do not interfere with the MRI is part of the objective. MRI scanners put out emissions that exceed 200 V/m, which can couple onto power and control lines and can interfere with the DC supply current energizing the LED light source. The sensation the human eye experiences when this happens is commonly known as flicker. To eliminate this potential situation, it is imperative that the lighting system and installation be configured to avoid harmful absorption and transmission of electrical pulses.

How we protect our product:

Assuming the system is properly designed and installation instructions are followed, the only path MRI scanner emissions have left to penetrate is through the luminaire itself. The first line of defense is the integrity and construction of the housing; Kenall's housings are aluminum, which has low resistivity and therefore an excellent shield. The housings are fabricated in-house and inspected to ensure no gaps exist that may leave the circuit board vulnerable to interference.

Finally, our robust electronic drivers are designed to withstand many small transients that exist on supply lines. These design properties ensure our products withstand pulses from 3.0T MRI units as well as emission levels in excess of 300 V/m as measured by an independent EMC test lab.

Electromagnetic Interference (EMI) Testing & Military Standard 461F

The most comprehensive, widely recognized and acknowledged domestic EMI standard is Military Standard MIL-STD-461F, a mandatory standard for military hospitals and other EMI-sensitive military facilities and a voluntary standard for public and private facilities applications. MIL STD testing measurements cover both radiated and conducted emissions, in addition to maximum allowable amounts of emitted energy based on both frequency range and field strength.

The MIL-STD-461F testing procedures and requirements appropriate to light fixtures are found under Navy and Air Force Limits for Electronic Devices, with the specific testing information for conducted emissions outlined in CE 102-1 and for radiated emissions in RE 102-4. While both are designed to emulate worst case operating conditions, both the test procedures and the standards themselves are logical and reasonable.

Kenall MedMaster fixtures have been tested and proven to be in compliance with MIL-STD-461F (Air Force/ Navy Fixed) by an independent laboratory (DLS Electronic Systems, Inc.) accredited by both NIST and the U.S. DOC. Copies of test reports are available from Kenall.

(Taken from the Kennal Catalogue: "LED Lighting for MRI Imaging Suites", http://www.kenall.com/LED-Lighting-for-MRI-Imaging-Suites.khtml?cid=518&iid=6251, downloaded 4 July 2012.)

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

IEC and CISPR

For those new to the fascinating field of EMC, general standardization activity is carried out by IEC TC77 and its sub-committees A, B and C, and by CISPR and its sub-committees A, B, D, F, H and I. TC77 deals with Generic immunity standards and EMC in the context of functional safety (a particularly fascinating field!), SC77B deals mostly with Basic EMC methods-of-measurement standards in the IEC 61000-4-series, while SC77A deals with all aspects of the interactions between the public electricity supply (including embedded generation equipment which is not necessarily *publicly-owned*) with load equipment.

Specific product and product-family EMC requirements (normally restricted to immunity requirements, because emissions are emissions and for protecting radio services and the quality of the electricity supply the source is irrelevant) may be standardized by the relevant product committees, but their provisions are supposed to be consistent with those of the Generic standards, unless deviation is justified; this reconciliation procedure is, however, not always carried out. Of course, sooner or later that causes trouble that could have been avoided.

So what have these committees been up to since we last looked?

TC77

Our expert on EMC and functional safety is very unhappy about maintenance team procedures in connection with the preparation of IEC 61000-6-7: *Electromagnetic Compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for safety-related systems and equipment intended to perform functions in a safety-related system (functional safety) in industrial environments.* The relevant committee has many members from one country, and appears to be using a voting procedure rather than seeking consensus.

The same maintenance team is to begin converting IEC 61000-1-2 from a Technical Specification (TS) to a standard. This involves many purely editorial changes, but technical changes can be made as well.

SC77A

This committee has several Working Groups and meetings are more or less continuous throughout the year. WG1 has over 50 members and the work is split between Task Forces. These and the WG met for a week at the end of May. Considerable progress was made, notably the long-standing problem of how to introduce the control of interharmonic conducted emissions seems to have been solved. Using a measurement bandwidth of 50 Hz effectively adds the interharmonics to the adjacent harmonics, and if the adjacent harmonic is an even harmonic, for which the limits are very stringent, the product may not meet the present limits, even though such products do not normally cause problems in the field. Agreement has been tentatively reached on a systematic relaxation of limits, to be applied only if necessary. If this is approved by National Committees, simultaneous amendments will be required to IEC 61000-3-2 and -12 and to IEC 61000-4-7.

Other developments include the issue of an Interpretation Sheet to IEC 61000-3-12, explaining what to do if the input current under test conditions is less than 16 A, although the rated current is above 16 A. A revision of IEC 61000-3-3, on voltage changes, has reached the first voting stage. A revised IEC TR 60725 on supply impedances has been published. IEC 61000-4-30, on methods of measurement of power quality, is to be revised. Three small amendments to IEC 61000-3-2 are proceeding, while a fourth, introducing requirements for LED lamps, is more complex and may have to be delayed to become an early amendment to a fourth edition of the standard.

SC77B

A CD revising IEC 6100-4-5 on immunity to surges has been issued. This seems to have been quite controversial, so many National Committee comments may be expected. Questions have been raised about the need for new work on close-in radiated immunity and in-situ immunity testing, both very difficult subjects indeed.

Both IEC 61000-4-3 and IEC 61000-4-6 are in process of amendment.

SC77C

This committee deals with high-energy phenomena, which we hope would be of natural rather than man-made origin. Large networks and installations are inevitably exposed to high-energy events caused, for example, by emissions from the Sun (the star, not the newspaper). Since we have been warned that such events may become more frequent and more energetic, the work of the committee may become more pertinent to a wider constituency than previously.

CISPR/A

This is the 'methods of measurement' committee of CISPR, and methods of measurement introduced into product standards are gradually being transferred to CISPR 16 or substituted by existing CISPR 16 methods.

A proposal for new procedures for measuring conducted disturbances has attracted serious criticism on the grounds of not correctly assessing common-mode emissions, which can generate more long-range radiated emissions.

CISPR/B

This committee's deliberations are considered by two BSI EMC committees; luckily they rarely disagree. CISPR /B has a very wide scope, reflected in its sesquipedalian title:

Interference relating to industrial, scientific and medical radio-frequency apparatus, to other (heavy) industrial equipment, to overhead power lines, to high voltage equipment and to electric traction

Embedded generation equipment is included as well, in respect of radio-frequency emissions. The reason for the two BSI committees being involved is that while CISPR/B deals with product-family standards, some of those, notably CISPR 11, raise general considerations that need to be examined outside the context of particular products. A particular example is grid-connected power converters, especially used with solar energy arrays. Proposals have been circulated for new limits and new methods of measurement for emissions on to the DC cable. Unfortunately, they have not been supported by any significant justification, even though it may exist. Consequently, the UK committee is less than impressed. This is a particularly important matter because the DC cable is typically terminated in a roof-top conducting array of several metres in dimensions, so it can be an efficient radiator of *differential mode* disturbances on the cable.

CISPR/F

CISPR 14-1/EN 55014-1 is to undergo a combined editorial and technical revision, by two separate teams. Some reconciliation work would appear to be inevitable. An amendment to CISPR14-2/EN 55014-2 is in process as well.

CISPR/I

A second CDV for CISPR 35 has appeared. Considering that there were over 100 pages of comments on the previous CDV, the outlook is not exactly positive. A few minutes examination discloses many simple errors that really should have been detected before circulation. For example, CISPR 32 is not referenced normatively, annexes I, J and K are informative and thus not 'integral parts' of the standard (Directives 2, 6.4.1.1), and clause F.5 and Annex L do not exist. The trouble is, these relatively trivial errors complicate and distract from the process of improving the technical aspects of the standard.

Because of the delays and the long transition period (5 years) for CISPR 32, the standards it will replace, such as CISPR 13/ EN 55013 and EN 55103-1, have to be updated to preserve their status as offering *prima facie* evidence of conformity with the Essential Requirements. The same applies to CISPR 20/ EN 55020, due to the long preparation period of CISPR 35.

CISPR 25

A question arose about the apparently odd limits in the frequency range 76 MHz to 108 MHz. This covers the Japanese, US and European FM broadcasting bands, and FM receivers are, if properly designed, highly immune to impulsive disturbances, so the limits can be relaxed. But some listeners demand a high signal-to-noise ratio, so the limits for continuous disturbances must be kept tight.

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Know Your Standards

In view of the fact that we stopped our review of the Sections of IEC 61000-4 at Part 20 last time, we should start with Section 21, if it exists, and indeed it does.

IEC 61000-4-21

Section 21, extensively revised in 2011, is about tests in reverberation chambers, but humorous vocalizations are not even mentioned. It concerns tests of immunity and intentional or unintentional emissions for electric and/or electronic equipment and tests of screening effectiveness. Conducted emissions are excluded. It is quite long (114 pages) and very detailed. As for IEC 61000-4-20, it may be best to follow the instructions of the particular chamber in use.

As for all Basic EMC standards, it does not prescribe tests or limits for specific products or product families. These are determined by the relevant product committees, in consultation with CISPR and IEC TC77. However, a Note indicates that the responsible committee considers that simulations are not adequate for quantative determinations.

IEC 61000-4-22

This section, first published in 2010, is about measurements of radiated emissions and immunity to them in fully-anechoic rooms (FARs). It is much shorter than Section 21, and covers the frequency range 30 MHz to 18 GHz. Nevertheless, it goes into much detail about the measurements and how to ensure that they are as accurate as possible. The method is generally more suited to physically small products, although large FARs do exist. The results are expressed as electric field strength, since the measurements are not in the far field at lower frequencies.

There are signs of inadequate editing; for example the above-mentioned Note in the Scope is more or less repeated as main text, and clause 4.2 more or less repeats the latter half of clause 4.1. However, there doesn't appear to be cases of inadequate clarity.

IEC 61000-4-23

This and the next two Sections are about HEMP (High-altitude ElectroMagnetic Pulse), defined as such a pulse produced by a nuclear explosion outside the Earth's atmosphere, so with luck, it appears that it can be omitted from detailed study by most people. However, it does include data useful in other circumstances, such as the shielding effectiveness of an 0.5 mm thick aluminium enclosure against electric and magnetic fields from 100 Hz to 10 MHz. There is also a four-page annex on the characteristics of coaxial cables.

This Section is 'Test methods for protective devices for HEMP and other radiated disturbances' Clearly, this might involve smoke and loud noises (there actually is a test described as 'the smoke test'), and indeed full-scale testing using a high-power Marx generator and a large guided-wave structure (tens of metres) is described. Another set-up uses a very large bicone antenna suspended from a helicopter and driven by a 1.5 MV Marx generator. However, less spectacular methods of measurement are also described. One surprising thing is that a diagram said to be of a Rogowski coil does not show the characteristic feature – that the lead-out from one end of the toroidal coil is fed through the centre of the winding to the other end of the coil, so that the terminations are close together.

IEC 61000-4-24

This is 'Test methods for protective devices for HEMP conducted disturbance', and is a less exciting document than is included in Section 23. A second edition is planned, expected to be published in 2015. Unfortunately, the Review Report has not been supported by a Document for Comment, outlining the planned improvements. In principle, the device under test is enclosed in a screening box and zapped with a high-voltage pulse, to see how much energy it lets through.

IEC 61000-4-25

There is a new 2012 edition of this Section, 'HEMP immunity test methods for equipment and systems'. It is actually the 2002 edition with Amendment 1 embodied. It is concerned with laboratory tests, as opposed to the large-scale tests described in IEC 61000-4-23. Rather too many trivial or obvious definitions are included, as is a wordy description of 'radiated' and 'conducted', part of which is then repeated! The tests are described as being carried out in simulators, in contrast to statements in other standards that simulation is not reliable. For conducted disturbances, three types of disturbance, characterized by early, intermediate and late time of arrival at the EUT, are considered. Early time disturbances are represented by the IEC 61000-4-18 damped sinusoid for lower energies, the 5/50 ns pulse of IEC 61000-4-4- for intermediate energies and pulses defined in Section 25 itself for the highest energies. For intermediate time, the 10/700 µs pulse of IEC 61000-4-5 is used, while for late time, Section 25 defines a 60 s trapezoidal pulse. Generators for the waveforms described in the Section are also specified.

IEC 61000-4-26

This was to be 'Calibration of probes and associated instruments for measuring electromagnetic fields', but that subject is really for CISPR/A to deal with, so the project was cancelled.

IEC 61000-4-27

The title of this Section is: Testing and measurement techniques - Unbalance, immunity test for equipment with input current not exceeding 16 A per phase. In fact it applies only to true 3-phase load equipment for 50 Hz or 60 Hz supplies, not 3-phase and neutral equipment that actually presents independent single-phase loads to the network.

Unbalance (different phase voltages and/or interphase angles) can be caused by large single-phase loads, arc furnaces and fault conditions. Induction motors present an abnormally-low impedance to unbalanced supplies, similar to that under starting conditions. Overheating, to the point of severe and dangerous damage, may occur. Other loads may be disturbed so as to produce abnormal conducted harmonic current emissions. Control equipment that does not have sensors on all three phases may operate incorrectly. Abnormal acoustic noise is also a possibility.

Immunity is determined by applying deliberately unbalanced supplies, and evaluating the response of the EUT according to the usual Performance Criteria, including Criterion D - unrecoverable loss of function.

IEC 61000-4-28

This Section is: Variation of power frequency, immunity test for equipment with input current not exceeding 16 A per phase. It applies only to 50 Hz and 60 Hz equipment. The Scope says that the standard should not be applied to products that do not show significant lack of immunity to the small variations of supply frequency that are characteristic of most public supplies, which means most products.

As usual for immunity testing, the results are assessed in terms of the Performance Criteria.

IEC 61000-4-29

This one is called: Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests

It's written in terms of quite high-power DC distribution systems – the test generator is specified for up to 36 V output at up to 25 A. But this subject really needs to be considered for quite low-power products; in most cases there is enough stored energy in capacitors across the supply to tide over any short interruptions, but not always. For example, a product was quite immune *unless* an incandescent lamp alarm indicator was on; if an interruption occurred then, the microprocessor reset and the alarm indicator went out. Not good!

IEC 61000-4-30

The subject of this Section is Testing and measurement techniques - Power quality measurement methods, and it is, actually, a 'hot topic', although this isn't widely publicised. The point is that governments have determined that electric power is a commodity that must have consumer-protection quality standard applied to it, such as EN 50160 (which, in my opinion isn't standard at all, but something between a promise and a prediction). So the supply authorities are committed to 24/365.24 monitoring of voltage value, stability and unbalance, frequency, waveform purity and mains signalling voltages.

Three levels of measurement are specified - Class A (precision), Class S (good enough for statistics!) and Class B ('grandfather' class for existing instrumentation). For classes A and S, the basic measurement time interval is 20 ms. Measurements are then aggregated over intervals of 3 s, 10 min and 2 h. Measurements must be continuous, with no gaps. Details are given of how to assess voltage dips, swells and interruptions, unbalance and harmonics. There is a large amount of detailed information about other matters, even down to specifications for test leads and practical guidance on their use. It seems doubtful that the people who need this information are able to obtain it directly from the standard, but must be able to get the information form training courses based on it.

That's all for this time: there are a few more Sections (some still in their eggshells) to be considered before we move to another fascinating field.

If there is a standard or standards that YOU would like me to dissect, please use the response email address. Please note that I cannot quote long sections of text, nor pass them on by email, and I cannot answer a question like 'What is the difference between the 2005 version and the 2009 version?', because it's too complicated to relate every little change, and an apparently trivial change may be very significant for YOUR product, if for no-one else's.

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Rohde & Schwarz takes wireless device precompliance testing into the lab with automated tests as in large RF test chambers

In wireless device precompliance testing, the compact R&S DST200 RF diagnostic chamber from **Rohde & Schwarz** now automatically sets the equipment under test (EUT) to the required position. The new options make the R&S DST200 the only RF test chamber on the market that enables OTA performance and RSE testing of wireless devices such as smartphones right on the lab bench. Test results are comparable with those obtained with large RF test chambers and are used for product optimization during the design phase – providing an ideal preparation for final compliance testing.

Rohde & Schwarz has added three new options for its compact R&S DST200 RF diagnostic chamber: the R&S DST-B160 automated 3D positioner, the R&S DST-B210 cross-polarized test antenna and the R&S DST-B270 communications antenna. The new options significantly speed up precompliance testing of wireless devices, allowing automated test sequences to be performed on the lab bench so that developers no longer require constant access to large RF test chambers.

RF diagnostic chamber together with the R&S CMW500 wideband communication tester from Rohde & Schwarz now enables fast, reproducible over-the-air (OTA) testing in accordance with the Cellular Telecommunications Industry Association (CTIA) test specification. In conjunction with an R&S ESU EMI test receiver from Rohde & Schwarz, the new options make it possible to carry out radiated spurious emission (RSE) measurements quickly and easily with the R&S DST200. These test setups are ideal for wireless device design optimization. Developers can compare the results generated with the R&S DST200 with the results obtained with larger RF test chambers, since similar test sequences are used in these chambers. The results generated with the different types of chambers exhibit a high level of correlation, differing from each other by no more than a few decibels. Using this solution, network operators can now perform conclusive qualification measurements on smartphones, for example, without the need to access large RF test chambers.

The new R&S DST-B160 automated 3D positioner uses servomotors to position the EUT in any orientation required for OTA measurements, eliminating the need for time-consuming manual positioning. The R&S AMS32 OTA performance measurement software supports all cellular standards, including LTE MIMO, as well as WLAN and Bluetooth, plus it enables assisted GPS (A-GPS) performance measurements. In RSE measurements, the system automatically determines the EUT position with the highest RF emission, and then uses the R&S EMC32 software to perform EMC measurements in accordance with ETSI EN 301 908 (for W-CDMA) or a similar standard.

The R&S DST-B160 automated 3D positioner is made of a special, low relative permittivity material for RF applications so as to minimize its effect on the measurements. The servomotors are accommodated in an RF shielded compartment at the bottom of the R&S DST200. The user attaches the EUT to a removable holder, which is snapped into a bracket so that the EUT is positioned at the center of the R&S DST-B160. The EUT can be rotated independently about two axes into any desired position relative to the test antenna.

The new R&S DST-B210 cross-polarized test antenna is designed for testing wireless devices and chipsets with the R&S DST200. The antenna has a wide frequency range of 300 MHz to 12 GHz, ensuring that all harmonics will be covered when performing RSE measurements. The R&S DST-B270 linear-polarized communications antenna has a frequency range of 700 MHz to 18 GHz and provides a stable connection between the EUT and the test receiver while the EUT is being rotated.

The new options for the compact R&S DST200 RF diagnostic chamber are now available from Rohde & Schwarz. For details, visit www.rohde-schwarz.com/product/DST200.

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New Magnetic Field Coil from Teseq Generates Fields Up To 1200 A/m

Teseq, a leading developer and provider of instrumentation and systems for EMC emission and immunity testing, has introduced a new magnetic field coil that generates fields up to 1200 A/m during magnetic field testing. The **INA 703** is designed for testing to IEC 61000-4-8 (supply frequency magnetic fields), IEC 61000-4-9 (pulsed magnetic fields) and IEC 61000-4-10 (oscillatory magnetic fields) standards. It is ideal for medical equipment, military, avionics, aerospace and industry applications.

By using a multi-turn (37 turn) configuration, the INA 703 is able to generate higher field levels of up to 1000 A/m using a programmable power source rated for e” 30 A like the TESEQ ProfLine Conducted Immunity Test Systems. This enables testing with a current THD (total harmonic distortion) of <8%, as required by IEC 61000-4-8, that can only be met with a low distortion sine wave from a programmable AC source.

Another advantage of using a programmable power source is that various supply frequencies can be tested, not only 50 Hz and 60 Hz as requested by IEC 61000-4-8, but also DC and 16.7 Hz as required by some railway standards (EN 50121-4). Together with a TESEQ NSG 1007 source, INA 703 is able to generate fields with frequencies from DC to 400 Hz in 0.1 Hz resolution steps.

Taps at turns one and five provide increased accuracy when generating low amplitude fields. The required coil drive voltage is increased by reducing the turns-ratio of the coil. This establishes a suitable input voltage range that allows good regulation of the test level amplitude. The tap off at one turn is primarily used for testing to IEC 61000-4-9 and IEC 61000-4-10, since both standards only require a single turn coil.

For testing to IEC 61000-4-9, the INA 703 can be used with any classic combination wave generator, including Teseq’s NSG 3040 or NSG 3060 along with the INA 752 pulse wave shape adapter. When connected to an appropriate slow oscillatory wave generator, the INA 703 easily enables testing to IEC 61000-4-10.

The INA 703 is also ideal for use with MFO 6501 or 6502 current sources and Teseq’s NSG 3000 series generators to generate mains frequency fields up to 120 A/m continuously and short term (three seconds), both at 50 Hz and 60 Hz. With its U-shaped rigid aluminium base and wheels, the INA 703 is easily and quickly positioned next to or around the EUT. The coil size is 1 x 1 m and has a homogeneous field volume of 60 x 60 x 50 cm.

The INA 703 has a maximum continuous supply frequency current of 10 A, a maximum short term supply frequency current of 35 A for three seconds, a maximum continuous supply frequency field strength of 330 A/m and a maximum short term supply frequency field strength of 1100 A/m for three seconds. The unit has a maximum pulsed current of 1500 A (8/20 µs wave) and a maximum pulsed field strength of 1200 A/m.

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PRODUCT GALLERY

Real-time FFT-based EMI receiver and analyzer

Narda Safety Test Solutions S.r.l. presents the new EMI Receiver and Analyzer PMM 9010F which cuts the time required for EMC emissions tests from hours to seconds, in full compliance with CISPR standards.

The new EMI Receiver PMM 9010F combines sophisticated FFT spectrum analysis with an RF front-end including a real multi-band preselector, thus offering full compliance with all CISPR 16-1-1 tests, single pulse included, and fast scanning of the 10 Hz – 30 MHz frequency range in real-time.

Emissions from Equipment Under Test (EUT) characterized by short operation cycles - e.g. electric tools, food machinery, appliances – can now be measured in seconds rather than hours; fast and reliable tests provide immediate feedback in the try-and-test process and make an effective contribution to reducing time-to-market.

According to the products standards, the CISPR detectors must be set for long hold times (1, 2, or more seconds) in order to obtain accurate measurements. Lower values can reduce the test time but at the cost of possible severe errors and under-estimation of the levels. PMM 9010F overcomes this limitation. For example, with a hold time of 1 s the analyzer scans the entire spectrum in less than 25 seconds using all detectors simultaneously. Pre-testing, smart detectors and frequency tables are no longer required.

PMM 9010F offers outstanding performance in terms of sensitivity and dynamic range: the internal preamplifier reduces the noise floor to less than -24 dBµV (band A) and -7 dBµV (band B) and the input can withstand up to 1 W of RF power without damage.

PMM9010F is very powerful in debugging: the Analyzer Mode performs real-time spectrum analy-sis of the full 30 MHz span at once. Like all PMM digital receivers, PMM 9010F features a compact, modular design, AC/DC and battery operation.

The receiver is almost entirely calibration-free: an internal reference provides auto-calibration of the RF front-end, attenuators, preselector, preamplifier and A/D conversion.

PMM Emission Suite is the user-friendly PC software supplied with PMM 9010F, featuring real-time display, automatic measurements and complete data management.

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AR's Family Of 1 - 2.5 GHz Microwave Amplifiers Designed To Provide An Alternative To TWTAs

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Offer *four-sight* with a fresh look at Kikusui's PBZ-series capable of *four-quadrant* power

Engineers dive under the covers of today's high speed power applications in an informative update from Telonic Instruments, Berkshire-based suppliers of highly regarded Kikusui power supplies.

From the humble capacitive load to the plethora of power-magnetic devices used in today's industry, demands for true *four-quadrant* power supplies are increasingly commonplace.

For these more demanding power applications, Kikusui's PBZ warrants a close look, offering lessons in greater reliability and intelligent control in ways even high-efficiency PSUs cannot. In this alien territory, ordinary PSUs – even those designed with today's advanced semiconductors - can be quite unsuitable due to the very nature of their design. For example, how many can dynamically respond to demand changes in 3.5uS or 100kHz at full power? A reliable four-quadrant power instrument must be stable and well protected. For many of today's power projects, a fresh look at Kikusui's approach can help us root-out glitches other PSU's cannot reveal and help ensure long-term reliability – for both your power source and for your equipment or devices under test.

No ordinary power supply and advanced testing capability

Kikusui's PBZ has earned its reputation as an intelligent, compact *four-quadrant* power supply that performs well in applications where other powers supplies fail. In short, PBZs deliver power with current-sink and source, for both positive-going and negative voltage levels / waveforms, with fast response time without compromising protection. To ensure future proofing and provision for scaling your applications upwards, for example in the automotive voltage variation test application shown in the diagram below, it can be synchronised, in 400W units. Here, two parallel and three further synchronised make a five-way solution packing up to *100Amp waveforms*. See Fig. 1.

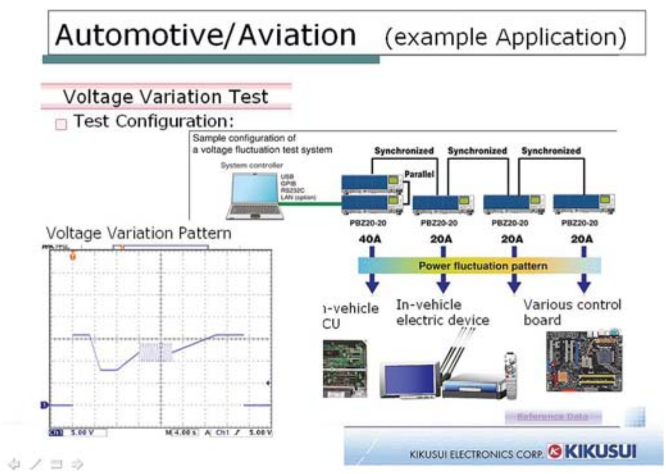

Fig. 1 Automotive and Aviation or Aerospace example application

For today's projects, power can easily exceed the dynamic or true-continuous output capabilities of ordinary PSUs. Tests such as fluctuating supply voltage or stress-testing of inductors, capacitors, motors, or for generating complex currents for precise control of medical instruments or electroplating – all these can be tested to very demanding standards and place unexpected strain on a power instrument. Procurers of the PBZ-series can easily overlook the many programmable limits, protection and safeguards that complement its four-quadrant capabilities. The strains imposed by modern industrial applications can be sudden or continuous, or both together, so a successful choice of power source often depends on choosing a supply with extensive protection as standard and a reputation for reliability.

This article covers some of these more demanding requirements, the underlying engineering principles with some handy reminders how four-quadrant works and, most importantly, what good performance really means. In Table 1, some noteworthy applications are given where engineers need a unique combination of capabilities found in Kikusui's PBZ-series: delivering power with current-sink and source, tracking both positive-going and negative voltage-levels/waveforms, with fast response.

Market	Some Example Applications
Automotive, aviation/aerospace devices: ECU Mother board Control board	Voltage variation test Power fluctuation test / EMC Car navigation systems
	Actual waveform test
Battery testing: Secondary (rechargeable) batteries	Charge/discharge test e.g. Digital Cameras
	Ripple current test
	Dummy battery test
DC motors/relays: Printers; Brush motors	Durability testing; Characteristic test; Motor endurance test
Capacitors: electrolytic, film, electric double layer capacitor	Capacitor ripple test SuperCap testing
Current sensors: Current transformer calibration	Current sensor test
Magnetic field generation: Medical; industrial;	Helmholtz coils Magnetic field test
Plating & Plasmas	Pulse plating

Table 1

To properly specify advanced power instruments for today's demanding power applications a little reflection on PBZ's four quadrant theory can ensure you choose a power source able to discover faults and glitches others cannot - and we can all benefit from a refreshing of some useful technical skills.

Engineers think outside the Quad:

First a basic requirement which many supplies don't meet: PBZ's extended output can provide positive-going and negative voltage-levels/waveforms, with both current-sink and source capability in either polarity to your chosen "load" i.e. device, DUT, UUT or EUT.

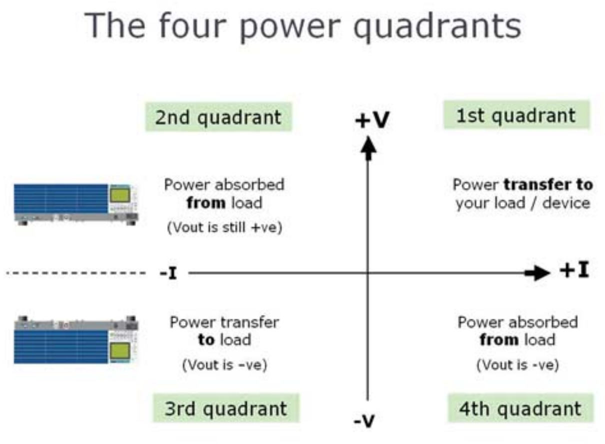

Fig. 2 The four power quadrants showing voltage and current polarity.

Note the power transfer happening in each quadrant in Fig. 2. This picture is helpful because it isn't every day we need to visualise what it really means to control power across all four I-V combinations and so a four-box view of these quadrants makes it easier to recall what's going on. For example, in battery charge/discharge testing shown in Fig. 3.:

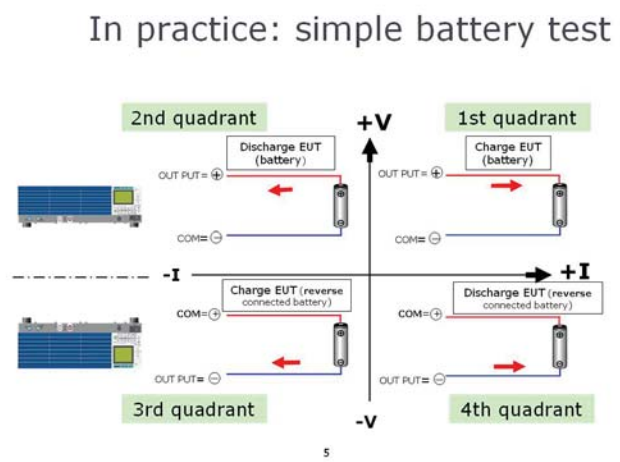

Fig. 3 In Practice simple battery test using the four quadrants.

The full coverage of PBZ can be quickly grasped with a walk around the four squares, comparing how ordinary power supplies only cover some of the quadrant(s):

Recall first how familiar traditional PSUs cover just one quadrant, then visualise extending functionality over the other quadrants using the graph pictured below:

- a traditional regulating power supply i.e. supplies a single rail with *positive current and voltage*, so both V and I are both positive in graph-quadrant-1 (Q1),

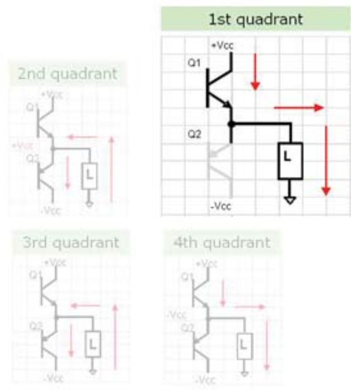

Fig. 4.1 Quadrant 1 is like a traditional regulating power supply

Now add to the above

- capability to *both source, and sink current*.(note output always positive, so now covers the *upper* half i.e. Q1 + Q2)

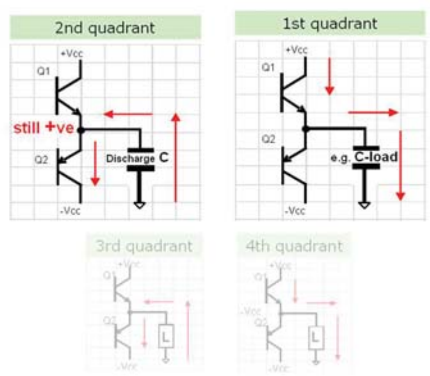

Fig. 4.2 Quadrants 1 and 2 are like source-plus-sink regulation also able to discharge C

Now add the ability to reverse polarity:

- dual-polarity or 'bipolar' (Q3 + Q4 *adds output of negative volts* without terminal swapping, in addition to purely uni-polar voltages of Q1/Q2 above)

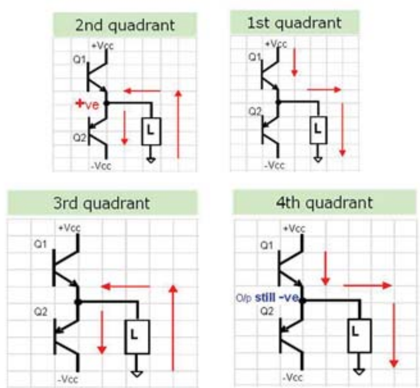

Fig 4.3 All quadrants - all possible polarities and phases of voltage and current flow

Figures 4.1 thru 4.3 above show stage-by-stage how PBZs go beyond ordinary PSUs, with extended output control needed for four quadrants. You'll already be grasping the simplified *equivalent output circuit* that looks a little like this:

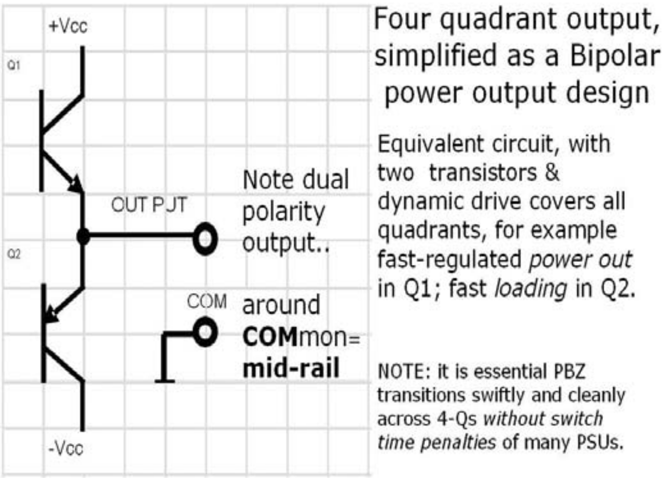

Fig. 5 Simplified equivalent output circuit of four quadrant sources

It is tempting to reduce four quadrant to simply an output stage like Fig. 5. An equivalent circuit is helpful, however its simplicity (perhaps it is over-familiar to those in the amplifier world) is very misleading and falls far-short of reliable PBZ power control. If this were the whole story behind so, many amplifiers with their claimed specs, often very skeletal, might be pretenders as reliable professional power supplies… until they suddenly burned out with no warning.

In fact we need to look beyond the quadrants to include three further important additional characteristics that mark-out PBZ offering much richer performance:

- fast response time, enabling fast accurate waveforms and rapid transients to be output as well as regulated DC levels

- full protection and safe limit-setting to ensure reliability and long life (often overlooked by amplifier-type designs not rated for continuous duty /difficult loads).

- unipolar operation, offering more power capability - ordinary amplifiers can be severely power-limited when operating at the extremes of some quadrants.

What can four quadrant *really do*? When do I need a PBZ?

Okay, so that's clearly different from many PSUs but engineers need to spot the *applications* requiring four-quadrant power and enrich our perceptions of what four-quadrant means in practice. The PBZ-series capably meets these needs as seen in the right-most column of Table 2.

Example Market	Application	Needs met by e.g. Kikusui's PBZ
Automotive, aviation/aerospace devices: ECU Mother board Control board	Voltage variation test Power fluctuation test Car navigation systems	**Rapid series of power test patterns;** prove system tolerance
		Simulate noisy power/EMC; Increase current; synchronize multiple outputs.
		Simulate sudden source/sink load; effect on power cable assemblies.
	Actual waveform test	**Eliminate defect DUTs** by reproducing suspect waveforms/transients.
		Increase reproducibility of the waveform.
Battery testing: Secondary (rechargeable) batteries	Charge/discharge test e.g. Digital Cameras	**Fast switching between charge and discharge;** Transient response.
	Ripple current test	**Superimpose** AC current on DC current.
	Dummy battery test	**Battery substitute**, high currents. Simulate the battery condition.
DC or other motors/relays: Printers; Brush motors	Durability testing; Characteristic test; Motor endurance test	**Repeat complex test patterns** e.g. normal with sudden reverse rotations; Breaker-testing solenoids, relays/actuators; **Stress-testing** under non-sine drive e.g. rectangle.
Capacitors: electrolytic, film, electric double layer capacitor	Capacitor ripple test SuperCap testing	**Overlap-ripple testing**; easily realize sine wave current test pattern.
		Superimpose AC current on DC current. **peak current *plus* transitions in *both* polarities.**
Current sensors: Current transformer calibration	Current sensor test	**Test with high-purity precise sine wave current.**
		Increase current. **Set and maintain phase** reliably; calibration of phase-shift.
Magnetic field generation: Medical; industrial;	Helmholtz coils Magnetic field test	Generate magnetic field with sine+ current to the coil. **Precise field variation.**
Plating & Plasmas	Pulse plating	**Const. current source for pulse plating** e.g. HDDs Control density; create required patterns; precision pulse currents.

Table 2

A proven four quadrant source delivers best test performance

Project results can often hit unexpected barriers or limits – very often arising from poor or thin specifications. Be particularly cautious of simplistic PSU specifications – where headline figures *alone* appear to go in the right direction. When extra-ordinary power problems arise it's too easy to jump at semi-custom designs that can lead down a blind alley – ending in inadequate fault-protection (usually only two or three protection features), or with no scalability (you can't extend in a modular way) or with no choice except expensive support. Overlooking well proven, fully specified solutions that PBZ-series addresses properly can lead to dead-ends where an unproven or part-custom system ends in disappointment. Such projects end in higher overall cost locked into a growing maintenance bill. Worse still, misplaced investment leaves you with an inflexible asset you might only use only be able to exploit in narrow applications or for only one project.

Watch out for hidden problems in specifications

There are some tell-tale signs to look out for in skeletal specifications. In particular watch out for these:

- peak voltage or peak current claims, without clearly showing you the protected operating regions

- claims of "pulse capability" without stating clearly what pulse means

- bandwidth claims, other than at rated-load

- also avoid imposed load limitations such as limiting you to e.g. load characteristics which should be mainly resistive.

Instead, look out for the following found in proven and reliable instruments:

- a clear rise time specification (e.g. less than 5us);

- bandwidths that are conservatively specified e.g. PBZ specifies a very good 100kHz. This is properly and conservatively stated for its rise time of 3.5us;

- overshoot, load-effect and source effects should be quantified. PBZ provides these figures and this also helps you judge the instruments ultimate precision.

- a good specification will say clearly what a *rated load* means e.g. causes rated current to flow when PBZ is generating its rated voltage.

- Power dissipation limitations with a chart clearly showing any operating regions. For example, Kikusui's PBZ specification explains clearly: "In bipolar mode, the sink range is limited to 100 W for 20 V model and 180 W for 40 V model. In unipolar mode, there are no limitations and it is capable to sink up to 400 W."

Some power supplies claim to be 'optimised' for certain loads. Beware this may indicate a poor design 'disguised as optimised'. Neither users nor suppliers should need to tinker with (or 'optimise') the load impedance. Some designs can even be unstable. Overshoot and rise-time will always depend on reactive loads - Kikusui's PBZ can be used to drive inductive or capacitive loads without needing to be optimised because its design and control systems are able to perform well for a wide range of reactive complex loads.

Engineering solutions with PBZ four quadrant supplies

With its advanced Switching-plus-Linear system, the PBZ is able to realize both high speed and low noise operation in a with substantial weight reduction. Equipped with a capable signal generator function, waveforms and sequences can be created, stored and sequenced. The PBZ is also capable of synchronized operation which is required for voltage variation tests, and it can also be expanded for large current applications through master-slave parallel operation.

Figure 6 Kikusui's PBZ-series four quadrant power sources

The PBZ series is a bipolar type DC regulated power source that can continuously change both + and – polarities passing through zero Volts without changing the output terminal. Not just power supplies, the PBZs pictured in Fig. 6 are also high power function/arbitrary waveform generators with sine/square/triangular outputs and frequency (up to 100kHz) plus variable rise time (from 3.5uS). There are soft start/stop functions, ramp up/down, AC on DC and user programmable sequence function.

Available in two models (+/-20V/+/-20A) and (+/- 40V/+/-10A), units can be paralleled for more current.

By adopting a Switching + Linear system, the PBZ has reduced weight as well as high speed and low noise operation in true four quadrant regions with full protection. The PBZ can also drive inductive or capacitive loads. The unit also incorporates a signal generator function which enables waveform and sequence creation. The PBZ is also capable of synchronized operation which is required for voltage variation tests, and it can also be expanded for large current applications through master-slave parallel operation.

Some key PBZ-series features include:

- **Low ripple and noise** e.g. Ripple in CV mode: 2mVrms, Noise 20mVp-p (PBZ20-20)

- **Waveform generation & sequencing functions built-in** In addition to the basic sine, square and triangular waveforms, the PBZ series is equipped with a user-defined waveform generating function that can register up to 16 waveforms. It allows the amplitude, frequency, start phase, frequency sweep and square wave duty to be set as needed.

  The 16 user-defined waveforms can be freely edited, and the original created and edited waveforms can be registered and easily recalled for use. The sequence function allows each waveform to be set as a single step, and a maximum of 1024 steps can be set in the 16 programs plus he built-in sine, triangular and square waveforms can each be set as a sequence step, allowing even complex sequences to be created easily. Sequences are composed of up to 1024 steps. This combination of steps forms a program, and the 1024 steps can be allocated and set in a maximum of 16 programs. In addition to executing a single program to realise a sequence, the script function also allows multiple programs to be combined and executed as needed.

- **Synchronized operation function** synchronizes the power output when a sequence is executed using multiple PBZ. It prevents time deviations from occurring even when a long sequence is executed.

- **Parallel operation function** expands the output current. It allows multiple units to be connected in parallel according to the required current. With 2 standard units of the same model and the optional parallel operation kit, the user can easily complete the setup. Although up to 5 units can be operated in parallel, if 3 or more units will be used, please consult with us.

- **Unipolar mode** is a special function unique to this product is an advantage for applications which need source-sink but don't require voltage-reversal (single polarity). In unipolar mode it is still possible to apply current in both directions i.e. quadrant 1 and quadrant 2 (2 quadrants). Whereas four quadrant operation has the usual power restrictions at the extremes of quadrants 2 and 4 (PBZ20-20: 100W, PBZ40-10: 180W) the PBZ-user can select unipolar mode, *operation to realise the full sink/source power, operating over the entire area of quadrant 2.*

- **Extensive Protection functions** including Over voltage/ Over current/Over heat/ Power limit.

  With CV/CC selectable modes, each with very fine setting resolution, PBZs have additional features for external voltage/resistance control, remote sensing plus outputs for signalling unit status and signals out for voltage/current monitors. Not forgetting, of course, an input for applying your own externally generated arbitrary waveform.

More product information on the 40V, 10A version can be found at: http://www.telonic.co.uk/products/categories/prd/proddetail.asp?Model=PBZ40-10

About the authors and engineers at *Telonic*

Berkshire-based Telonic instruments has been solving problems for UK customers in power, measurement and instrumentation for over 30 years in close partnership with Kikusui. Telonic provides wide ranges of AC and DC power supplies, frequency converters 50Hz/60Hz/400Hz and beyond, highly reliable safety testers, professional bench meters and flexible, programmable power supplies, Telonic is recognised for sustained services and ISO9001 standards UK Customers find reassuring, especially in test and production where time means money.

***Doug Lovell**, Sales Director at Telonic Instruments adds: "we pride ourselves in giving customers the in-depth information to find the instrument they need. We see a wide range of applications and for many, the extensive features of PBZ makes it easy to integrate into reliable solutions in testing, research and production. We believe quality is paramount and Kikusui's range has long-served our customers' requirements for both quality and performance."*

Telonic also remains well-placed to go on serving UK customers, recently expanding its ranges to encompass more measurement instruments, advanced waveform generators, RF spectrum analysers and oscilloscopes to 3+GHz. All are backed by substantial Telonic stock and UK-based staff plus options to hire instruments.

With expertise, support and maintenance services Telonic is an attractive partner for industrial production, test engineers, R&D and researchers across applications in communications, automotive/ aerospace / defence, research, education, industrial and consumer electronics and RF instrumentation industries. Telonic has power to maximise your potential.

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

A brief digression on the latest draft standard for Active Infeed Converters (AICs) - IEC TS 62578. Ed.2

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

The other article with the same heading in this Issue (No.101) of The EMC Journal introduces itself by describing my attempt – in this series of "Stand Alone" articles – to cover the entire field of switch-mode power converters, so I won't repeat that text here.

I have just read an IEC Technical Specification (TS) which will probably be a full international standard one day, and which is very relevant to the subject matter of this series:

> IEC/TS 62578/Ed.2/CD, entitled: "Power electronics systems and equipment – Service Conditions and Characteristics of Active Infeed Converter Applications including recommendations for Emission limits below 150kHz".

The acronym CD shows that it is a Committee Draft, and it was recently circulated amongst the British National Committee on EMC as BSI document GEL/210/12_12_0093. Unfortunately, by the time this Journal is posted the last date for submitting comments on it (27 July 2012) will have passed.

IEC/TS 62578 covers what are officially called "Active Infeed Converters" (AICs), which are switch-mode power converters that are connected between the AC electrical power supply system ("the mains") and the DC-Link in a power converter – replacing the AC rectifier in an ordinary AC-DC converter or AC-AC inverter. Figure 1 shows an example of block diagram for the semiconductor chopper used in one of the several types of AIC.

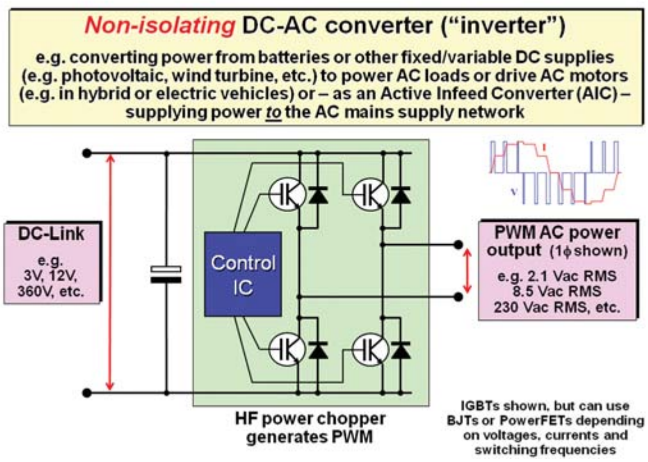

Figure 1 Chopper block diagram for a voltage source type of AIC

Figure 1 shows a single-phase AIC's chopper without any filters, feedback, or other circuits required for it to function correctly. A three-phase AIC chopper only needs to add another IGBT totem-pole to the two shown.

Unlike an ordinary mains rectifier, AICs can transfer electrical power (both active and reactive) in both directions – from AC mains to DC-Link, or from DC-Link to AC mains – and the direction can be controlled millisecond-by-millisecond.

They are commonly used with the DC-Links of variable-speed power drive systems, to absorb the inertial energy of the rotating motor and its load in the AC mains supply during regenerative braking. This is generally regarded as being better than wasting the energy as heat in a braking resistor, helping to save the planet by reducing the CO_2 emissions from burning fossil fuels to make electricity, and at the same time reducing energy bills (but only when a suitable electricity meter, that measures energy put back into the supply, is installed).

AICs are also used in photovoltaic, wind, and all other types of 'green energy' electricity generation schemes, at all voltages and power sizes, so that their excess energy (beyond what is consumed by their locally connected loads) can be sent to the AC mains supply to earn money for their owners.

They are also used in uninterruptible power systems (UPS), motor drive systems, and active filters, to help control low-frequency AC mains harmonics. They do this by synthesizing a sinusoidal AC current. Some of them can additionally compensate the pre-existing harmonic distortion of a given supply side voltage.

AICs can also be used to control the power factor of a power supply system section by moving the electrical power (active and reactive) in both directions (generative or regenerative), which enables energy saving in the system and stabilizes the power supply voltage or enables coupling of renewable energy sources or electrical energy storage devices to the supply.

The use of AICs in "green energy generation" is a very rapidly growing industrial sector, with a significant future impact on the performance, power quality and stability of national electricity power supply networks (often called national electricity grids).

Their use is also important for the operation of Smart Grids – the generic name chosen for national electricity power supply distribution networks with embedded computer-based control that continually balances the mix of electricity generators and their loads to optimise overall efficiency (and hence meet national targets for reducing CO2 emissions and help save the planet) and also maintain power quality and stability (hence maintain or improve the availability of supply, its “uptime”).

Given the rapid increase in, and very large future numbers of AICs, and their national and international importance, it is of course necessary to have standards for their operation and EMC.

IEC/TS 62578 describes the operation conditions and typical characteristics of all types of AICs. It also provides a practical and analytical approach for emission limits for AICs in power supply systems, based on the latest results for line impedance values between 2 kHz and 9 kHz and on the withstand capability of capacitors connected directly to the supply. This approach also results in recommendations for emission limits below 150 kHz.

Copies can be obtained from the UK’s National Committee (GEL/210/12), by a Trade Association with members who represent them on that committee, which includes: EMCTLA, EMCIA, IABM, PLASA, AMDEA, IET, BEAMA-TACMA, LIF, LA, RSGB, ACE, UK Weighing Federation, GAMBICA, ENA and Intellect.

If you are not based in the UK, you will need to obtain copies from Trade Association representatives that attend your equivalent National Committee (the National Committee will know their names).

Some large manufacturers and government agencies have representatives on the appropriate committees, and if you work for those organisations you can obtain copies from your appropriate colleagues.

Although by the time you read this it will be too late to submit comments on this CD to your National Committee, there will be many future opportunities to do so.

Here are some of the especially interesting sections of IEC/TS 62578/Ed.2/CD in the context of these articles:

4.1 Basic topologies and operating principles

4.2.1 Converter rating under sinusoidal conditions

4.2.2 Converter rating in case of harmonic currents

4.2.3 Converter rating under dynamic conditions

5.1.3 Power supply system impedances in the range between 2 kHz to 20 kHz

The values of the power supply system impedances in the range of the pulse frequency of an AIC and its harmonics might have significant influence on the conducted emissions of an electric or electronic device. With increasing impedance values, the voltage disturbance level increases approximately in proportion.

The power supply system impedances at the IPC (the point of connection to the MV or HV grid network) in various industrial and public supply systems in Central Europe have been examined in a dedicated research project, and conclusions drawn on the values to be used when simulating or testing an AIC to determine its harmonics and conducted emissions.

5.1.4 Proposal of an appropriate line impedance stabilisation network (LISN)

In order to predict system perturbations by means of simulations, analytical models of power system impedance are necessary. In this clause a model that can be used for simulation is shown.

5.1.5 Recommendations for setting emission limits in the range of 2 kHz to 9 kHz

5.1.5.1 Immunity of power capacitors which are connected to the power supply system and recommendation for the compatibility level in the frequency range 2-9 kHz

5.1.6 Justification of reasonable AIC emission levels below 150 kHz

5.1.7 Effects on industrial equipment in the frequency band 2 kHz – 9 kHz

5.2 High-frequency phenomena (> 150 kHz)

5.4 Leakage currents

5.5 Aspects of system integration and dedicated tests

6 Characteristics of a PWM Active Infeed Converter of Voltage Source Type and Two Level Topology

7 Characteristics of a PWM Active Infeed Converter of Voltage Source Type and Three Level Topology

8 Characteristics of a PWM Active Infeed Converter of Voltage Source Type and Multi Level Topology

9 Characteristics of a F3E AIC of the Voltage Source Type

An F3E AIC consists of a standard diode bridge with antiparallel connected IGBTs. If the current flows in the direction of the load (e.g. a PWM motor inverter) it goes through the diodes. If the current flow is in the direction of the power supply system it goes through the IGBTs.

10 Characteristics of an AIC of Voltage Source Type in Pulse Chopper Topology

11 Characteristics of a two level PWM AIC of current source type

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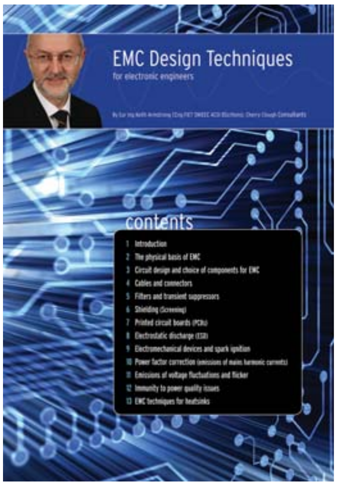

Contents:
Introduction;
The Physical basis of EMC;
Circuit design and choice of components for EMC;
Cables and connectors;
Filters and transient suppressors;
Shielding (Screening);
Printed Circuit Boards (PCBs);
Electrostatic discharge (ESD);
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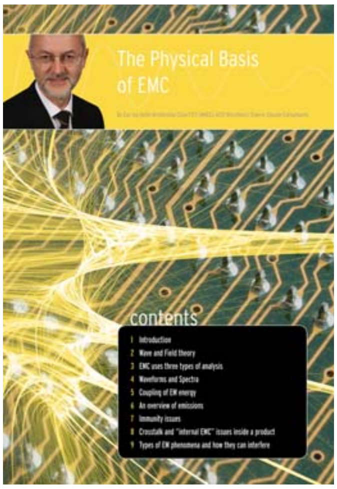

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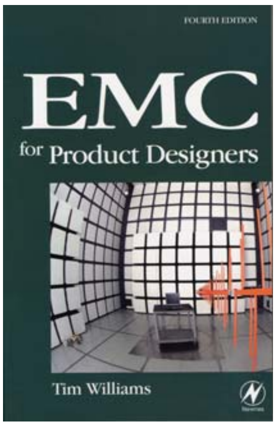

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EMC design of high-frequency power “switchers” and “choppers”

Suppressing RF noise in DC inputs, outputs, and DC-Links

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 93-100 of The EMC Journal carried the preceding parts of this “Stand Alone” series – 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), covering *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. Hybrid & electric automobiles, electric propulsion/traction; “green power” (e.g. LED lighting); and power converters for solar (PV), wind, deep-ocean thermal, tidal, etc., are also covered.

Issues 93-95 used a different Figure numbering scheme from the rest, for which I apologise.

I generally won’t repeat material I have already published, instead providing appropriate references to the EMC Journal [14] and my recently-published books based on those articles [15], so that you don’t get bored by repetition.

7 Suppressing RF emissions from inputs and outputs

I began Section 7 in Issue 98 [72] and so far it has continued up to Issue 100 [92]. Despite my aim to only publish ‘stand-alone’ articles, each covering a single topic, the issue of suppression is so large that it is impossible to publish it all in a single issue.

Suppression is such a large topic, because it is so difficult to do and requires attention to a great many details. It is also very costly.

Please don’t forget that it is much better (more cost-effective, shorter time-to-market, see section 7.1 in [72], [11] and Chapter 1 of [5]) to design the power converters in such a way as to minimise their input and output emissions. These design topics were covered in the early parts of this series, [13] [42] [64] [65] and [66], because they are more important for technical and financial success.

7.6 Filtering DC with big capacitors

7.6.1 Introduction

The DC to be filtered that I will discuss here could be a DC power input, DC power output, or an intermediate DC power-coupling stage (generally called a DC-Link).

The example used in the previous issue on shielding power converters’ AC output cables, was based on an AC-AC inverter powered by an AC supply, driving an AC motor.

Exactly the same noise emission issues apply to the AC inputs or outputs of AC-DC or DC-AC converters, as apply to their DC outputs or inputs considered in this article.

These noise emission issues also apply to the inputs and outputs of DC-DC converters. And any noise voltage on a converter’s DC-Link tends to ‘escape’ via the converter’s power inputs and outputs.

But the big advantage that we have when filtering DC inputs, outputs and DC-Links, is that we can use very large values of capacitance. Figures 7.6-1 and 7.6-2 show AC-DC and PWM AC-AC converters respectively, with simplified sketches of the noise voltages at various points in their circuits.

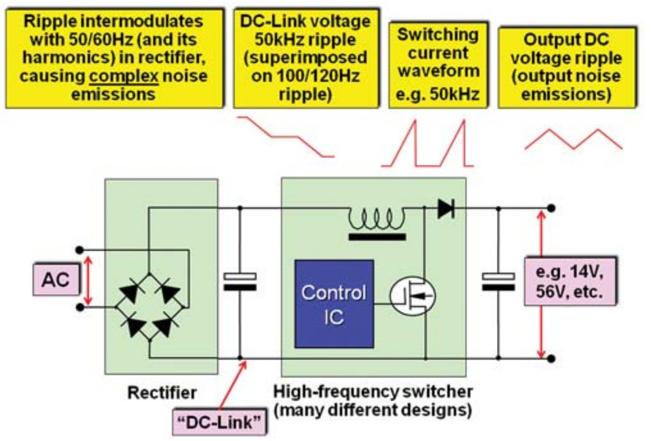

Figure 7.6-1 Example of the noise voltages in the circuit of a simple AC-DC converter

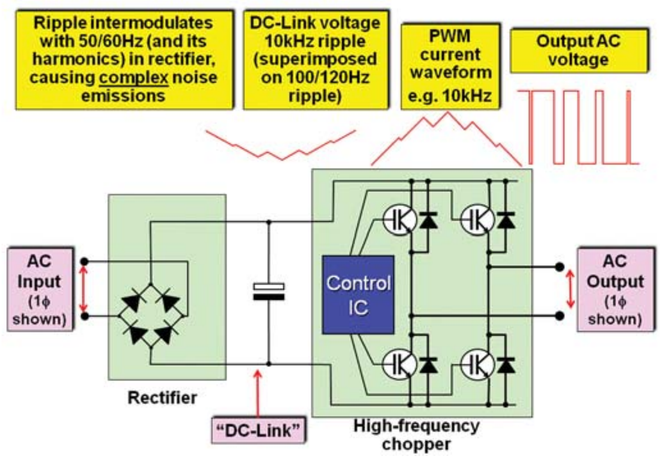

Figure 7.6-2 Example of the noise voltages in the circuit of a simple PWM inverter

Note that no noise waveform is drawn for their AC mains inputs – because these waveforms are too complex. The bridge rectifier acts as a frequency mixer, so that the rectified AC mains frequency and its harmonics intermodulates with the DC-Link's noise frequency and harmonics.

Figure 7.6-3 shows an example of the noise spectrum emitted from the 50Hz (designated f_1) mains power input of a 700kW variable-speed AC motor drive running at 39.4Hz (designated f_2), with the intermodulation products (IPs) marked.

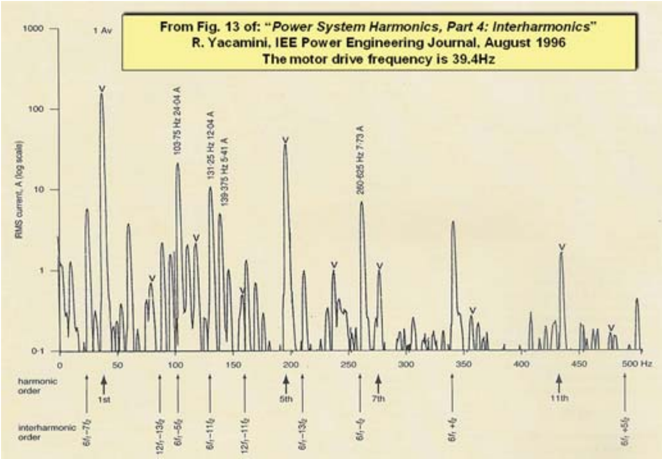

Figure 7.6-3 Mains input noise emissions (unfiltered) from a high-power AC motor drive

Thus we have:

- Approx. 6A rms of noise current at $6f_1$-$7f_2$ (i.e. 24.2Hz)
- 110A rms of noise current at f_2 (i.e. 39.4Hz)
- Approx. 3A rms of noise current at $12f_1$-$13f_2$ (i.e.87.8Hz)
- 24A rms of noise current at $6f_1$-$5f_2$ (i.e. 103Hz)
- 12A rms of noise current at $6f_1$-$11f_2$ (i.e. 133Hz)
- 5.4A rms of noise current at $24f_1$-$34f_2$ (i.e.140Hz)
- Approx 50A rms of noise current at $5f_2$ (i.e.197Hz)
- 7.73A rms of noise current at $6f_1$-f_2 (i.e.260.6Hz)
- Etc…

The harmonics of f_1 are all in multiples of 6, because a symmetrical 3-phase bridge rectifier – also known as a 6-pulse rectifier – has output ripple at the fundamental frequency of 300Hz (i.e. $6f_1$), plus 2nd, 3rd, 4th, etc. harmonics at 600Hz ($12f_1$), 900Hz ($18f_1$), 1200Hz ($24f_1$) etc.

The harmonics of f_2 start with the 5th, because symmetry in the 3-phase chopper circuit mostly cancels out the even-order harmonics and the triplens (3rd, 9th, 15th, etc.) leaving only the 5th, 7th, 11th, 13th, 17th, 19th, etc. at significant levels.

Then intermodulation between these two sets of harmonic currents flowing simultaneously in the non-linear the bridge rectifier causes all their various frequencies to be added and subtracted, generating hundreds more noise currents at brand-new frequencies, known as Intermodulation Products (IPs).

Chapter 7.3 of [4], which is the same as Chapter 2.9.3 of [5], discusses demodulation and intermodulation in general, but fails to give a good idea of the huge intermodulation complexity that results from having just two different frequencies in a circuit as simple as a single diode, the simplest possible situation, shown in Figure 7.6-4 – never mind the dozens of frequencies in the 6 rectifiers of a three-phase bridge, in the example of Figure 7.6-3.

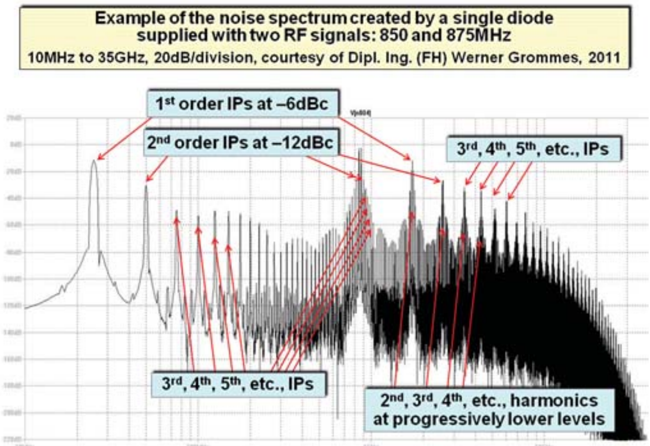

Figure 7.6-4 Intermodulation between 850MHz and 875MHz in a single diode

Frequencies as high as 850MHz are not (yet!) seen in switch-mode power converters, but the same results would have been achieved if the two frequencies in Figure 7.6-4 were 85Hz and 87.5Hz, or 85kHz and 87.5kHz – the only difference would be the frequency scaling of the horizontal axis.

7.6.2 Filtering techniques for DC

The cable shielding techniques described in [92] can be applied to DC inputs and outputs just as well as to AC outputs.

Applying them to AC mains power supply inputs is more awkward, because of the difficulties of 360°-bonding cable shields to the metal cases of AC mains distribution transformers, which are not a properly shielded boxes anyway because of the other unshielded and unfiltered cables that enter or exit them (cost-effective design of shielded enclosures is covered in Chapter 6 of [5]).

But the topic here is *filtering* DC power, and all of the filtering techniques discussed in the previous two articles [72] and [84] can be applied just as well to DC, as to AC power inputs and outputs.

The amount of charge stored in the filter or storage capacitor is one of the key issues in reducing power converter emissions at the switching frequency (and its harmonics), and results in a noise voltage often called "ripple" – an AC waveform riding on the DC voltage level.

Ripple noise voltage is obviously an important issue for DC inputs and outputs, and it is also an important issue for internal DC-Links.

A helpful and simple equation for the change in voltage on any capacitor is $C\Delta V = I_{AV}\Delta t$, where C is the capacitor's value in Farads, ΔV is the change in voltage on the capacitor caused by the average current I_{AV} Amps flowing during the time period Δt seconds.

So, for example, a perfect 1000µF capacitor that is being charged or discharged by a current with an average value of 25

Amps during a time period of 1µs, will experience a change of 0.025V from whatever its voltage was originally. On this basis, it seems possible to arbitrarily decrease the noise voltage by simply increasing the capacitor value to whatever value is necessary.

But a capacitor is not simply a capacitor! Real components are never 'pure' – as simple circuit simulators assume – and Figure 7.6-5 shows a 1st-order approximation of what we actually get when we purchase a capacitor, rather than an idealised capacitor that cannot possibly exist in this universe. This figure is based on an electrolytic capacitor, but exactly the same analysis applies to all non-polarised capacitors too.

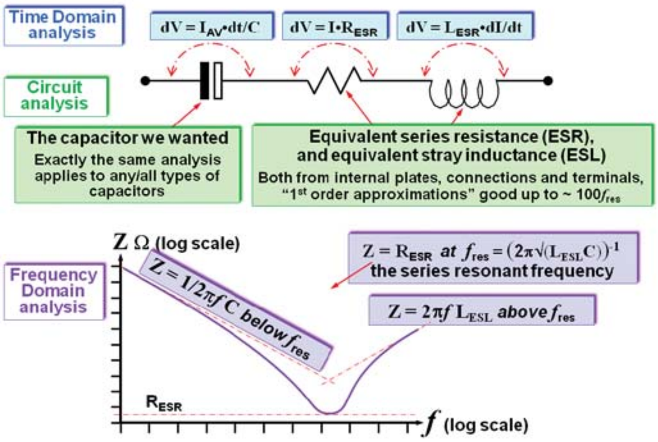

Figure 7.6-5 A 1st-order equivalent circuit showing that real capacitors are complex

The circuit analysis in Figure 7.6-5 shows that the real capacitors that we assemble our products from all suffer from "pollution" caused by their Equivalent Series Resistance (ESR) and Equivalent Series Inductance (ESL). The simplified time-domain and frequency-domain analyses on this figure show what we should expect when we pass switching currents through capacitors.

(There is also a leakage resistance bypassing the capacitor, but it is only important for precision sample/hold analogue circuits, and where a circuit must run from the energy stored in tiny batteries, or capacitors, for long periods of time, so I ignore it in this article.)

The ESR and ESL limit the effectiveness of the DC-Link (= DC storage) capacitor as a filter, but even adding low-value non-polarised capacitors in parallel doesn't always help as much as we might hope, because they also suffer from ESR and ESL. Also, paralleling capacitors adds a totally new problem for ripple voltage reduction: the capacitors' ESLs cause *parallel* resonances to arise, which have very *high* impedances (see 7.6.3 below) – not what we want for low emissions!

Like many designers, I have happily paralleled all sorts of types and values of capacitors without suffering any surprise ill effects. What this means is that the parallel resonances thus caused did not happen to coincide with the switcher's fundamental frequency or any of its harmonics.

Murphy's Law [93] tells us that paralleling capacitors with no regard to the high-impedance resonances thus caused will be just fine, until some years later when we are asked to make a small increase in the switching rate (maybe to save cost by reducing the size of the magnetic components).

This simple task that the designer's boss expects to take a few hours can cause either the fundamental frequency or a harmonic to "just happen" to coincide with a parallel resonance in the DC-Link or filter capacitors. It is not unusual in such situations for the conducted mains emissions at that new frequency to suddenly shoot up from nowhere, to 20dB or more above the limit line.

Of course, the reason for this isn't obvious to the poor designer, and his boss can't understand how he or she could have made such a simple job take so long. Murphy's Law is the bane of all designers, but no-one has yet found a way of getting around it. (Actually I once did, and might write about it one day.)

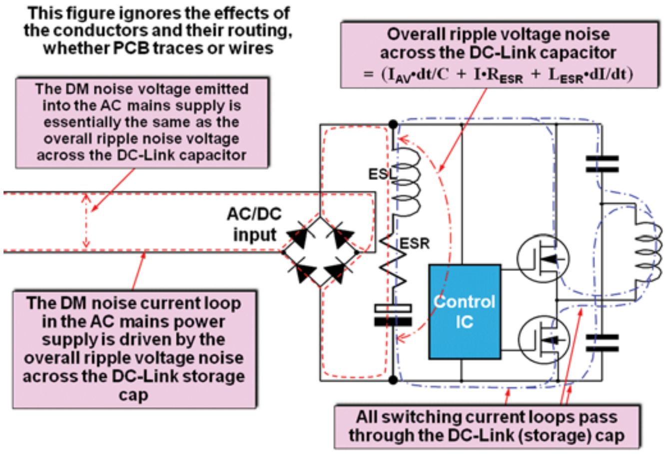

Figure 7.6-6 Showing how the ripple voltage directly influences conducted emissions

Figure 7.6-6 is an example that attempts to show how the ESR and ESL in a DC-Link capacitor increase the ripple voltage noise, and how this drives a differential mode (DM) noise voltage and current through the bridge rectifier and into the AC or DC power supply. This figure is based on a half-bridge switcher, but applies to any/all kinds of switchers that have a DC-Link.

This figure doesn't show the mains filter that will be needed to suppress this DM noise, and the common-mode (CM) noise caused by the noise current flowing in the (unbalanced) power supply distribution network. In power input and output filters (see 7.3 in [72] and its continuation in [84]) exactly the same problems are created by the ESR and ESL of the filter capacitors, whether the power supply is DC or AC.

It is generally more cost-effective to suppress conducted power supply emissions at their source (i.e. the ripple noise voltage on the DC-Link capacitor) than it is to suppress the noise in the AC or DC power supply conductors, and this was the basis for my one-capacitor modification to the military submarine winch motor drive, that I described in 7.3.8 in [84].

From Figure 7.6-5 we can see that the overall impedance of a capacitor, Z_{CAP}, is:

$$Z_{CAP} = \{(j/2\pi f \cdot C) + (-j2\pi f \cdot L_{ESL}) + (R_{ESR})\}$$

(Remember, this uses a 1st-order approximation that is probably only good to around 100 times f_{RES}).

Purists will note (hopefully with approval) that I have included the phase-angle operator, j, in the above equation. When I was a student this used to terrify me because it was the square root of minus one, and therefore an imaginary number, and my AC circuit theory tutors used to refer to “imaginary” voltages, currents, impedances, and even “imaginary” electrical power (i.e. ‘wattless power’)!

But all it means in practice (i.e. the real world) is that any quantity multiplied by j has a phase-angle that is 90° ahead (i.e. ‘leading’), whereas one multiplied by –j has a phase-angle that is 90° behind (i.e. ‘lagging’), and you can see these phase angles clearly on any oscilloscope, there is nothing imaginary about them at all!

The reason for the “square root of minus one” aspect of j becomes apparent when you set the capacitive current in a circuit exactly equal to the inductive current, and so achieve a series or parallel resonance – in which situation the circuit has only the characteristics of resistance. Try it, in the above equation for a 1st-order approximation of a capacitor, and prove it for yourself.

(Without considering the +j and –j phase angles associated with the capacitive and inductive impedances, resonance cannot occur, and we could never have made any tuned circuits and so could never have been able to tune to different radio frequency “channels”).

When selecting DC-Link capacitors, a large value of capacitance is generally aimed for, to provide a low impedance at the fundamental switching frequency. But, above some number of μF, diminishing returns set in because the R_{ESR} value becomes larger than the value of $1/2\pi f{\cdot}C$. So we need a very low ESR, to reduce the ripple and emit less noise.

The above assumes that the fundamental frequency of the switcher is so low that the effect of the ESL is negligible, which is not always the case. In some applications the ESL is high enough that $2\pi f{\cdot}L_{ESL}$ can equal or exceed the value of $1/2\pi f{\cdot}C$ and/or R_{ESR}. So we sometimes also need a low ESL to suppress the fundamental frequency.

The same considerations apply to suppressing the harmonics of the switching frequency, and of course as the frequency increases the impedance due to $1/2\pi f{\cdot}C$ reduces whilst the impedance due to $2\pi f{\cdot}L_{ESL}$ increases, eventually – above some frequency – making the ESL the dominant, most important, issue for suppressing ripple voltage and noise emissions.

The current flowing in the ESR of a capacitor results in “I^2R” heating that can be so large that it shortens the life of the capacitor, especially wet electrolytic types through drying out of their electrolyte. This is why – if an operational life of more than a few months is required – it is so very important to choose electrolytic capacitors with ambient temperature ratings, plus ESRs and ripple current ratings that the design will not exceed. This heating issue is especially important for high-power converters, and later on I will briefly discuss some special capacitor types that have been developed to have very low ESRs and very low self-heating in such situations.

It is always tempting to try to choose a DC-Link capacitor that has its series resonance at the fundamental frequency, although where this lies below the lowest frequency tested by the so-called “CE marking” standards many designers will instead try to series-resonate their DC-Link capacitance at the first harmonic that equals or exceeds the lowest tested frequency. (The wisdom, or not, of ignoring emissions that lie below the tested frequency range is discussed later).

Let’s take a practical example of a capacitor that – at the time of writing – is supplied as being suitable for use as the DC-Link in a switch-mode power converter, the EPCOS (TDK) B43455A5158M000: 1,500μF, 450Vdc, rated 10,000 hours life at 85°C, aluminium electrolytic with screw terminals, see Figure 7.6-7. Please note that I am not recommending this type of capacitor, it’s just the first one I came to when flicking through a distributor’s catalogue to find an example to use in this article.

From the EPCOS data sheet for the B43455 and B43457 General-purpose grade capacitors sold as being suitable for use in: uninterruptible power supplies; frequency converters, and professional power supplies

Technical data and ordering codes — B43455 B43457

U_R VDC	C_R 100 Hz 20 °C μF	Case dimensions $d \times l$ mm	ESR_{max} 100 Hz 20 °C mΩ	Z_{max} 10 kHz 20 °C mΩ	$I_{\sim max}$ 100 Hz 40 °C A	$I_{\sim max}$ 100 Hz 85 °C A	$I_{\sim R}$ 100 Hz 85 °C A	$I_{\sim R}$(B) 100 Hz 85 °C A	Ordering code1)
450	470	51,6 × 80,7	390	420	7,0	3,1	2,6	4,1	B4345*A5477M000
	1 000	51,6 × 80,7	180	200	12	5,1	4,2	8,6	B4345*B5108M000
	1 500	64,3 × 105,7	120	130	16	6,9	5,8	9,4	B4345*A5158M0002)
	2 200	64,3 × 105,7	81	70	18	7,9	6,6	12	B4345*B5228M0002)
	3 300	76,9 × 143,2	54	48	25	11	9,1	14	B4345*A5338M0002)
	4 700	76,9 × 220,7	42	39	31	14	11	15	B4345*A5478M0002)
	4 700	91,0 × 144,5	42	39	31	14	11	19	B4345*J5478M0002)
	6 000	76,9 × 220,7	33	31	38	17	14	19	B4345*A5608M0002)
	8 200	91,0 × 221,0	24	24	48	21	18	25	B4345*A5828M0002)

Figure 7.6-7 Some data on the EPCOS B43455 capacitor range

And let’s also assume that it is used as the DC-Link that follows the bridge rectifier in a 230Vac rms input 300W output switching power converter similar to the half-bridge type sketched in Figure 7.6-6, with a switching frequency of 51kHz.

The storage capacitor is nominally charged up to 325Vdc and experiences a sawtooth current waveform into the switching devices with an RMS current of, say, 1A and a peak current of 2A.

Now, I know that your current project has a different switching waveform so has a frequency spectrum that is very different from a sawtooth wave, and has different voltage and power requirements, different switcher type, different everything, but this is just a simplified example to help us discuss the issues associated with the value, ESR and ESL of the DC-Link capacitor.

A sawtooth wave can be “decomposed” into frequencies using Fourier analysis [94], as follows: Fundamental -1/2(2nd harmonic) + 1/3(3rd harmonic) – 1/4(4th) + 1/5(5th) – 1/6(6th) + 1/7(7th)….etc., up to a very high frequency limited by the rise and fall-time of the switching devices (almost certainly exceeding 51MHz in a converter of this rating).

Because the harmonics alternately add and subtract, to achieve our overall current of 1A rms and 2A peak, the current at the fundamental frequency has to be a little larger, and I have estimated it at 1.5A rms and 3A peak.

Knowing the currents at the fundamental and harmonic frequencies, we *could* calculate the various contributions to the ripple noise voltage across the 1500µF capacitor from the three components of the 1st-order approximation equivalent circuit shown in Figure 7.6-5, remembering to take into account their various phase angles. Instead, EPCOS have provided us with a handy graph of overall capacitor impedance (Z) versus frequency, which is copied in Figure 7.6-8. This graph implies an ESR of about 30mΩ, an ESL of about 16nH, and although the series-resonant frequency would be expected to occur around 32kHz, the graph shows that it actually occupies quite a wide range, approximately from 3kHz to 200kHz.

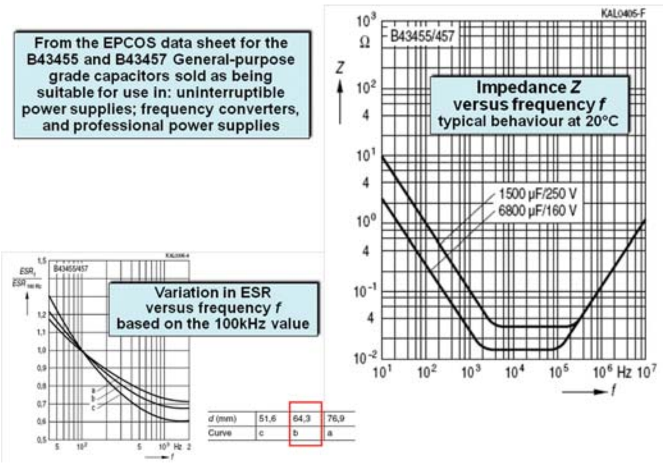

Figure 7.6-8 Variation of overall impedance with frequency, for the B43455 capacitor range

Using this handy graph and the harmonic series for our sawtooth current waveform, for our example 300W switcher we can say that its DC-Link capacitor will experience (approximately) the peak currents and develop the peak noise voltages as listed in Table 7.6-1.

Measuring the conducted emissions of a product adds a CISPR-specified LISN in series with its power supply, which sources the power from an impedance of 50Ω in the range 150kHz to 30MHz.

However, the source impedance of the DM ripple noise voltage is the impedance of the DC-Link capacitor at the frequency concerned, which we can see from Figure 7.6-8 is always less than 3Ω between 100Hz and 30MHz. So we can assume that the noise voltage on the DC-Link capacitor will not be significantly attenuated by the LISN's 50Ω, and will be what is measured by a receiver or spectrum analyser.

Because the fundamental frequency and its harmonics are fixed (i.e. they are not using spread-spectrum or chaotic techniques to reduce emissions by "smearing" them widely over the frequency spectrum, see 2.8 in [42]), when tested for conducted emissions they will measure almost exactly the same when using the measuring receiver's Peak detector as they will using its Quasi-Peak detector.

This means we can compare our peak noise voltage calculations with the Quasi-Peak limits in the relevant emissions test standards, such as CISPR 22 (EN 55022) and CISPR 11 (EN 55011) to see how much filtering would be required for our 300W converter to pass their conducted emissions test.

Note that in the final column of Table 7.6-1, I am aiming for 6dB below the limit line. This is a good practice to help ensure that component tolerances and assembly variations don't result in non-compliant products being sold during serial manufacture.

Relationship	Frequency kHz	Peak Current Amps	Capacitor impedance Z Ω	Peak voltage noise across the capacitor µV (dBµV)	Filtering required to be 6dB below the "Class B" Quasi-Peak conducted emissions limit line
The switching frequency	51	3.0	0.03	90,000 (99)	n/a (no limits < 150 kHz)
2nd harmonic	102	1.5	0.03	45,000 (93)	n/a (no limits < 150 kHz)
3rd harmonic	153	1.0	0.03	30,000 (90)	30dB
4th harmonic	204	0.75	0.03	22,500 (87)	30dB
5th harmonic	255	0.60	0.04	24,000 (88)	33dB
10th harmonic	510	0.30	0.06	18,000 (85)	35dB
98th harmonic	4.99 MHz	0.03	0.6	18,000 (85)	35dB
588th harmonic	29.99 MHz	0.0051	3.0 (extrapolated)	15,300 (84)	30dB

Table 7.6-1 Analysis of noise spectrum of the ripple voltage

Table 7.6-1 is not precise, and I am particularly worried by the fact that the datasheet lists the 1500µF capacitor's Z as being a maximum of 130mΩ at 10kHz (see Figure 7.6-7) whereas the graph provided by the same datasheet (see Figure 7.6-8) shows it as typically being about 30mΩ at 10kHz.

The difference between 130mΩ and 30mΩ is about 12dB, so it seems that to be sure of complying with the EMC Directive in serial manufacture despite tolerances in capacitor ESR and ESL and still have a few dB "margin" for other parameter tolerances, we should increase the filtering figures in the right-hand column by 12dB.

We haven't even asked how the capacitor impedance varies with temperature, and all the figures we have used so far are based on its datasheet specifications at 20°C. Most likely, once we have investigated temperature coefficients, we will find that when our capacitors are running at between 40°C and 60°C, as they will most of the time in this example, we will need to add another few dBs of attenuation to our filtering.

We can say then, in round numbers, that we are aiming for 50dB of differential-mode attenuation from our filter, in order to meet Class B conducted emissions limits. For Class A, we can (rather crudely) assume that about 37dB of filter attenuation would be needed.

If, instead of choosing the 1500µF capacitor from the B43455 range we chose their 6800µF one, the impedance below 100kHz would reduce from about 0.03Ω to about 0.012Ω, i.e. by about 8dB, but this size increase would only help the 3rd and 4th harmonics of our 51kHz switcher comply with the conducted emissions limits.

If we could reduce the capacitor's impedance over the frequency range by, say, 20dB, we could reduce our filtering requirements by the same amount. Spending more on the DC-Link capacitor might well result in an overall cost saving, by reducing the cost of the power input filter (see [12]).

One good way of reducing capacitor impedance is to use many smaller capacitors in parallel. This is because quite a lot of the impedance (ESR, ESL) in a capacitor comes from the way the metallised foils that create the actual capacitance are connected to its terminals, plus the terminals themselves. Paralleling many capacitors also parallels the ESRs and ESLs of these interconnections, and so has a better effect overall.

For example, paralleling four 1500µF B43455 capacitors to give us 6,000µF should result in an impedance versus frequency curve that is one-quarter of the 1500µF curve in Figure 7.6-8 over the entire frequency range to 30MHz, whereas the single 6800µF capacitor in that same range only shows an approximately quarter impedance up to 200kHz.

So, using four 1500µF B43455 capacitors in parallel (using good PCB layout / planar bus structures / cabling discussed in the next issue of this series) should reduce our power-input filtering requirements by 12dB over the frequency range 150kHz to 30MHz, i.e. from 50dB to 38dB.

Ten such capacitors in parallel would win us 20dB, reducing the filtering specification for Class B conducted emissions to 30dB, and for Class A to 17dB.

For other viewpoints on DC-Link capacitor selection, see [95] and [96]. [95] focuses on low-power board-mounted switchers, but its principles can be applied at any power level. It sings the praises of ceramic and tantalum capacitors, and I have used dozens of large ceramic capacitors in parallel to provide low DC-Link impedances at 28Vdc for power converters used in aerospace applications.

[96] compares aluminium electrolytic capacitors with ECI's proprietary polypropylene film capacitors in high-power inverters, for example as used in wind turbines. These non-polarised types are available with values of up to 300µF with voltages up to 2.2kV, and Figure 7.6-9 shows some examples of them.

UL31, 32, 34 AND UL35 ELECTRICAL SPECIFICATIONS										
				ESL FOR UL31 AND UL32		ESL FOR UL34 AND UL35				IN CIRCUIT
PART NUMBER	VOLTAGE	VALUE	CASE "H"	"L"	Fres	"L"	Fres	I pk	dv/dt	E.S.R.
	VDC	uF	mm	nH	kHz	nH	kHz			mOHMS
UL3_Q157K	500	150	40	25	82.2	12	118.6	5769	38	0.47
UL3_Q207K	500	200	51	32	62.9	15	91.9	5809	29	0.57
UL3_Q277K	500	275	64	50	42.9	25	60.7	5672	21	0.77
UL3_Q307K	500	300	79	55	39.2	27	55.9	5022	17	1.70

Figure 7.6-9 Some information on the ECI 'Unilytic' range of film capacitors

One of the most important issues for high-power converters, such as those used in electricity generation (e.g. wind turbines) and for motor control in electric or hybrid vehicles, is heating, which (as mentioned before) is only caused in capacitors by the I^2R effects of the ripple current flowing in the ESR. This concern is very plain in [96], and it is also a major consideration in [97] and [98], which discusses another proprietary film capacitor construction intended for high-power converters – SBE's Power Ring Film Capacitor™, some examples of which are shown in Figure 7.6-10.

Figure 7.6-10 Some pictures of SBE's Power Ring film capacitors

[97] says that it shows that a 1000µF 600V Power Ring Film Capacitor with a "properly designed terminal structure" (such as the one on the right of Figure 7.6-10) can have an ESL of approximately 3nH.

[97] shows an example construction for a three-phase IGBT inverter, that I have copied bottom-left in Figure 7.6-10, and says that with careful design of a planar DC bus structure, this total package can achieve an ESL of approximately 20nH, with most of this forced on the structure by the non-optimal way the IGBT packages' terminals are arranged. The overall impedance of the DC bus is important for overshoots in the switching waveform delivered to the load, but with good design of the PCB/planar bus/cabling (which will be covered in the next issue in this series) its significance for conducted emissions on the power input can be reduced to nearly zero.

[97] gives no figures for ESR, and neither does [98], but [98] does mention that the heat generated within SBE's 700D348 1,000µF capacitor when it is carrying 200A rms is less than 6W (!), and from this we can estimate the ESR as 0.15mΩ. This is a very low ESR indeed.

So, using this model of 1,000µF capacitor in our example 300W converter above, plus good design techniques for the converter's PCB/planar bus/cabling (see the next issue) to achieve a DC-Link capacitor with an ESR of 0.15mΩ and an ESL of 3nH, we could reduce the emissions listed in Table 7.6-1 by about 46dB around 150kHz, reducing to about 15 dB at 30MHz.

This could reduce the filtering specification over the range 150kHz to 30MHz from 50dB overall for Class B, to a filter that attenuates progressively from 0dB at 150kHz to 35dB at 30MHz.

Class A would only need a power input filter that attenuated from 0dB at around 2MHz up to about 22dB at 30MHz.

Of course, in the above I have ignored the cost/benefit analyses that every engineer needs to do. It is almost certain that, for our above example 300W converter, the use of the proprietary power film capacitors such as those in figures 7.6-9 and 7.6-10 would be a costly overkill, and it might even be the case that using four 1500µF B43455 capacitors in parallel would be more costly than providing the 12dB of filtering they replaced – especially since some sort of power input filtering is certain to be required anyway.

However, it is important to remember that, in real-life, filters resonate (see 7.3.7 through 7.3.9 in [84]) and providing a reliable 50dB of attenuation from 150kHz to 30MHz in real life is often not as easy as distributors' catalogues of filters make it seem (as proven by my story about suppressing the emissions from a submarine winch motor drive, that I described in 7.3.8 in [84]).

Also, a 1500µF DC-Link capacitor might not provide sufficient hold-up time to cope with AC mains supply dips, dropouts and short interruptions.

Assuming that the permissible DC-Link voltage droop during an interruption is 50V (e.g. from 325Vdc to 275Vdc) a 1500µF capacitor would only supply 1A rms for 75 ms, whereas the generic immunity test standard IEC/EN 61000-6-1 (for domestic, commercial and light-industrial environments) applies 60% dips lasting for 5 mains cycles (i.e. 100ms). The heavy industrial version (IEC/EN 61000-6-2) adds tests with 60% dips for 50 cycles (1 second).

So it might turn out that spending more money on the DC-Link capacitor is cost-effective after all!

Some experimentation (with measurement of conducted emissions) or simulation is clearly generally required, to be sure of making the correct decisions early in the project (when design changes are effectively free), instead of struggling to pass EMC tests at the end of a project, when design changes are very costly indeed and many of the most desirable design changes are not even practicable (see the introduction to [91]).

7.6.3 Circuit simulation techniques

The only way to get switched simulation results that bear some resemblance to real-life circuit operation and filter attenuation and resonances, is to include 1st-order (at least!) effects like ESR and ESL in them.

This can be done by making these non-idealities part of the component specifications, so that each time we add a capacitor chosen from the component library we actually import a complex circuit like that shown in Figure 7.6-5. Alternatively we can actually draw the 1st-order approximated circuit for each component and enter the appropriate values for ESR and ESL.

Data on the first-order approximated characteristics should be available from the datasheets of reputable manufacturers, and we should never attempt to design any switching circuit without it.

Although I am discussing capacitors here, the same issues of including 1st-order approximated equivalent circuits for each component, applies to all of the passive and active components in the circuit, especially the switching devices, where they will help predict overshoots and ringing that may need snubbing or modifications to the circuit design or component choices.

In the mid-late 1980s I was managing a new product design project in a large (for the UK) company, and we purchased a simulator. Its 500MB hard-drive was the size of a small domestic oven, which shows how far technology has progressed in 30 years. The product used a 200W 25kHz sine-wave inverter, which proved quite difficult to get working properly. This inverter was the first thing we simulated with our new toy, but when we saw that it was predicting five switching edges at each switching transition, we couldn't see how this could possibly occur and assumed the simulator was giving silly results.

So we ignored the simulator and designed the inverter the good old-fashioned way, with a limited understanding (we didn't realise how limited, of course, until later on) and a lot of trial and error using prototype constructions. It took us 6 months of frustration to discover that the circuit really was switching five times (very quickly indeed!) for every once that we wanted it to.

Once we realised that this extra switching was a real problem, we very quickly learned what was causing it and the design then started to make good progress. But the true cost of the 6 months delay in that part of the project was about the same as the purchase price of what was generally considered to be a very expensive state-of-the-art simulator!

To prove the value of including at least the 1st-order approximated equivalent circuit components in a circuit simulation, try simulating 100µF in parallel with 1µF and measuring how their combined impedance varies with frequency – firstly as ideal (perfect) capacitances – and then with their ESRs and ESLs added in, which reveals the high-impedance parallel resonance. Dramatic, isn't it!

Figure 7.6-6 and this article ignore the effects of the conductors and their routing, whether they are PCB traces, planar bus structures or wires. These non-idealistic effects of what are basically conductors are never covered by circuit simulators, although some simulators can be linked to 3-D field solvers to extract the relevant parameters from the field solver and import them into the circuit simulator.

Updating a circuit simulator's schematic with the "construction parasitics" extracted from a 3D field solver makes it possible, after some iteration of the design, for a simulation to *virtually* guarantee all aspects of switcher operational performance *and* its conducted emissions *before the first prototype is made*.

This is essentially the way that manufacturers of personal computer motherboards, which have a sales life of less than 90 days, ensure their products are "right first time" for functionality and EMC.

The computer software necessary to perform such wonderful feats is not cheap (most people laugh loudly when told the price!) – but in fact it is easy to make a good business case that shows such software should pay back its purchase price on the next project, never mind the 3 years that the usual business plan considers acceptable.

7.6.4 Reducing emissions at frequencies below 150kHz

Many designers are encouraged by their managers to only do the minimum for EMC, because they think it is only a regulatory compliance issue – they don't realise that good EMC is an essential part of how their products are perceived by their customers, and can have a strong negative effect on the cost of sales, the financial success of a product, and (eventually) on the manufacturer's market share.

I have seen 50kW variable-speed motor drive conducted emissions at around 20kHz ruin the control of most of the other equipment in a factory. The 5th harmonic of the 4kHz-switching motor drive was amplified by a natural 'parallel' resonance of the factory's mains distribution network around 20kHz, creating about 20 volts peak-to-peak all over the site.

Fitting a better mains filter (interestingly, the one recommended by the drive manufacturer (Siemens) rather than the custom-designed one that had the lowest cost whilst still complying with the emissions standards above 150kHz) solved the problem, but not before the very costly new machining centre containing the drive had been unable to be used for nearly 6 months, at a great loss to production and great financial loss to the user.

And I have seen 1kHz - 20kHz (fundamental plus harmonics) emissions from 700kW AC motor drive cause large offshore drilling platform cranes to go out of control, creating serious safety hazards and costing the manufacturer US$54 million overall. They thought they had been clever in saving costs on EMC, but – even with a discounted cash flow analysis – the $54 million this single project cost them due to EMI far exceeded what they had "saved on EMC" over the previous decades, never mind the loss of market reputation.

So when designing power converters (at least those >1kW), it is best to suppress *all* emissions, however low their frequency, because:

a) we don't want to upset customers...
b) we don't want to cause safety hazards...
c) complying with the European EMC Directive requires not causing unacceptable interference *at any frequency*...

This last point is worth expanding upon. Article 10 ("Safeguards") in the EMC Directive 2004/108/EC makes it perfectly plain that a product can comply with all the emissions tests and so achieve a "presumption of conformity" and affix the CE mark, but still face legal action if it actually causes interference in real-life.

However, the cost of any enforcement action usually pales in comparison to the commercial costs of having supplied products that cause EMI problems for their users, especially if there are safety implications, like the offshore platform crane example above.

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