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EMC Yearbook 2012

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EMC UK 2012

EMCUK 2012
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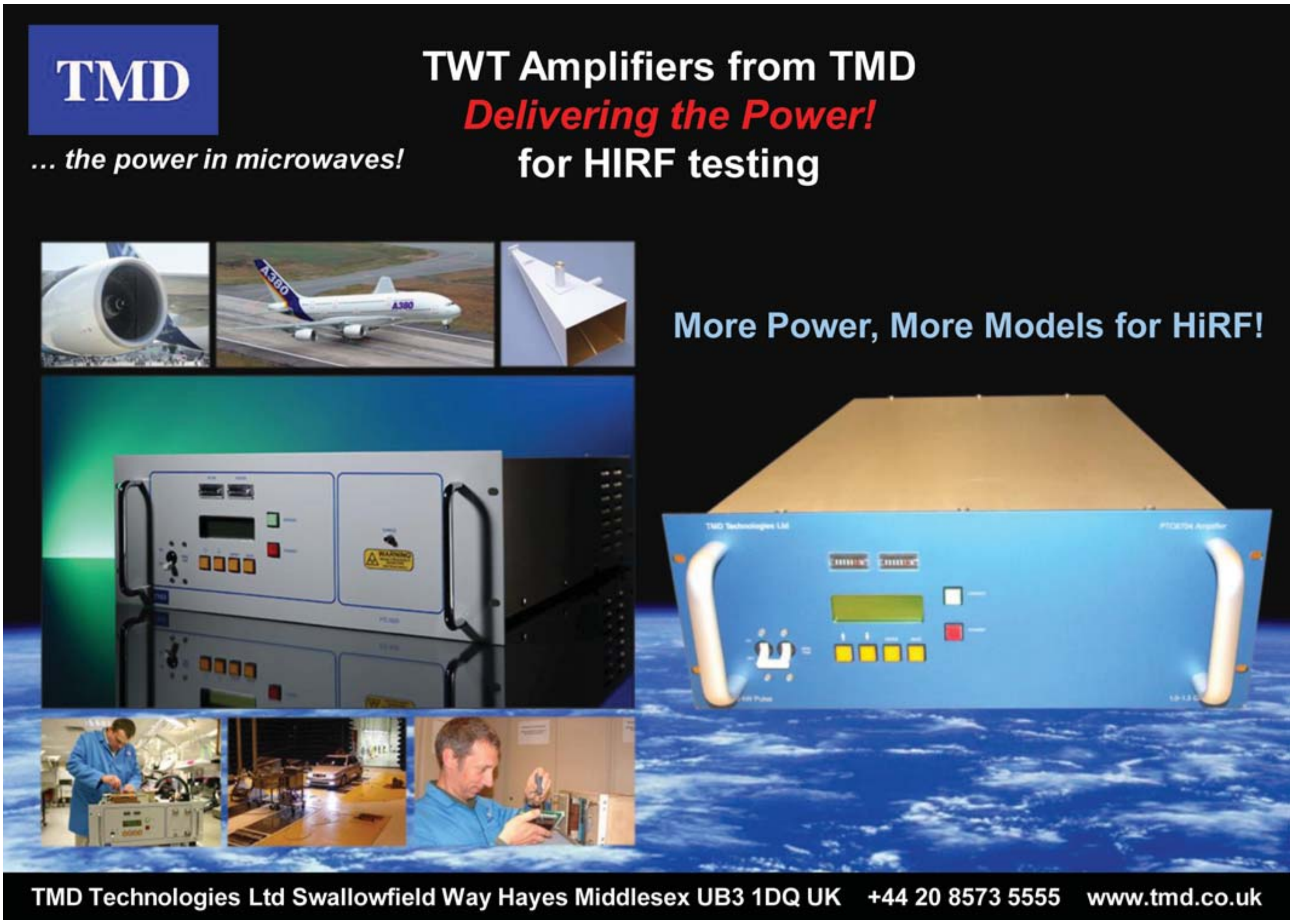

What's In This Issue

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News

Teseq Holding AG Acquires MILMEGA to Expand RF Power Amplifier Capabilities

Teseq Holding AG , a leading developer and provider of instrumentation and systems for EMC emission and immunity testing, has acquired UK-based MILMEGA, Ltd., a leading specialist in the design and manufacture of solid state, high-power microwave and RF amplifiers. The acquisition strengthens Teseq capabilities in commercial, industrial, automotive, military and communications applications, further positioning the company as a global leader in immunity testing.

Johannes Schmid, President of Teseq, said, “When we began Teseq a mere five years ago, after a management buyout from leading developer and provider of instrumentation and test systems for EMC emission and immunity, Schaffner, our vision was to provide the best in testing solutions. Our acquisition of MILMEGA is a testament to that forward thinking strategy and builds upon the half-century of EMC experience with which we were founded.”

Schmid continued, “RF amplifier power, linearity and harmonic performance is critical to achieving accurate immunity testing results. Adding MILMEGA’s high quality amplifiers to Teseq’s extensive range of EMC testing products extends our product offering

(Left to Right) Pat Moore (Managing Director Milmega), Dr Fritz Gantert (Director Teseq Holding), Jason Gould (South East Growth Fund), Peter Balsiger (Aventic Partners), Graeme Goodall (Financial Director Milmega), Johannes Schmid (Chairman & President Teseq Group)

to include both EMC and non-EMC applications, strengthening our position as the supplier of choice for innovative, high quality test instrumentation to an increasingly wide range of customers.”

Established in 1987, MILMEGA expertly designs and manufactures high power amplifiers for commercial and government applications. The company’s core strength lies in the development of broadband RF power amplifiers operating in a frequency range from 80 MHz to 8 GHz with power levels to 1 kW.

Pat Moore, Managing Director of MILMEGA Ltd., said, “Becoming part of the Teseq group allows us to offer the very best in global sales and support as well as EMC system expertise in software design and installation services, positioning us as a leader in the field. Our customers now have access to an extensive RF product range as well as engineering expertise that will facilitate the development of innovative system solutions to meet their needs today and in the future. Combining our individual strengths ensures our market focused approach to new developments and enables us to more accurately define new amplifier requirements for years to come.”

The MILMEGA brand and all aspects of the company’s product range, including its industry unique five year warranty, will be retained. The MILMEGA factory will become a competence centre for RF amplifiers within the Teseq organization, which is currently comprised of eight subsidiaries and seven accredited labs worldwide.

Sequans Communications certifies the R&S CMW500 wideband radio communication tester for the alignment of its LTE chipsets

Sequans Communications, a leading 4G chip maker, now uses Rohde & Schwarz test equipment to align its new generation LTE chipsets. The jointly-developed test solution is built around the multi-standard, market-leading R&S CMW500 radio communication tester.

Michael Altmann, Head of Mobile Radio Tester Product Management at Rohde & Schwarz, comments: “On the basis of the R&S CMW500, Sequans and Rohde & Schwarz have created a test solution for LTE chipsets that will keep pace with future developments. This flexible multistandard platform also benefits user equipment manufacturers who can use it to test the chipsets or to develop and produce their own products.”

The R&S CMW500 wideband radio communication tester is the ideal solution for all phases in the development and production of chipsets and wireless devices as well as for lab tests at network operator locations. In a single box, it supports all common wireless communications standards and is prepared to handle future standards. The R&S CMW500 is also a core component of the R&S TS8980 RF conformance test system, which Sequans uses for development and certification.

Front Cover

Hero image, EMC Yearbook, page 21
Circle top, Rohde & Schwarz, page 23
Circle middle, EMC Partner, page 22
Circle bottom, Teseq, page 23

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iNARTE Certification Exams to be offered at University of Oxford

Each year the University of Oxford, Department for Continuing Education offers Professional Development opportunities in a variety of disciplines. In June, 2012, the University will be offering courses in **High-speed digital engineering and EMC.** Led by Dr Howard Johnson, author of "High-Speed Digital Design - A Handbook of Black Magic", this programme offers a number of short courses delivered by some of the world's leading digital design experts:

- **Electronic Product Design and Retrofit for EMC (19-20 June 2012)**
- **High Frequency Measurements (probes and equipment used in Signal Integrity and EMC work) (19-20 June 2012)**
- **EMC and ESD Lab Techniques for Designers (troubleshooting to proactively avoid field or compliance problems) (21 June 2012)**
- **Advanced Troubleshooting Techniques for Circuits and Systems (22 June 2012)**
- **High-Speed Digital Design (26-27 June 2012)**
- **Printed Circuit Board Design for Real-World EMI Control (26-27 June 2012)**
- **High-Speed Noise and Grounding (28-29 June 2012)**
- **Advanced EMC: Fullwave Modelling for EMC and Signal Integrity (28-29 June 2012)**
- **Power Distribution Design (2-3 July 2012)**

At the conclusion of the two week period, on Saturday, June 30th, **iNARTE** will offer examinations leading to Certification in **EMC Design Engineering**.

iNARTE is an independent, international credentialing organization, offering certification to engineers and technicians in a number of fields related to telecommunications and electromagnetics. This, the latest **iNARTE** programme, has been developed in close cooperation with many of the world's leading electronics corporations, and is indicative of the knowledge they expect of qualified electronic systems design engineers. **iNARTE** certification requires four factor to be considered:

- **Examination, (pass the two part iNARTE examination)**
- **Education, (post secondary qualifications)**
- **Experience, (years working in the field)**
- **Endorsement, (references from management and peers)**

The **iNARTE** examinations in **EMC Design Engineering** will be held at the Department for Continuing Education at the University of Oxford. There will be two exam papers, each of three (3) hours duration, and covering the following subject matter:

- **EMC Countermeasures & Components**
- **EMC Design & Design Review**
- **EMC Simulation & Rule Check**
- **Signal Integrity & Power Integrity**
- **Electronics Circuits & Power Electronics**
- **Electromagnetics & Shielding**
- **Electrical Circuit Theory**
- **Measurement & Analysis**
- **Specification & Standards**
- **Mathematics**
- **EMC Basic Knowledge**
- **Terminology**

Two levels of question papers will be available; the **EMC Design Engineer** questions are suitable for recent graduates or engineers with less than two years experience in the discipline, but having a sound knowledge of EMC principles and their application in electronic systems design, the **Senior EMC Design Engineer** questions are suitable for persons having four or more years of related work experience, who understand the cause and effect of EMC phenomena and are able to direct the work of junior engineers.

This **iNARTE** programme has been developed in response to requirements for validation of engineering credentials at many global electronics industries and in cooperation with leading EMC experts:

- **Dr. Bruce Archambeault** - Committee chair, IBM Distinguished Engineer, IEEE Fellow, EMC CoC, (also one of the course presenters at Oxford)
- **Dr. Richard DuBroff** - Professor at Missouri University of Science & Technology, Head of MUST EMC Research Laboratory
- **Dr. Charles Bunting** - Associate Professor Oklahoma State University, Electrical & Computer Engineering Dept., IEEE EMC Society Director at large
- **Kimball Williams** - Technical Fellow at DENSO Corporation, past president IEEE EMC Society, previously Principle EMC Engineer at Underwriters Labs. and Eaton Corporation
- **Bob Scully** - Lead E3 Engineer at NASA Johnson Space Center, VP of Technical Services at IEEE EMC Society
- **Sam Connor** - Senior Technical Staff at IBM, previously Systems Engineer at Lockheed Martin
- **Colin Brench** - EMC Engineer at Amphenol, previously Staff Engineer at Southwest Research Institute, Master Engineer at HP and Senior Technical Staff at Compaq, IEEE EMC Society Director at large
- **Dr. Yukihiro Fukumoto** - Committee Chair, Corporate R&D division, Panasonic Corporation
- **Dr. Ryuji Koga** - IEEE EMC Society Director at large, Professor Emeritus at Okayama University
- **Dr. Kennichi Hatakeyama** - Dean of Graduate School of Engineering University of Hyogo
- **Dr. Takashi Harada** - Director of Research, NEC Corporation.
- **Dr. Tsuyoshi Funaki** - Professor Graduate School of Engineering, Osaka University
- **Takashi Suga** - Research Laboratory Leader, Hitachi Ltd.
- **Akihisa Sakurai** - IBM Distinguished Engineer, IBM Japan
- **Kaoru Uno** - General Manager, Funai Electric Company Ltd., EMC Centre

Candidates can register for the June 30th examinations without having attended any of the University courses. However, the course materials will include much relevant information. Examination registration will be conducted separately from course registration, and the appropriate links are:

Information about this **iNARTE** Certification Programme - http://www.narte.org/h/emcdesignengineer.asp

iNARTE registration page - **http://www.narte.org/h/oxfordexamregform.asp**

University of Oxford course details - **http://www.conted.ox.ac.uk/courses/professional/staticdetails.php?course=216**

EMC-Safety Compliance & Design Courses in Australia

Melbourne: April 30th to May 9th
Sydney: May 10th to May 18th

Keith Armstrong will be teaching courses on cost-effective EMC, and Safety, compliance and design in Australia from April 30 to May 18, 2012.

Details at: http://www.emctech.com.au/Seminar2012.html

Another First for Hursley EMC

In January 2012, Hursley EMC Services became the first laboratory of its kind to be assessed by the United Kingdom Accreditation Service (UKAS) under the new criteria included in EN ISO/IEC 17020. As an inspection body accredited by UKAS, the Hampshire-based company will be able to use the UKAS Inspection Body logo on its certificates in addition to the Testing version for which it is already qualified.

Under the previous standard, URN 07/922, it had been possible, under certain circumstances, for manufacturers to achieve NB status, thereby being able to assess and certify their own products. In addition to technical competence, the new standard places increased emphasis on impartiality and independence, making this anomaly very difficult to achieve.

Rob St John James, Managing Director of Hursley EMC Services Ltd shows off the UKAS Inspection mark for which his company has recently qualified.

Hursley EMCS is no stranger to UKAS inspections, having been a Notified Body (NB) for Electromagnetic Compliance since its formation in 1997 by a management buyout from IBM. The company has always placed great emphasis on maintaining its accreditations in order to provide its customers with access to as many markets as possible. It is accredited for the testing and certification of both Military and Commercial products throughout the world.
www.hursleyemc.co.uk

Name Change

MS Testing (formerly Mariner Systems Test Laboratory) is a leading independent UKAS accredited test facility that has a earned a reputation over 10 years for providing industry leading turnaround times, flexibility, knowledge and quality of service to our clients worldwide.

Based in the North East of England, MS Testing was formed in 2001 under the banner of Mariner Systems, a world leader in the design, manufacture and supply of Marine Type Approved computer systems to the commercial maritime market. Initially we were founded for the purpose of testing hardware for our parent company. However we found that the services we provided were very attractive to our external customers. Steadily our core business has moved from testing computer hardware for our parent company, to providing a comprehensive range of Electromagnetic Compatibility (EMC) testing, Marine Type Approval testing and Environmental testing for our external clients who span all Industries from all around the globe. Resulting in relocation to larger premises.

After a period of significant investment, the EMC and Environmental test capabilities were redeveloped and expanded. This culminated in the installation of a state-of-the-art 3m automated semi anechoic chamber which provides our clients with incredible levels of efficiency and repeatability, further reducing lead times in the process. Our UKAS accreditation now encompasses all major commercial industries.

With demand ever growing and an increasing UKAS schedule, it has now become necessary to rebrand the laboratory as the Mariner Systems branding no longer reflected the diverse range of testing on offer at the laboratory.

The MS Testing brand officially launched in February 2012. This more accurately reflected the laboratory's service proposition whilst remaining true to its roots by maintaining the symbolism of 'MS' for Mariner Systems which continues to be a world leader in its field.

The revised logo highlights the three distinct areas of specialist testing undertaken today - Marine Type Approval testing, EMC testing and Environmental testing.

You can read more about MS Testing, together with information on our facilities and capabilities by visiting our website **www.mstesting.co.uk**

Rohde & Schwarz and HAMEG Instruments consolidate cooperation

Almost anywhere in the world, test and measurement products from HAMEG Instruments are now directly available from Rohde & Schwarz. This is why these products will receive a new logo that contains the names of both companies – a move that is intended to further increase the brand awareness and growth of HAMEG Instruments in both the domestic and international marketplace.

HAMEG Instruments has been a Rohde & Schwarz subsidiary since 2005, complementing the parent company's T&M portfolio in the lower price segment. After several years of separate branding, the new dual logo containing both company names is an important step toward integrating HAMEG products more tightly into the Rohde & Schwarz portfolio.

Holger Asmussen, CEO of HAMEG Instruments, is convinced of the advantages the dual logo offers: "In recent years, HAMEG has shown much stronger growth than the market. This trend has been driven in particular by the new oscilloscopes and lab power supplies. Our name is well established, mainly in Germany and Europe. Visually combining Rohde & Schwarz and HAMEG will increase awareness of our brand also in other regions and create even greater potential for growth."

Since the end of last year, HAMEG products have been an integral part of the portfolio offered by the Rohde & Schwarz sales organization. The new logo underscores this fact. Customers can now order the entire T&M portfolio, from the lower price segment to high-end products, from their personal Rohde & Schwarz contact. Rohde & Schwarz is one of few companies in the market to offer its customers this opportunity.

Within the next three months, the dual logo for HAMEG products will be introduced in nearly all regions.

News and Information

AR Installs Radiated Immunity Test System At Kidde Safety

AR RF/Microwave Instrumentation is known not only as a leader in RF and microwave amplifiers, but also for its innovative, all-in-one test systems. One of AR's Radiated Immunity Test Systems (model AS04210M2) was recently installed at Kidde Safety, Colorado Springs, Colorado. The unit, which tests to IEC61000-4-3 standards, will be used to test Kidde's fire and safety products.

The AS04210M2 system is designed to produce fields of up to 10V/m with 80%AM (18V/m CW) at a 3m test distance from 80MHz-4.2GHz for radiated immunity testing in a compliant EMC chamber. The system is supplied without the signal generator and field monitoring equipment (other AR systems do include all equipment); it does include larger than required amplifiers to add margin to the test capability. This system also includes all necessary directional couplers, system controller, power meter, power head, antennas, and tripod.

The AS04210M2 Radiated Immunity Test System is just one of a wide variety of all-in-one test systems available from AR.

Link Microtek appoints Dee Mitchell as service and calibration administrator

Link Microtek, the leading UK supplier of RF radiation safety equipment, has appointed Dee Mitchell to the position of sales administrator for service and calibration.

Having led an interesting and varied working life so far, Dee brings a diverse range of experience to her new role: after serving as a radio operator in the Royal Navy for six years, she then spent two years as a prison officer, followed by several years in retail management and sales.

Link Microtek's service and calibration activities are mainly related to the family of RF radiation safety instruments manufactured by Narda Safety Test Solutions. Products such as the Nardalert line of personal RF radiation monitors are widely used in the telecommunications and broadcast sectors by personnel working in the vicinity of high-power antennas.

Dee is now responsible for co-ordinating the calibration, service and repair of this large installed base of equipment - liaising with customers from around the world and dealing with issues such as Customs clearance to ensure the quickest possible turnaround. **www.linkmicrotek.com.**

Joseph Diesso appointed Vice President Marketing at AR RF/Microwave Instrumentation

AR RF/Microwave Instrumentation is pleased to announce the appointment of Joseph J. Diesso to the position of Vice President Marketing. Jim Maginn, President of AR/RF Microwave Instrumentation states that with his new promotion, Mr. Diesso will be putting additional focus on new product development and forming strategic business alliances.

Mr. Diesso joined AR in April 2010 as Marketing Manager and has over 30 years of experience in the marketing & sales of RF/Microwave devices, components and assemblies. He held the positions of Vice President of Business Development and Vice President of Programs during his employment with Stellex Electronics before joining AR.

Prior to his work with Stellex, Mr. Diesso was a founding partner of Phoenix Microwave Corp. where he served as Vice President of Sales & Marketing. In addition, he has held positions in Applications and Systems Engineering for prestigious microwave companies. Mr. Diesso holds a BSEE and an MBA degree in marketing and has taken numerous advanced courses in both marketing and sales.

IEEE UKRI EMC Chapter – Event Calendar for 2012

Thursday 28st March 2012
De Montfort University, Leicester LE2 7DR.
Afternoon meeting 13:20 – 16:45

Wednesday July 11th 2012.
Special event at a site of interest.
Shuttleworth Collection, Nr. Biggleswade, Beds SG18 9EP. www.shuttleworth.org
Meeting 10:00 – 16:30.

Tuesday 9th & Wednesday 10th October 2012
EMCUK2012 demonstration sessions at Newbury.

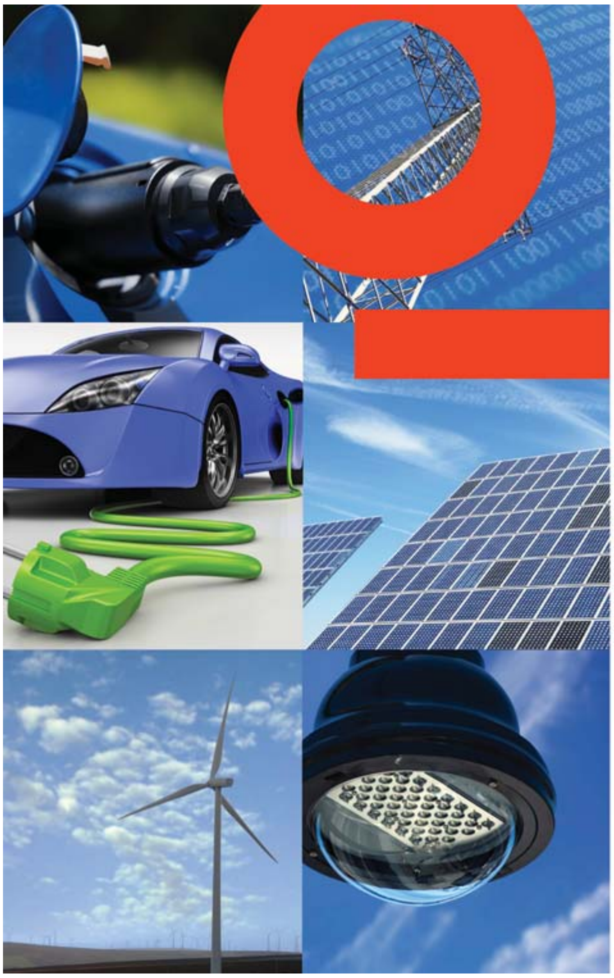
Wednesday December 12th 2012
Special Section Hosted EMC Event.
Morning Chapter AGM 10:30 -12:00, plus afternoon Section hosted enhanced EMC Chapter technical event 13:00 - 17:00.
Open to all members of UKRI Section and industry, at academic site in Central London (TBC).

KEC seeks partners to field trial new EMC interconnect design and test facility

For the past two years KEC has been working with the University of Reading on a Knowledge Transfer Partnership (KTP) to create an EMC interconnect design and test system based on computer simulated techniques. The initial design stage of the development programme has now been completed and the final report on the project from the Technology Strategy Board has gained an 'excellent' rating.

When complete the project will enable KEC to offer a design and test service for EMC assemblies and cable harnesses by simulating the EMC characteristics. This means that equipment required to meet EMC specifications can be designed 'right-first-time' thus saving on expensive redesign and re-test prior to certification.

The next stage of the project is to carry out field trials on the system and KEC is working with partners from a range of industries to finalise the product. KEC managing director, Cheryl Watson, explained: "We are already working with a major company in the aerospace industry and several others have expressed interest in the project. We want to work with companies from as many areas of industry as possible with a broad cross section of applications and EMC problems. It is an ideal opportunity for companies that wish to prove an EMC assembly as we are confident that the system will make a big improvement in the time and cost of designing EMC interconnect solutions."
www.kec.co.uk



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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

DM Systems & Test 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

Kemtron Ltd

Laplace Instruments Ltd

MBDA UK Ltd

MDL Technologies Ltd

MILMEGA Ltd

MIRA

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

If you are interested in taking a stand please contact Lynne Rowland on +44 (0)1208 851530 or email: lynne@theemcjournal.co.uk

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Excellent EMC Books

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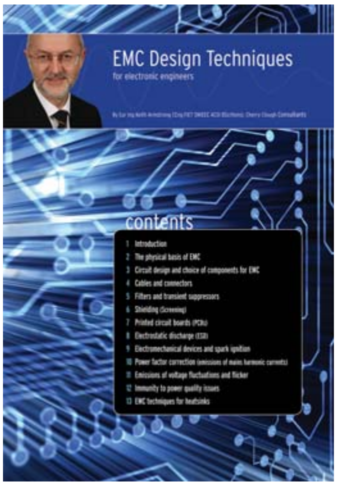
Cost £55 plus p&p. ISBN 978-9555118-4-4



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);
Electromechanical devices and spark ignition;
Power factor correction (emissions of mains harmonic currents);
Emissions of voltage fluctuations and flicker;
Immunity to power quality issues;
EMC techniques for heatsinks.

The Physical Basis of EMC
Author: Keith Armstrong C.Eng FIET SMIEEE ACGI BSc (Hons)

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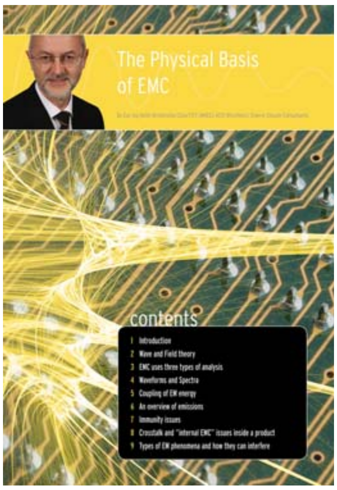


Contents:
Introduction;
Wave and Field theory;
EMC uses three types of analysis;
Waveforms and Spectra;
Coupling of EM energy;
An overview of emissions;
Immunity issues;
Crosstalk and "internal EMC" issues inside a product;
Types of EM phenomena and how they can interfere.

Find out more on our web site:
www.emcacademy.org/books.asp

EMC for Printed Circuit Boards
Author: Keith Armstrong C.Eng FIET SMIEEE ACGI BSc (Hons)

Cost £47.00 plus p&p. ISBN 978-0-9555118-5-1

More than just a book. It is a true learning aid. Graphics in full colour. Designed to lay flat for easy learning. Written in a clear concise no nonsense style. Destined to become the Standard for EMC PCB Design. 168 A4 pages.

This book is about good-practice EMC design techniques for printed circuit board (PCB) design and layout. It is intended for the designers of any electronic circuits that are to be constructed on PCBs, and of course for the PCB designers themselves. All applications areas are covered, from household appliances, commercial and industrial equipment, through automotive to aerospace and military.

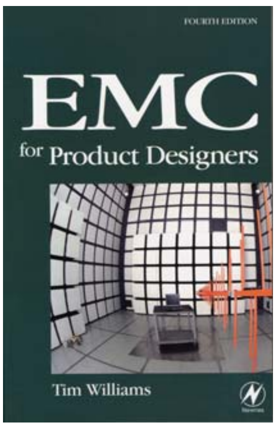
This is a book for electronic and PCB engineers who need to employ good EMC and SI techniques to save time and money when designing with the latest technologies, to make reliable and compliant products.

The book uses very little maths and does not go into great detail about *why* these techniques work. But they are well-proven in practice by successful designers world-wide, and the reasons they work are understood by academics, so they can be used with confidence. Numerous references lead to detailed explanations and mathematical foundations.

It is difficult for textbooks to keep up to date with fast-changing PCB technology and EMC techniques, which is why most of the references are recent conference papers and articles available via the Internet.

EMC for Product Designers
Fourth Edition
Author: Tim Williams

Cost £44.99 plus p&p. ISBN 978-0-75-068170-4



This book is almost certainly regarded as the bible on EMC Design across all International borders.

Brilliantly written and extremely informative, it is divided into three parts, Legislation & Standards, Testing and Design plus a number of interesting and useful Appendices.

Every EMC product designer should buy this latest edition.

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!

686 Gym machines that throw runners off due to EMI

In a message dated 15/02/2012 10:53:16 GMT Standard Time, john-davies @emcgoggles.com writes:

I dealt with a real EMC problem where some running machines in gyms would suddenly stop unexpectedly, dangerously throwing their runners off the machines. After a bit of work I discovered that heavy and slow runners were causing fluctuations on the mains supply. This in turn would cause a glitch in the software of other machines. The software was modified to be more robust and the problem was solved.

With a mains dips and interruptions generator, I was able to replicate the fluctuations produced by a heavy, slow runner, and I caused the running belt to stop. I was also able to observe that the software fix eliminated this problem.

If I recall correctly, the software fix was related to a "watch-dog" function.

In a message dated 16/02/2012 12:32:41 GMT Standard Time, richard.marshall99 @btinternet.com writes:

More specifically, John's quoted problem is almost certainly associated with the determination of the zero-crossing point of the mains voltage waveform . The timing of this is being used for timing one (victim) machine's power control and is being disturbed by a strange current waveform being drawn by the other (culprit) machine.

The problem could have been fixed in either the analogue or digital domains. The analogue solution would have involved discrete components – possibly quite large ones. The digital solution would have involved a software phase-locked loop.

Over the years I have had two clients for whom this specific problem had very serious implications!

I do not see any conflict between my views from outside and John's view from inside. In the EMC world we often have to express opinions or take actions from inadequate data.

(Taken from an email thread with the permission of John Davies of EMC Goggles Ltd, www.emcgoggles.com, and Richard Marshall of Richard Marshall Ltd, www.design-emc.co.uk, both highly experienced and independent EMC expert consultants.)

687 Urban Wi-Fi interference

British telecom regulator Ofcom has commissioned a report that concludes that Wi-Fi performance in central London can be up to four times slower than that found in less densely populated areas.

Although users of Wi-Fi have blamed nearby networks for much of the interference in the 2.4-GHz Wi-Fi band, the authors of the report pin the primary sources of interference on cautious parents using analog baby monitors, tired citizens watching retransmitted TV in their bedrooms, and microwave ovens.

The report notes that in central London, there are too many networks with resends, beacons, and housekeeping filling 90 percent of the data frames sent over Wi-Fi, thus leaving only 10 percent for users' data.

Another source of Wi-Fi trouble is caused by London's "Free Public Wi-Fi" points that are sending out beacon frames ten times more frequently than they should (every 0.01204 seconds) resulting in a significant amount of traffic on the Wi-Fi band.

Further complicating the situation is the fact that the makers of inexpensive unlicensed devices such as analog baby monitors or remote switches have no real incentive to develop more expensive digital models that cause less interference.

The entire 93-page report can be viewed online at: http://stakeholders.ofcom.org.uk/market-data-research/technology-research/research/exempt/wifi/. "Estimating the utilisation of key license-exempt bands spectrum bands", Final report, Issue 3, April 2009, for Ofcom by Mass Consultants Ltd, Cambridge, UK, systems@mass.co.uk, MC/SC0710/REP003/3, 149 pages.

(From: http://www.interference technology.com news/top-stories/single-news-article/article/urban-wifi-interference.html)

688 Vacuum cleaner upsets burglar alarm system

I have just disposed of an Orek upright vacuum cleaner which we were given as every time I used it set off the internal alarm on our burglar alarm system which could only be turned off by a full power down reset by the engineer. Normal keyboard reset codes had no effect.

The burglar alarm system is pre EMC Directive being around 15 years old. It was cheaper to buy a new vacuum cleaner than replace the alarm system. I certainly wasn't going to pull up the floorboards to harden the system.

(Kindly sent in on 18 Oct 2007 by Nigel Carter, now retired from QinietiQ.)

689 Nintendo DS Health & Safety Precautions

WARNING - Radio Frequency Interference

The Nintendo DS can emit radio waves that can affect the operation of nearby electronics, including cardiac pacemakers.

- Do not operate the Nintendo DS within 9 inches of a pacemaker while using the wireless feature.
- If you have a pacemaker or other implanted medical device, do not use the wireless feature of the Nintendo DS without first consulting your physician or the manufacturer of your medical device.
- Observe and follow all regulations and rules regarding use of wireless devices in locations such as hospitals, airports, and on board aircraft. Operation in those locations may interfere with or cause malfunctions of equipment, with resulting injuries to persons or damage to property.

(From: http://www.nintendo.com/consumer/manuals/precautions_ds_english.jsp)

690 Ferry electronics out of control

Perhaps the most serious design failing was the lack of a backup power supply for the microprocessor. Whenever the CPU shut down temporarily during a power transient, it would start up again with its memory in a random state – and the ferry would be out of control. If the captain spotted the failure, he could switch to manual control, but no alarm existed for the condition.

Starting up a motor, or even putting a quarter in a vending machine on board with a faulty ground, was enough to trigger the failure, which in some instances disengaged the propellers, and in others, randomly changed the propeller blade angles. Moving the blades to certain positions could cause the ferry to reverse direction, but usually it would simply overload the engine and shut it down.

Intermixing of system grounds contributed to the problem. In one boat, a chafed wire grounded a circuit and made it possible to change propeller pitch by starting an engine or to start an engine by changing propeller pitch. Also, although drawings called for it, no shielding for electrical noise was installed on most cables.

Poor software and hardware documentation and inexplicable differences between ferries frustrated troubleshooting, Davis said.

Installing a dc power supply for the control system and software changes eliminated some of the more embarrassing failures, but problems persisted. Even though a pneumatic control system experimentally installed on a Issaquah-class boat in 1984 reacted more slowly than the digital system the digital system and required more periodic maintenance (replacing seals, for example), a 1986 Lockheed Shipbuilding Co. study recommended switching to pneumatics to improve reliability.

The agency chose a hybrid system that operates electrically from control handles to control cabinet to improve reaction time, but operates pneumatically from cabinet to propellers and engine governors, which would last longer because of gentler treatment.

After a trial last summer on one ferry, assistant deputy director Terry McCarthy said the agency was “ecstatic” about the success of the pneumatic system supplied by Mathers Contol Inc., Seattle, and has recently retrofitted another Issaquah ferry with the same system.

(Taken from IEEE Spectrum magazine, Feb 1990.)

691 Interference onboard the Crystal Ocean

The Crystal Ocean is an oil production storage and off take vessel that is moored (without anchors) over an oil well on the sea floor, using satellite positioning along with bow, stern and centre thrusters. Crude oil is pumped from the oil well and natural gas is separated and forced back into the well. The crude oil is then pumped to the shuttle tanker Basker Spirit, moored 1.5 km away.

Located on board the Crystal Ocean are 4 large diesel driven generators which power all of the vessels electrical systems including thrusters, pumps and hydraulics. The reliable operation of these generators is critical for positioning and operation of this vessel. UHF radios are used on board to enable the crew to communicate with each other. It had been observed by crew members that when these radios were used near the AC power generators, the generators would intermittently shut down without warning. Compliance Engineering Pty Ltd was called in to investigate and resolve this interference issue.

To enable investigations to be performed without impeding the vessels operation, one of the AC power generators was removed from service. A UHF radio was operated around this generator instigating a shut down. The UHF radio appeared to have the greatest effect when operated in the vicinity of electrical cabling attached to the generator. The amplitude and direction of the UHF radios signal was not configurable, and further investigations required a repeatable method of simulating and applying the interference to individual cables.

An RF Signal Generator (with variable output level and modulation capabilities), RF Power Amplifier and RF Injection Clamp were configured to form a controlled interference generating system (500 MHz with 1 kHz modulation). The interfering signal was applied to various cables, each of which caused the generator to cease operation. However, it made little difference as to which cable the interfering signal was applied to, as all cables appeared to efficiently cross couple the RF signal. During application of the simulated interference it was observed that the generators speed gauge behaved erratically, displaying a speed inconsistent with the actual rotational speed of the generator.

The generator was immobilised and the injection clamp positioned around the speed pickup sensor cable, above the metal housing of the flywheel. An oscilloscope was used to examine the control signals within the generator’s junction box (with and without the interfering signal applied) to identify signals supplied to the PLC and Load Sharing/Speed Controller, located in the control room above. With the generator immobilised and with the interfering signal applied, a 5V signal was present on the output lines from the speed pickup sensors. It was evident that the interference was inducing a false speed signal, which was processed by the PLC and Load Sharing/Speed Controller.

The interference mechanism was identified:

The UHF radios carrier frequency (500 MHz) is coupled onto unshielded cabling (directly or indirectly via cross coupling) attached to the speed pickup sensors. The speed sensors internal amplifier circuit demodulates the carrier frequency rendering the modulation signal (1 kHz in this case). The modulation signal is then amplified and fed back to the PLC and Load Sharing/Speed Controllers, which interpret the signal to be outside normal operating conditions, forcing the generator to shut down.

Cables interconnecting the vessels generators and PLC and Load Sharing/Speed Controllers are all unshielded. Transients produced by high current switching on power cables may be induced onto signal lines, causing interference issues that have not been investigated.

Recommendations to remedy the interference were presented:

Initially the unshielded cables interconnecting between the speed pickup sensors and the PLC and Load Sharing/Speed Controllers should be replaced with twisted pair shielded cables. This is expected to provide a substantial improvement to the generators immunity to RF interference. At a later stage all unshielded cabling interconnecting the generators and their controllers should be replaced with twisted pair shielded cable, with the shield terminated at both ends. The speed sensors used have plastic female push connectors, which do not allow for the cables shield to be terminated. The speed sensors should be upgraded to the FA2J version, which are fitted with a metal canon connector (14-5PN VG95234), providing a 360 degree termination for the cable shield.

It is commonly recognised that circuits which are the most prone to RF interference are typically those with sensitive analog inputs (as opposed to digital circuits), as has been observed in this example.
(Taken from: EMC Society of Australia, Newsletter, Issue 39, Dec 2007 and http://www.compeng.com.au/document_library/interference_onboard_crystal_ocean.aspx.)

692 Robot car loses GPS due to EMI from video screen
Not all went according to plan. Tartan Racing's winning vehicle refused to start, after its GPS receivers lost the signal from the satellites, and hence their ability to produce a reliable position estimate.
The problem was later traced to electromagnetic interference from a large video screen nearby.
(Taken from: Engineering & Technology magazine, http://eandt.theiet.org, December 2007, page 11, describing a race for driverless vehicles.)

693 Cement mixer dumps load due to CB interference
A cement truck complete with spinning mixer stops at an intersection. A semi, equipped with a CB radio pulls alongside and a convertible stops behind the cement truck.

While waiting for the light to change, the semi starts talking on his CB. The CB's signal activates the cement mixer, which dumps its load of wet cement into the convertible.
(Kindly sent in by Dr Antony Anderson, Dec 2007 – source: Jeff Bennett – Business writer, Detroit Free Press, 5 Dec 2002)

694 Airport navigation disrupted by domestic coffee machine
In the 1970s new domestic electronic Mr Coffee machines caused interference that disrupted the navigation systems at Baltimore and Washington DC airports and forced both airports to shut down for two hours every morning.
(Kindly sent in by Dr Antony Anderson, Dec 2007 – source: Jeff Bennett – Business writer, Detroit Free Press, 5 Dec 2002.

695 Black Hawk helicopter knocked out of the sky by radio waves
The Army's most advanced helicopter can be knocked out of the sky by routine radio waves from microwave towers, radio antennas and radars. Investigators believe that such radio waves made five of the army's UH-60 Black Hawks nose dive into the ground since 1982 killing 22 servicemen.

Navy Sea Hawks, with improved protection against electromagnetic interference, did not appear to suffer from the same problem.
(Kindly sent in by Dr Antony Anderson, Dec 2007 – source: The Boston Globe, 8 Nov 1987.)

696 Protecting valuable assets from CM currents
A typical application for the Sinus Filter Plus++ is for protecting the bearings of an underground pump motor used in a combined geothermal/solar panel heating system. The cable run from the frequency inverter to the pump is necessarily very long and the water column provides a low impedance path back to ground, which encourages current pulsing through the motor bearings. To replace or repair such a pump would also prove a very costly exercise. The filter is connected to the output terminals of the frequency inverter to reduce the damaging common-mode disturbances; the general EMC performance of the equipment is also greatly improved.

Bearing failure isn't the only problem that can be solved by applying Sinus Filter Plus++. Water abstraction bore holes are often sited in remote locations; in the middle of a forest for example, and the cable run to the pump motor is usually over a long distance. The high-frequency common-mode disturbances flow back along the path of lowest impedance, to earth through the water pipe as shown in the diagram.

One of the conditions of the abstraction license is that an accurate record is maintained of the water pumped out of the bore hole. However, the high-frequency interference causes the metering equipment to give inaccurate measurements – a problem that can be solved by fitting the REO filter.
(Taken from: DPA Magazine, 1 Feb 2008, http://www.dpaonthenet.net/article/13506/Protecting-valuable-assets.aspx)

697 Ground based air-conditioning system interfered Aircraft communication channel
Abstract—This paper describes a very unusual cause of VHF band interference and the technique for how the source of radiation was determined. An electronic circuit that controls a motor driven air intake flap of an air-conditioner heat exchanger, "mutated" into a broadband VHF transmitter, jamming a large segment of the VHF band.

I. INTRODUCTION
Pilots on aircraft NATO 1 (N1) reported multiple squelch breaks on radio VHF 5. This specific feature occurred during taxi, takeoff and landing with the radio tuned to the main operating base Geilenkirchen tower frequency of 140.075 MHz. When the VHF radio squelch opened, a very loud buzzing was heard on the headset. Furthermore, this fault was reported only intermittently by the pilots, as it did not occur on some days. Because the phenomenon could not be isolated and eliminated in an adequate time frame, aircraft commanders refused to fly N1 until the problem was solved.

II. FACT-FINDING
A spectrum analyzer (SA) connected to the dual band antenna VHF 5 of N1 (parked at spot 10) showed a broad band of spectral lines cluttering above and below the tower frequency of 140.075 MHz (see Fig. 1). A similar measurement was done on the legacy aircraft 444, which was parked on spot 9 (see Fig. 2).

III. LOCATING THE SOURCE OF INTERFERENCE
In order to avoid a possible ground loop with the SA, the external power source and the ground potential of the aircraft, a battery operated DC to AC converter was used to apply power to the SA. All aircraft power was shut down and the aircraft power cable was disconnected. The test result was virtually the same as shown in Figure 1 above. It was now clear that the defect was an externally generated VHF band-jamming signal. The signal source was pinpointed to the area inside Hangar 1 by use of a handheld VHF band radio scanner. The buzzing signal was heard at all locations inside and in front of Hangar 1 and towards the runway. Hangar 1 is located 300 meters away from the center of the runway. However the buzzing signal could be received at both ends of

the runway. The length of the runway is more than 3000 meters. With the SA, a plot was taken inside Hangar 1 (see Fig. 3). The audio output of the handheld scanner was measured with an oscilloscope (see Fig. 4 and 5) in order to determine the modulation type of the interfering signal.

IV. FINDING THE SOURCE OF INTERFERENCE
In order to confirm that the signal source was located somewhere inside Hangar 1 it was decided to completely shut down the mains power from the adjacent Building 217 and Hangar 1 on the next day. The test result is shown in Fig. 6 & 7.

During the power shut down time of Hangar 1, a plot was also taken at the VHF 5 antenna on aircraft N1. The distance between the aircraft N1 and Hangar 1 is about 200 meters (see Fig. 8).

V. TRIANGULATE THE INTERFERENCE
The challenge was now to find the actual source that generated this kind of interference. With the assistance of the StOV-German Garrison Administration's electricians and air conditioning specialists, Hangar 1 was powered down again. Power was reapplied to the Hangar in discrete sections in an effort to localize the source. The interference returned when power was applied to the air conditioning system. The air conditioning specialists attempted to isolate the subsystem that was causing the interference. While the handheld scanner was monitored, various functions were switched off and back on. The interference coincided with power being removed and restored to the motor control circuit that moves a flap inside of one of the heat exchangers mounted on the roof of Hangar 1. Heat exchanger 24 was identified as the originator and was inspected on the roof of the building (see Fig. 9)

The motor driven air intake flaps control the airflow inside each of the heat exchangers. The suspected motor assembly was removed for further investigation (see Fig. 10).

All heat exchangers mounted on the roof were inspected with the handheld scanner. The results revealed a second assembly showing similar symptoms. It was also removed for further investigation.

The bench test for the above-mentioned flap controller confirmed that the electronic motor control circuitry had "mutated" to become a broad band VHF air band transmitter when the flap reached the mechanical limit at the flap open position (see Fig. 11 and 12).

VI. TROUBLESHOOTING THE MOTOR CONTROL UNIT
It was necessary to re-engineer the schematic diagram of the circuit board in order to fully understand the circuit function of the motor control unit and to isolate the failing mechanism (see Fig. 13 and 16).

VII. OBSERVATIONS
The circuit operates with 24 VAC under normal conditions. When the circuit is operated with 24 VDC instead and the clockwise motor rotation is stopped, the circuit begins to oscillate at a stable frequency of 133.5 MHz (see Fig. 14).

VIII. FUNCTIONAL DESCRIPTION OF MOTOR CONTROL CIRCUIT AND TROUBLESHOOTING
The circuit consists of a constant current source, which supplies 50 mA of current to the connected DC motor. Connecting 24 VAC between KL2 pin 1 and 2 supplies 17 VDC across the motor terminals KL1 pin 1 and 2. The current is regulated to 50 mA and causes the motor to turn in a clockwise direction. The flap moves to the upper mechanical limit, which forces the motor to stop. The resistance across the motor decreases and, due to the current regulation of the voltage across the motor, drops to 7 VDC to prevent the motor from overloading. At that moment the circuit starts to oscillate at VHF frequencies. A 50 Hz (20ms) AC ripple is riding on the bias current to the base of transistor T1, which produces a combination of pulse and amplitude modulation.

This modulation generates multiple radio frequency side bands (see Fig. 11 and 12). Connecting 24 VAC between KL2 pin 1 and 3 supplies 17 VDC with reversed polarity across the motor terminals KL1 pin 1 and 2. The motor turns counterclockwise and the flap stops at the lower mechanical limit. No oscillation occurs at this point.

Troubleshooting the circuit was difficult because probing the circuit with an oscilloscope stopped the oscillation at almost any test point. For example, oscillation stopped when the emitter of T1 was measured. C1 and C2 were therefore removed for the measuring of their capacitance. Both values were well within limits. Reinstalling the capacitors in reverse positions stopped the oscillation at both mechanical flap stops. Measuring the equivalent series resistance (ESR) values indicated the location of the problem. C1 had a twice as high ESR as C2. In addition, the circuit board layout adds some instability due to the design of the trace between T1 and R4 (see Fig. 15).

IX. RF-COUPLING PATH
The electrical control central that provides power to all motor control circuits is located in a separate room inside Hangar 1. It supplies 24 VAC motor control signals and ground to the motor control circuits on the roof of Hangar 1 via unshielded cables (30 to 50 meters long vertically mounted). Measurements were taken with an RF-current probe at the cable that was connected to the defective motor control circuit reviled, that the cable was the radiating element. This explained the large transmitting range of the oscillating circuitry.

X. CONCLUSION
Because of flight safety considerations the motor control units in all heat exchangers were replaced with a newer model.

BIOGRAPHY
Norbert Kohns was born in Weißenthurm, Germany, in 1949. For 25 years, he has been employed as a NATO civilian. Currently he serves as a Principal Technician and Maintenance Instructor of the NATO AWACS Electronic Support Measures shop, located at the NATO Airbase in Geilenkirchen, Germany.
In addition, he is the focal point of EMI/EMC related issues of the NATO E-3A fleet.
(Taken from the EMC Society Newsletter, Issue 215, Fall 2007, ***For the figures, see: http://www.emcs.org/acstrial/newsletters/fall07/practical_papers.pdf)***

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

At last? No, not by a long way!

Well, we now know that the CISPR 35 saga isn't even nearly over yet, despite the publication of the first edition. The reason is that five contentious topics were eliminated from the standard in order to secure sufficient support for terminating the very long preparation period. While far from an ideal procedure, it has had to be used also by TC108 to terminate the first development stage of the safety standard IEC 62368-1. Maybe this will cause a reconsideration of how major changes to standards should be handled.

The elimination was accompanied by an undertaking to deal with those topics by means of an immediate maintenance project. In addition, there were numerous comments submitted at the FDIS stage, and consideration of these will be included in the maintenance process. At the moment, it is planned to issue an amendment, but this may be so complex that a new edition will be required.

The eliminated topics are:

- Emission tests in fully-anechoic rooms (FAR);
- An informative annex on Gigahertz TEM (G-TEM) and reverberation chamber (RVC) tests;
- Emission tests on outdoor units of home broadcast satellite receivers;
- Emission test arrangements where doubts about implementation and/or poor repeatability have been reported;
- Clarification of the application of detectors, especially in the 1 GHz to 6 GHz frequency range;

Text on each of these was circulated to national committees as a CD, and each CD elicited numerous comments. To a significant extent, the situation was complicated by the highly contentious issue of 'alternative test methods' that was under intensive discussion at the same time. The subject was very widely misunderstood, with the results that comments often addressed the subject inappropriately. Now that issue has, we hope, been resolved, it should be simpler to make progress.

The issue with alternative test methods is that they cannot be expected to produce the same numerical results, and there is no way to determine whether any mathematical correlation between results is valid for all EUTs. The only real way of showing 'equivalence' is that EUTs that conform to the limits of any of the methods are equally unlikely to cause interference. Clearly, this is not a simple matter, but attempts to establish a more practical solution have either been shown to be too simple, in the opinions of some experts, or have not been tried.

But comments on the CDs were by no means restricted to correlation issues, so a considerable amount of work still needs to be done to resolve all the issues. It may, for example, be necessary to have two separate annexes for RVC and G-TEM. It has been suggested that the emission tests on outdoor units of home broadcast satellite receivers are so specialized that they should be in a separate standard. The subject of emission test arrangements is also very complicated due to the large diversity of physical form and size of multimedia products and the very large range of cable lengths involved in typical installed systems. The detector issue is critical for a different reason - the linear and logarithmic average detectors do not always give comparable results with some types of equipment. These detectors are defined in clause 6 of CISPR 16-1-1, but that may not be the best cross-reference, as the text is quite long and complicated. A more definite text is in 7.6.5 of CISPR 16-2-3.

Better reproduction

No, not hi-fi but radiated emission measurements. Cables attached to the EUT (Equipment Under Test) may be the chief sources of radiation , and better consistency between results could, at least theoretically, be obtained if the common-mode impedances of these cables were stabilized at the point where they leave the 'test volume'. There are three candidates for the job of stabilizing - the CMAD (Common-mode Absorption Device), the VHF-LISN (Very High Frequency Line Impedance Stabilizing Network) and the CDNE (Coupling-Decoupling Network for Emissions). These all have different impedance characteristics, and for some equipment the number of stabilizing devices might be large, so there is ample opportunity for a very long discussion.

Interim measures

The difficulties in securing consensus on the immunity standard CISPR 35/EN 55035 has led to the need to update CISPR 24/EN 55024. Several changes are planned, including re-introducing the 4 % step in frequency scanning, updating the xDSL test configuration and various technical clarifications and editorial improvements.

Light thrown

The International Amateur Radio Union has complained about interference caused by 12 V LED lamps. What happens is that 12 V halogen lamps are replaced by LED lamps having on-board switch-mode rectifiers. The 230 V/12 V transformers intended for the halogen lamps are not only transparent to conducted emissions from the LED lamps, but may actually increase the emission voltage (though probably not by nearly 20 times). The provisions of CISPR 15/EN 55015 in this respect need to be clarified and an Interpretation Sheet is currently under active preparation.

Basic standards

Several Parts of IEC 61000-4 are undergoing maintenance at various stages, and yet another new Part is proposed.

61000-4-4: This is at the FDIS stage and the voting has not closed at the time of writing.

61000-4-5: A CD was circulated which has attracted 29 pages of comments. Clearly, much work needs to be done.

61000-4-19: Tests for immunity to conducted, differential mode disturbances in the frequency range 2 kHz to 150 kHz. This is a **new EMC phenomenon.** The CD has been issued as a BSI Draft for Public Comment DPC12/30258875, which can be downloaded free from BSI if you can follow the correct procedure.

61000-4-20: Proposals to add provisions for, among other things, measurement uncertainty, large EUTs, use of a horn antenna for site characterization above 1 GHz and a series of annexes on specific applications where industry has shown a need for guidance.

61000-4-21: A list of 16 quite radical proposals for change has been issued.

61000-4-25: The amendment has reached the final voting stage and has passed.

61000-4-30: A CD has been issued: the most significant development may be the inclusion in an informative annex of limited information on a measurement method for conducted disturbances in the range 2 kHz to 150 kHz. There is more information in draft IEC 61000-4-19.

61000-4-x (new TS): Surface-current sense wires method for in-situ testing. The draft has not been written in accordance with the ISO/IEC Directives, which is an immediate disadvantage as a lot of work needs to be done to bring it in line.

Generic standards

It is intended to review the Generic immunity standards IEC 61000-6-1 and -2 and IEC TS61000-1-5; the latter is likely to be changed from a Technical Specification to a full standard. IEC 61000-2-5 on electromagnetic environments is also to be reviewed. There is also a Questionnaire active about the future of IEC TS 61000-1-2 on functional safety in the context of EMC - a very fraught subject. While not exactly a Generic standard, it shares some properties with them. It could be changed to a full standard or revised and changed to a full standard. It **could** be reconfirmed as a TS, or revised as a TS, but the Questionnaire does not allow those responses.

The future is nearly (but not quite) here

There are volumes of stuff circulating in the standards community about smart grid and electric vehicles. but what is being discussed is still mainly ‘what needs to be done’. It is very difficult indeed to get the timing of standardization right in the face of rapidly-developing technologies. But without standards, there is a real risk of serious incompatibilities, which could prove very expensive.

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Know Your Standards

Diversion ends

We were due to start looking at the monster multi-section standard IEC 61000-4 last time, but the New Legislative Framework intervened. IEC 61000-4 is a collection of Basic EMC standards (according to some, Parts 7 and 15 aren't Basic). There is a Section of IEC 61000-4 for every EMC susceptibility phenomenon (emission phenomena are covered by CISPR 16) and every method of measuring immunity that the EMC experts have found necessary or consider *might* be necessary.

What this means is that they address two groups, and this is important to understand, because an IEC 61000-4 series standard **does not** apply to a product unless the product or product-family standard has it as a Normative reference (not just an informative reference).

The first group is product (and product-family) EMC Committees. IEC 61000-4 says to them, 'If your product needs an immunity test method and one or more test levels for **this** phenomenon, make this Section a Normative reference in your standard, and select from its *recommended* test levels that or those which suit your product's intended environment'.

The second group addressed is those who want to carry out the tests. IEC 61000-4 says to them 'That's the way to do it.' In some cases, the instructions are rather too terse or opaque for comfort. They are almost always too costly for comfort!

IEC 61000-4-1

This is an overview of the whole 61000-4 series. It may be helpful for understanding *but it is not really a Basic standard ; no product can conform to it because it sets no requirements for a product.* It is almost entirely a guidance document, but it does set requirements for test reports, which is curious because so do most of the other Parts.

IEC 61000-4-2

This section deals with immunity to electrostatic discharge (ESD), which is a very difficult subject. Unlike, for example, emissions from a high-speed switching device, ESD is usually a random chance event, caused by a charged body (which may be somebody) coming close to, or touching, a point on the surface (or, in the case of *inter alia* servicing, the interior) of a product. In fact, 'close' may not be necessary; there is a possibly apocryphal story of Band 1 TV reception in Brighton suffering interference that was traced to the students at Roedean girls' public school discarding nylon underwear *en masse* at bedtime. It's certainly true that the TV signal, from Alexandra Palace in those days, was very weak in Brighton.

Once a discharge event has occurred, it's impossible to know where the energy went unless it causes detectable damage, and in many cases, it's a mystery how the discharge current get back to the high-voltage source. No-one really knew how the test equipment and the devices made to verify its operation actually behaved until oscilloscopes with bandwidths of several gigahertz became available. At that time, some people wanted to improve the test equipment but this was resisted on the grounds that it actually offered very little advantage over the existing equipment and might lead to new results inconsistent with previous ones.

The EMC consultant and lecturer Douglas C Smith has published a large amount of very interesting experimental data on ESD and other EMC subjects, which can be traced through http://emcesd.com/

IEC 61000-4-3

This Section covers immunity to radio-frequency fields, to which almost all equipment is continuously exposed. This subject has probably been studied longer than any other in EMC, so the methods and requirements are well established. Measurement in the open air is no longer legally possible, so an anechoic chamber is required. These, of course, are large and costly, so other methods have been developed which are the subjects of later Sections.

IEC 61000-4-4

The subject here is immunity to 'electrical fast transients/bursts'. Such transients occur on the public mains supply due to switching and other events. Sixty years ago, equipment was generally much more resistant to high-voltage transients, so there was no need for any testing, but there is now. Direct-on-line selenium rectifiers, replacing vacuum rectifiers, had stacks of diodes in series, so were also resistant to transients, and it came as a bit of a surprise how high the peak inverse voltage rating of single-junction silicon rectifiers had to be in order to achieve adequate reliability.

IEC 61000-4-5

This Section is about a 'surge immunity test'. Surges can occur on power supply cables and on signal cables, especially if they leave a building. This is another case where equipment has become much less inherently resistant over the years.

IEC 61000-4-6

Much equipment is too small, and too close to the ground, to act as an efficient receiving antenna for potentially disturbing radio-frequency signals, but cables can be fairly efficient antennas. In that case, the radio-frequency energy is presented to the equipment as conducted currents. The test methods require the use of 'coupling and decoupling devices' to control where those currents flow. Unfortunately, while these devices are fairly simple, many different types are required, not only to suit different cables but also to accommodate the huge number of different connectors that are used these days.

In the past, the standard did not cover 9 kHz to 150 kHz, but that frequency range is now covered in the 2008 edition.

IEC 61000-4-7

This is described as a ‘general guide’ and it started out that way, but it is now a specification for a measuring instrument for power system harmonic currents and voltages. The title may be changed in a future edition. Measuring harmonics of 50 Hz or 60 Hz sounds an easy task, but in fact there are many complications. Some transient high levels of harmonics are not considered unacceptable so can either be averaged out or, in other cases, specifically accepted. Also, the instruments are now digital, so special precautions are necessary to overcome certain ‘features’ of the Digital Fourier Transform, used to perform the frequency analysis.

The standard includes provisions for ‘grouping’ interharmonics (signals at non-harmonic frequencies) with adjacent harmonics by using a measurement bandwidth of 50 Hz or 60 Hz, but this has been found to be too stringent for some equipment which is in use without causing significant interference. So those provisions are at present suspended, by allowing the use of a method of measurement, with a 5 Hz bandwidth, that does not include grouping. Work is actively in progress to try to eliminate that, but it has so far proved too difficult. Maybe one day....

IEC 61000-4-8

Power frequency magnetic fields can cause many problems; obviously audio equipment in various forms may be particularly affected, but so can video displays and any equipment that handles very small voltages or currents may be disturbed by induced currents in conducting loops. The recommended test levels of continuous field strength range from 1 A/m to 100 A/m, but anything above 5 A/m is now considered inadvisable for human exposure in this frequency range. For fault conditions, the highest value is 1000 A/m, and even though that is supposed to last for no more that 3 seconds, i.e. until the fault is cleared by a protective device, the bioelectric effects (nerve stimulation by induced currents) are considered to act in time scales of tens of milliseconds.

The magnetic fields are supposed to be generated by large (1m square and 1 m by 2.6 m) single-turn coils, which require hundreds and even thousands of amps to produce the required field strengths, but the standard does allow other coil configurations to be used, provided that field strength is verified. It is a bit surprising that the test procedure requires a ground plane, but not necessarily a very large one. It isn’t clear what the ground plane is supposed to do.

IEC 61000-4-9

The subject of this Section is a ‘pulsed magnetic field immunity test’, which is considered applicable only to products installed in electrical power plants.

IEC 61000-4-10

This Section is about another ‘power plant’ phenomenon, ‘damped oscillatory magnetic field immunity test’. It is interesting that neither this Section or the previous one are called up in IEC TS 61000-6-5, Generic TS for immunity for power- and sub-station environments. However, that publication is under review and may become a standard that **does** reference IEC 61000-4-9 and -10.

I think ten Sections is enough for now, so look forward to further excitement next time. The last Section at present is IEC 61000-4-38, but not all of the numbers have been used.

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Conductive form-in-place gasket selector guide helps design engineers solve housing EMI shielding challenges

Chomerics Europe - a division of Parker Hannifin, has introduced a comprehensive new selector guide for its range of CHOFORM form-in-place (FIP) conductive gaskets. The range of materials provide lowest total cost of ownership solutions for the EMI shielding of enclosures with small section and complex patterns in applications such as medical electronics, automotive, telecoms, consumer, plus marine and aerospace.

The materials included in the selector guide use either thermoset or RTV curing systems in combination with a wide range of conductive particle technologies to offer designers a choice of cost versus shielding performance options to best match their application needs. Chomerics' corrosion resistant FIP materials provide protection against galvanic activity and can eliminate the need for nickel or tin plating and secondary environmental gaskets.

For outdoor, harsh environment applications, CHOFORM 5572 and 5557 that use Silver / Aluminium (Ag/Al) and Silver / Nickel (Ag/Ni) fillers respectively, provide an ideal high temperature, high corrosion resistance solution. CHOFORM 5506 and 5519 that utilise a Silver / Copper (Ag/Cu) filler are more suitable for less demanding indoor applications. CHOFORM 5519 has a very low Shore A hardness meaning it offers the most effective solution for equipment where low closure forces are needed.

All Chomerics CHOFORM materials offer shielding effectiveness in excess of 60 dB at frequencies ranging from 200 MHz to 12 GHz and electrical conductivity as low as 0.005 ohm-cm. Operating temperature ranges up to 150 ºC for some variants mean that materials are available to suit even the most demanding applications.

The FIP selector guide lists all of the specifications for each material to enable designers to make the optimum choice for their product design. Furthermore, Parker Chomerics engineers can provide additional customer support at all stages of the design process to help selection of the most appropriate material, optimise the design of the component housings, dispense technique and supply chain management.

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emcia Member

18 GHz EMI receiver with direct connection to the antenna

Narda Safety Test Solutions S.r.l. (Italy) presents the new EMI Receiver Unit PMM 9180 which extends the frequency range of the popular Digital EMI Receiver PMM 9010 up to 18 GHz for measurements of EMC emissions in full compliance to CISPR and MIL-STD standards.

Narda's Digital EMI Receiver PMM 9010 features the unique characteristic of modularity that allows the main unit (10 Hz – 30 MHz) to be extended in frequency to 3 GHz (PMM 9030), 6 GHz (PMM9060) and to 18 GHz with the recently released model PMM 9180 by simply adding one of these external modules.

All these modules are real EMI receivers, fully compliant to the latest CISPR and MIL-STD standards. Small-sized and lightweight, these modules can be easily installed inside the anechoic or shielded chamber, directly connected to the measuring antenna and fixed to the mast by means of an adapter. The connection with the main unit PMM 9010 – which remains in the instrument's room – is made by high-speed digital link via fiber optic cable. Up to four hours of continuous in-room operation are provided by the plug-in, rechargeable Li-Ion battery.

This unique solution is the result of Narda's very advanced capabilities in miniaturized RF and digital design. The most evident advantage offered by the PMM's system is the possibility of replacing the coaxial cable by fiber optic, with several advantages:

- elimination of signal loss due to the coaxial cable and to the connections
- improvement of the receiver dynamic range without needing expensive preamplifiers
- improvement of the overall uncertainty: such contributions from cables and connectors (loss, mismatches, aging) are just not present
- elimination of interfering signals that may be picked up along the coaxial cable path
- elimination of scattering phenomena due to the coaxial cable • expensive calibrations of the coaxial cables are needed no more
- in comparison with the coaxial cables, the unpaired flexibility of fiber optic allows for easier installation even in the same path of power cables and reaches much longer distances (up to 100 m). In addition, the fiber optic is very convenient.

The PMM Emission Suite software is supplied with the receiver, and allows for complete control of the tests, including mast and turntable functions.

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New A350 Voltage Spikes

Available from **EMC Partner** is the MIG2000-6 a modular generator capable of delivering all 5 impulse types required by the latest ABD0100.1.8 standard. The latest edition specifies testing on 28Vdc, 115Vac and 230Vac power supplies using impulses with pulse durations from 10us up to 400us and impulse amplitudes up to 2kV. MIG2000-6 with the AMD24C1 module and CN-MIG-BT4 coupler meet and exceed this requirement. Up to 4 systems can be synchronized to facilitate a simultaneous test on multiple power interfaces.

As well as the ABD0100.1.8 tests, MIG2000-6 mainframe can be fitted with modules to meet MIL-STD-461 CS115 impulse excitation, CS116 damped sinusoidal transients and CS106 power lead transient requirements.

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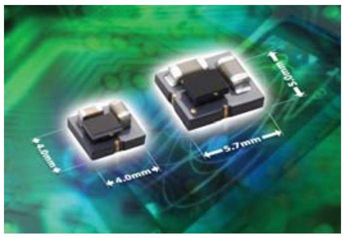
emcia Member

Murata expands the line-up of micro DC-DC converters aimed at small portable devices

Murata have announced additions to its LXDC series of ultra compact DC-DC converters that are aimed at a broad range of mobile consumer electronics such as smartphones. The new devices, comprising the LXDC55B step-down and LXDC44A step-up models complement the existing LXDC2UR and LXDC3EP devices. The LXDC55B measures 5.7 x 5.0 x 2.1 mm and can support output currents up to 3.0 A. Input voltage is within the range 2.7 to 5.5 VDC across the series and single output models provide the nominal output of 1.2, 1.8, 2.5, 3.0 or 3.3 VDC.



Constructed on a ferrite substrate with an embedded inductor, multi-layer construction and integrating the power IC and I/O capacitors together the LXDC family has good EMI suppression and reduced harmonic noise characteristics.

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New 4 GHz oscilloscope from Rohde & Schwarz delivers highest precision and acquisition rate in its class

The new 4 GHz high-performance oscilloscope from **Rohde & Schwarz** with its 20 Gsample/s sampling rate addresses a wide variety of applications: The R&S RTO1044 is ideal for analyzing fast signals and steep edges. It can handle different data interfaces up to a data rate of 1.6 Gbps and can also be used to test fast clock signals up to a frequency of 800 MHz.

User benefits of the R&S RTO family: High sensitivity and measurement accuracy make the R&S RTO an indispensable tool for measurements of typically low-amplitude (< 1 V) signals. Thanks to the extremely low-noise frontend, the full measurement bandwidth of 4 GHz is available at even the smallest scaling (1 mV/div). The 10 GHz single-core A/D

converter provides an outstanding dynamic range (ENOB > 7 bit). Another unique characteristic is the unprecedented high acquisition and analysis rate of 1 million waveforms per second. The digital trigger system makes it possible to accurately pinpoint narrow glitches (down to 50 ps) and their origin. And an adjustable trigger hysteresis allows users to optimize the trigger sensitivity to the signal characteristics.

The combination of fast FFT analysis, high dynamic range and a bandwidth of up to 4 GHz makes the R&S RTO1044 ideal for frequency domain measurements: When verifying circuit designs and during debugging, even sporadic EMI interferers are reliably detected. The spectra of up to four RF signals can be observed in parallel and phase-coherent.

Rohde & Schwarz oscilloscopes feature touchscreen operation that redefines ease of use. The cleverly designed screen with its semitransparent dialog boxes, drag-and-drop measurement windows, configurable toolbar and preview icons with live waveforms allows users to accomplish even complex measurement tasks quickly and efficiently. The 10.4 inch touchscreen strikes the right balance between usability and compactness.

"The many features offered by the new 4 GHz oscilloscope make it the ideal solution for general research, medical technology and the development of RF chipsets," says Jörg Fries, Director of the Oscilloscope Subdivision at Rohde & Schwarz.

The 4 GHz R&S RTO1044 and the R&S RT-ZD40 differential probe with 4.5 GHz bandwidth can now be ordered from Rohde & Schwarz. For detailed information, visit www.scope-of-the-art.com.

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Teseq Introduce New 3-Phase Coupling/Decoupling Network Series

Teseq, a leading developer and provider of instrumentation and systems for EMC emission and immunity testing, has designed the CDN 3043 3-phase coupling/decoupling network series as a competitively priced, high performance extension to the NSG 3040 multifunction generator series.

6 different models are available to provide customers with an optimum price/performance solution. All models feature a high level of user comfort and common safety functions, they range from a single function 16A unit up to a combined version rated at 32A. Higher current ratings are covered by the CDN 3063 series.

Dedicated EUT (Equipment Under Test) terminals allow direct and easy EUT connection and no specific adapter plugs are required. A safety isolated terminal key is supplied as standard. High value shielded high voltage safety plugs are used to interconnect the high voltage pulse output from a NSG 3040 multifunction generator to the CDN input.

The CDN 3043 series features a dynamic cooling system with all internal elements which increase in temperature under load equipped with thermal sensors. At standby or with lower EUT currents, when there is no need for cooling, the internal cooling fans will turn at a very low speed, generating very little audible noise. Fan speed will increase as required when the CDN is in use. In the event of intentional or unintentional overload, when

maximum internal cooling becomes insufficient, the CDN 3043 will remove power to the EUT using the built in EUT power contactor, preventing damage to the instrument and removing the risk of fire. In the event of over temperature shutdown the CDN 3043 control electronics will also send a signal to the NSG 3040, immediately stopping the firing of pulses. This advanced thermal control provides the CDN 3043 series with large overload capabilities allowing up to 1.5 nominal current loading for 10 to 20 minutes, as well as high inrush currents or peak loads.

The phase rotation detector visible at the back off the CDN units shows clearly if a phase is connected and if the rotation of L1, L2 and L3 are correctly set. This important feature ensures correct coupling which is especially important in synchronous mode.

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Bringing License Free Wireless Products to Market in the EU
(Part 2)

By Tim Jarvis, RadioCAD Limited

Summary

This article is the second part of two covering unlicensed wireless products sold and used in the European Union (EU). The first part was published in the previous issue of the EMC Journal (issue 98).

Part 1 introduced wireless regulation commencing with a brief history and proceeding to introduce the recommendations and specifications that govern spectrum use and product approvals for wireless Short Range Devices (SRDs).

In this second article Tim explains how to use the reference documents introduced in part 1 by employing some real world product examples.

Part 2

Introducing our example products

The following four products will be used as examples to explain how to use ERC REC 70-03[1] and OfCom IR 2030[2].

1 Static caravan intruder alarm
2 Personnel worn RFID tag
3 IEEE 802.15.4[3] radio-data system
4 POCSAG radio-paging transmitter

1 - Static caravan intruder alarm

An intruder alarm fitted to static caravans that signals back to the site office. Covering a caravan site requires a longer range and hence a higher power transmitter. For historical reasons this system uses one of the old MPT1329[4] channels.

2 - Personnel worn RFID tag

A personnel worn Radio Frequency Identification (RFID) tag used at industrial sites for identifying personnel passing various gates and arriving at muster points in an emergency. This system uses two frequencies: LF for the tag function and UHF for data communications.

3 - IEEE 802.15.4 radio-data system

A multi-hop (mesh) telemetry system for gathering data over a rural site. This system uses spread-spectrum techniques and node to node data relay to cover a large site at low RF power.

4 - POCSAG radio-paging transmitter

A 500mW radio-paging transmitter operating in the 440 to 470 MHz PMR band. This system is used to send short text messages at an industrial / commercial site and is expected to cover the entire site.

Starting with ERC REC 70-03

The first thing to do is to look through ERC REC 70-03 and see if there are any harmonised license free allocations for our four products. ERC REC 70-03 is maintained by ECO (European Communications Office). It defines harmonised spectrum allocations for license free SRDs across all CEPT member countries (a geography larger than Europe).

Example 1

The alarm system – looking at the contents page of ERC REC 70-03 we find that there is an annex dealing specifically with alarms – annex 7.

Regulatory parameters related to Annex 7

Frequency Band	Power	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
a 868.6-868.7 MHz	10 mW e.r.p	< 1.0 % duty cycle	25 kHz		The whole frequency band may also be used as 1 channel for high speed data transmissions
b 869.250-869.300 MHz	10 mW e.r.p	< 0.1 % duty cycle	25 kHz		
c 869.650-869.700 MHz	25 mW e.r.p	< 10 % duty cycle	25 kHz		
d 869.200-869.250 MHz	10 mW e.r.p	< 0.1 % duty cycle	25 kHz		Social Alarms
e 869.300-869.400 MHz	10 mW e.r.p	< 1.0 % duty cycle	25 kHz		
f 169.4750-169.4875 MHz	10 mW e.r.p	< 0.1 % duty cycle	12.5 kHz	ECC/DEC/(05)02	Social Alarms (exclusive use)
g 169.5875-169.6000 MHz	10 mW e.r.p	< 0.1 % duty cycle	12.5 kHz	ECC/DEC/(05)02	Social Alarms (exclusive use)

From Annex 7 of ERC REC 70-03 (2011)

Straightaway we see that there aren't any allocations with sufficient power to support the 100mW that the product is currently using. At this point we can also look through annex 1 for Non-Specific SRDs.

Neither ERC REC 70-03 or Ofcom IR 2030 define what a Non-Specific SRD is, but I offer this definition from OfCom…

> "the Rec 70-03 Annex 1 or the IR2030/1/ series of allocations are open to any application, so long as the apparatus meets the conditions of the IR2030 and it meets the Essential Requirements of the R&TTE Directive (i.e it is lawfully CE marked)"

"any application" means any, including applications listed elsewhere in Rec 70-03 or IR2030.

As it turns out only annex 1.g3 gives the required power in the UHF band.

Regulatory parameters related to Annex 1

Frequency Band	Power / Magnetic Field	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
g3 869.400-869.650 MHz	≤500mW e.r.p	≤ 10% or LBT+AFA (note 1)	25 kHz (for 1 or more channels)		Narrow / wide-band modulation The whole stated frequency band may be used as 1 channel for high speed data transmission

From Annex 1 of ERC REC 70-03 (2011)

This would mean migrating the existing product from 458.825 MHz to a channel between 869.4 and 869.65 MHz. The channel bandwidth of 25 KHz is compatible and the 10% transmit duty cycle limit is also acceptable so this is an option.

Example 2

The RFID personnel tag – in this case ERC REC 70-03 has two annexes that apply to this product. Annex 9 for inductive applications covers the LF proximity sensing function and annex 11 for RFID applications covers the communications function.

Regulatory parameters related to Annex 9

Frequency Band	Magnetic Field Strength	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
a3 119-135 kHz	66 dBµA/m at 10m (note 1)	No requirement	No spacing		No requirement No spacing In case of external antennas only loop coil antennas may be employed. Field strength level descending 3 dB/oct at 119 kHz

From Annex 9 of ERC REC 70-03 (2011)

Regulatory parameters related to Annex 11

Frequency Band	Power	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
b1 865.0-865.6 MHz	100 mW e.r.p	No requirement	200 kHz		
b2 865.6-867.6 MHz	2 W e.r.p	No requirement	200 kHz		
b3 867.6-868.0 MHz	500 mW e.r.p	No requirement	200 kHz		

From Annex 11 of ERC REC 70-03 (2011)

For the LF function 125 KHz was chosen as the carrier frequency. This falls into annex 9.a3, note 1 places further member state restrictions on this allocation.

Station	Frequency	Protection bandwidth	Maximum Field strength at 10 m	Location
MSF	60 kHz	+/-250Hz	42 dBµA/m	United Kingdom
RBU	66.6 kHz	+/-750Hz	42 dBµA/m	Russian Federation
HBG	75 kHz	+/-250Hz	42 dBµA/m	Switzerland
DCF77	77.5 kHz	+/-250Hz	42 dBµA/m	Germany
DCF49	129.1 kHz	+/-500Hz	42 dBµA/m	Germany

Annex 9 Table 1 from Note 1

The maximum transmit level is reduced to protect various national time standard signals. For example the National Physics Laboratory (NPL) MSF station broadcasting from Anthorn in Cumbria on 60 KHz[5].

Our chosen frequency of 125 KHz and bandwidth of 1 KHz is unaffected by any of the stations listed in annex 9 table 1.

For the UHF communications function we pick annex 11.b1 because this is the lowest power allocation in annex 11. Since the tag is required to be worn on the body by employees its use is captured by Directive 2004/40/EC[6]. The directive limits human exposure to non-ionising radiation (radio waves). To avoid having to do time consuming and expensive Specific Absorption Rate (SAR) testing, and also to optimise battery life, we'll limit our transmit power to 5mW ERP. This may give us interference problems with other RFID applications using this band at higher powers, in which case we could switch to the adjacent band specified in annex 1.g4.

Example 3

A Zigbee® like mesh data gathering system. It's based on Atmel's AT86RF212 IEEE 802.15.4 transceiver. The chip operates in the 862 → 870 MHz license-free band but it can't confine itself to a single channel because it utilises direct sequence spread-spectrum chipping to improve range and noise immunity. Because the product doesn't fall into any of ERC REC 70-03's product specific categories, only annex 1 can be applied.

Regulatory parameters related to Annex 1

Frequency Band	Power / Magnetic Field	Spectrum access and mitigation requirement	Channel spacing	ECC/ERC Decision	Notes
g 863-870 MHz (note 3, 4 and 6)	≤ 25 mW e.r.p	≤ 0.1% or LBT (note 1 and 5)	≤ 100 kHz for 47 or more channels (note 2)		FHSS modulation
	≤ 25 mW e.r.p (note 6) Power density : -4.5 dBm/100 kHz (note 7)	≤ 0.1% or LBT+AFA (note 1, 5 and 6)	No spacing		DSSS and other wideband modulation other than FHSS
	≤ 25 mW e.r.p	≤ 0.1% or LBT+AFA (note 1 and 5)	≤ 100 kHz, for 1 or more channels modulation bandwith ≤ 300 kHz (note 2)		Narrow /wide-band modulation
g1 868.000-868.600 MHz (note 4)	≤ 25 mW e.r.p	≤ 1% or LBT+AFA (note 1)	No spacing, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
g2 868.700-869.200 MHz (note 4)	≤ 25 mW e.r.p	≤ 0.1% or LBT+AFA (note 1)	No spacing, for 1 or more channels (note 2)		Narrow / wide-band modulation. No channel spacing, however the whole stated frequency band may be used
g3 869.400-869.650 MHz	≤500mW e.r.p	≤ 10% or LBT+AFA (note 1)	25 kHz (for 1 or more channels)		Narrow / wide-band modulation The whole stated frequency band may be used as 1 channel for high speed data transmission

From Annex 1 of ERC REC 70-03 (2011)

The chip is limited to 10mW ERP and at this power level all of band 1.g is open for use, however the available duty cycle is too restrictive for our application. Note 1 to the annex offers a way out.

Note 1: When either a duty cycle, Listen Before Talk (LBT) or equivalent technique applies then it shall not be user dependent/adjustable and shall be guaranteed by appropriate technical means.
For LBT devices without Adaptive Frequency Agility (AFA), or equivalent techniques, the duty cycle limit applies.
For any type of frequency agile device the duty cycle limit applies to the total transmission unless LBT or equivalent technique is used.

Fortunately the AT86RF212 supports LBT and an AFA algorithm can be implement in the product firmware. We'll look at this again at the close of this paper.

Example 4

An old fashioned POCSAG rec 584[7] paging transmitter. This operates in the 440 to 470 MHz PMR band. ERC REC 70-03 can't help us with this product as it has no radio-paging annex and no harmonised allocations in this band.

ERC REC 70-03 National Limitations

As we've already seen with example 2, CEPT member states apply limitations to the harmonised allocations in ERC REC 70-03. These are summarised in the tables and notes of appendix 1. Each allocation appears as a row in the table of appendix 1 and each member state as a column.

For the purpose of this paper we'll restrict our interest to Germany (column D) and the UK (column G)*. The entries in each box can be either:

Y – fully implemented
L – implemented with limitations
P – pending implementation
U – under consideration
N – not implemented

The red boxes above show that both the UK and Germany have fully implemented the allocations pertaining to our examples. Where limitations apply these are detailed in appendix 3.

Annexes to ERC REC 70-03	AUT	BEL	BUL	CZE	CYP	DNK	EST	FIN	F	D	GRC	HNG	ISL	IRL	I	LVA	LIE	LTU	LUX	MLT	HOL	NOR	POL	POR	ROU	SVK	SVN	E	SUI	S	G
Annex 1 - Non-Specific SRDs	EU member states and EFTA countries																														
Annex 1A 6765-6795 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1B 13.553-13.567 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1C 26.957-27.283 MHz ERC/DEC(01)02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1D 40.660-40.700 MHz ERC/DEC(01)03	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1E 138.20-138.45 MHz	Y	N	Y	Y	Y	Y	Y	Y	N	N	Y	N	Y	P	N	N	N	Y	Y	Y	N	Y	N	Y	Y	N	N	N	N	N	P
Annex 1F 433.050-434.790 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1F1 433.050-434.790 MHz ECC/DEC(04)02	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1F2 434.040-434.790 MHz	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1G 863-870 MHz	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	U	L	Y	Y	Y	Y	Y	L	Y	N	Y
Annex 1G1 868.000-868.600 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1G2 868.700-869.200 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1G3 869.400-869.650 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1G4 869.700-870.000 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1H 2400.0-2483.5 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1I 5725-5875 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1J 24.00–24.25 GHz	Y	Y	Y	Y	Y	Y	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	L
Annex 1K 61.0-61.5 GHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 1L 122-123 GHz	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P
Annex 1M 244-246 GHz	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	P
Annex 1N 3.1-4.8 GHz ECC/DEC/(06)04	L	N	Y	N	N	Y	Y	Y	N	Y	N	P	N	N	N	N	Y	N	N	N	Y	N	Y	N	Y	N	Y	Y	Y	N	Y
Annex 1N 6 - 9 GHz ECC/DEC/(06)12	L	N	Y	N	N	Y	Y	Y	N	Y	N	P	N	N	N	N	Y	N	N	N	Y	N	Y	N	Y	N	Y	Y	Y	N	Y
Annex 9 - Inductive Applications																															
Annex 9A1 9-90 kHz	N	N	L	P	N	L	Y	Y	L	Y	N	Y	Y	N	N	L	Y	L	Y	N	P	N	Y	N	Y	N	Y	L	Y	Y	Y
Annex 9A2 90-119 kHz	L	N	Y	Y	N	L	Y	Y	Y	Y	N	Y	Y	N	N	L	Y	L	Y	N	P	N	Y	N	Y	N	Y	Y	Y	Y	Y
Annex 9A3 119-135 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	L	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 9B 135-140 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	P	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 9C 140.0-148.5 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	P	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 9D 6765-6795 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 9E 7400-8800 kHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 11 - Radio Frequency Identification Applications																															
Annex 11A 2446-2454 MHz	Y	Y	Y	Y	Y	Y	Y	Y	L	Y	Y	Y	Y	Y	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	L	Y
Annex 11B1 865.0-865.6 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 11B2 865.6-867.6 MHz	Y	Y	Y	Y	Y	Y	Y	Y	L	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Annex 11B3 867.6-868.0 MHz	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

Selected From Appendix 1 of ERC REC 70-03 (2011)

* It's not at all clear why the UK is column G and prior to being enlightened by Robin Donoghue of OfCom I thought the UK didn't have its own column in appendix 1.

Applying UK National Requirements - OfCom IR 2030

The appendices of ERC REC 70-03 give considerable information on national requirements where they relate to harmonised allocations. To get the full picture concerning harmonised and non-harmonised requirements there's no subsitute for investigating the publications of member states. We'll start with the UK's IR 2030 published annually by OfCom.

IR 2030 specifies the UK's interface requirements for licence-exempt SRDs. The document is decomposed by product category in a similar manner to ERC REC 70-03. We'll apply the document to our four examples in the same manner as before.

Example 1

Our 458.825 MHz, 100 mW alarm allocation appears in IR 2030 part 22.

Interface Number/ Notification Number/Date	Normative Part								Informative Part
	Application	Comments to application	Frequency band	Comments to Frequency band	Transmit power/ Power density	Comment to Transmit power/ Power density	Channelling	Channel access and occupation rules	Reference
IR2030/22/1 2010/0168/UK Oct 2010	Fixed Alarms		173.225 MHz		10 mW e.r.p.		Channel spacing 12.5 kHz		EN 300 220
IR2030/22/2 2010/0168/UK Oct 2010	Fixed Alarms		173.225 MHz		10 mW e.r.p.		Channel spacing 25 kHz		EN 300 220
IR2030/22/3 2010/0168/UK Oct 2010	Fixed Alarms		458.825 MHz		100 mW e.r.p.		Channel spacing 12.5 kHz		EN 300 220

From OfCom IR 2030 part 22

The term 'fixed' here is interesting as it has meaning in the world of wireless approvals:

(i) Fixed (meaning not regularly moved)
(ii) Mobile (meaning attached to a vehicle or its trailer)
(iii) Portable (meaning readily picked up and hand carried)

Our unit is fixed to a static caravan and therefore qualifies as being a 'fixed alarm'. If we were to use the unit in a touring caravan it would then become a 'mobile alarm' and would not strictly be covered by IR2030/22.

Example 2

Our RFID tag uses fully harmonised allocations so we need not consult IR 2030. However we can check to make sure there aren't any notes that might affect the operation of the product. The allocations we're using are specified by IR2030/13/2 and IR2030/15/6.

Interface Number/ Notification Number/Date	Normative Part								Informative Part
	Application	Comments to application	Frequency band	Comments to Frequency band	Transmit power/ Power density	Comment to Transmit power/ Power density	Channelling	Channel access and occupation rules	Reference
IR2030/13/2[1] 2010/0168/UK Oct 2010	Radio Frequency Identification	Equipment may be used airborne	865 – 865.6 MHz		100 mW e.r.p.		Channel spacing 200kHz Channel numbers 1 to 3. Channel centre frequencies are 864.9 MHz plus (0.2 MHz times channel number.		EN302 208
IR2030/13/3[1] 2010/0168/UK Oct 2010	Radio Frequency Identification	Equipment may be used airborne	865.6 – 867.6 MHz		2W e.r.p.		Channel spacing 200kHz Channel numbers 4 to 13. Channel centre frequencies are 864.9 MHz plus (0.2 MHz times channel number.		EN302 208
IR2030/13/4[1] 2010/0168/UK Oct 2010	Radio Frequency Identification	Equipment may be used airborne	867.6 – 868 MHz		500 mW e.r.p.		Channel spacing 200kHz Channel numbers 14 to 15. Channel centre frequencies are 864.9 MHz plus (0.2 MHz times channel number.		EN302 208
IR2030/15/6 2011/0401/UK Dec 2011	Inductive Applications	Equipment may be used airborne	127 – 135 kHz		66 dBμA/m at 10 m				EN 300 330

Selected From OfCom IR 2030 parts 13 and 15

Example 3

Similarly the telemetry system is fully harmonised being covered by IR2030/1/13 to IR2030/1/20 (not reproduced here).

Example 4

Like ERC REC 70-03, IR 2030 doesn't have any allocations specific to radio paging. Where it survives, paging technology tends to be used for alerting members of staff in commercial and industrial applications. There is a suitable allocation for industrial and commercial telemetry applications in IR 2030.

Interface Number/ Notification Number/Date	Normative Part								Informative Part
	Application	Comments to application	Frequency band	Comments to Frequency band	Transmit power/ Power density	Comment to Transmit power/ Power density	Channelling	Channel access and occupation rules	Reference
IR2030/2/6 2010/0168/UK Oct 2010	Industrial/ Commercial Telemetry And Tele-command	Music and speech are only permitted when using a digitised signal	458.5 – 458.95 MHz		500 mW e.r.p.		Channel spacing 12.5 kHz Channel numbers 1 to 25 inclusive and 26 to 31 inclusive and 33 to 35 inclusive are available with a channel centre frequency of 458.5 MHz plus (Channel Spacing times channel number).		EN 300 220
IR2030/2/7 2010/0168/UK Oct 2010	Industrial/ Commercial Telemetry And Tele-command	Music and speech are only permitted when using a digitised signal	458.5 – 458.95 MHz		500 mW e.r.p.		Channel spacing 25 kHz Channel numbers 1 to 12 inclusive and 14 to 15 inclusive and 17 are available with a channel centre frequency of 458.5 MHz plus (Channel Spacing times channel number).		EN 300 220

From OfCom IR 2030 part 2

This is our old friend MPT1329, having been restricted to use in industrial and commercial applications. Our desktop pager can be used license-free in the UK providing that it complies with ETSI EN 300 220[8]. Radio paging transmitters however are usually approved using ETSI EN 300 224[9]. A Product approved with only the latter would require a license from OfCom before it could be used. We'll cover wireless product approvals briefly in the final section.

Applying German National Requirements

The German regulatory authority is “Regulierungsbehoerde für Telekommunikation und Post” or the Bundesnetzagentur (Federal Network Agency) for short. Luckily their website is available in both English and German[10]. The German spectral use regulations “Bundesnetzagentur Frequenznutzungsplan[11]” seem only to be available in German however.

At this point we’ll drop examples 2 and 3 as their use is fully harmonised. We’re interested in taking products 1 and 4 from the UK to Germany. We find that there aren’t any alarm specific allocations in the 440 → 470 MHz UHF band (section 223). However ‘fernwirkfunk’ (telecontrol) channels are available. The use of these channels is defined in the usage plan as (my translation) “Radio-telecontrol used to transmit data signals for measurement and control purposes. Including temporary traffic control lights/systems, radio equipment to transmit correction data for satellite-based navigation, radio systems for identification purposes and data communications for remote monitoring and alerting purposes. Note: voice transmission is not permitted.”

Entry	Band (MHz)	Chan BW KHz	Max ERP	Notes
223011	447.96875→448.00625	12.5	12 W	3 channels
223013	448.04375→448.14375	12.5	12 W	8 channels
223020	448.56875→448.58125	12.5	5 W	Single channel
223029	450.100→451.000	12.5, 25, 50 & 100	6 W	Telecommand/Telemetry (duplex 460.1→461.0 MHz)
223044	456.160→456.180	20	0.5 W	Single channel (duplex 466.16→466.18 MHz)
223046	456.200→456.220	20	0.5 W	Single channel
223048	456.240→456.260	20	0.5 W	Single channel
223049	456.280→456.300	20	0.5 W	Single channel
223051	456.320→456.340	20	0.5 W	Single channel (duplex 466.32→466.34 MHz)
223053	456.440→456.460	20	0.5 W	Single channel
223063	456.520→456.600	20	6 W	4 channels
223067	460.100→461.000	12.5, 25, 50 & 100	6 W	Telecommand/Telemetry (duplex 450.1→451.0 MHz)
223084	466.160→466.180	20	0.5 W	Single channel (duplex 456.16→456.18 MHz)
223085	466.200→466.220	20	0.5 W	Single channel
223088	466.240→466.260	20	0.5 W	Single channel
223091	466.320→466.340	20	0.5 W	Single channel (duplex 456.32→456.34 MHz)
223093	466.400→466.420	20	0.5 W	Single channel
223106	469.980→470.000	20	5 mW	Single channel

Fernwirkfunk (telecontrol) 440 → 470 MHz (Section 223)

Example 1

Following email communication with the Bundesnetzagentur I am told that allocations 223011, 223013, 223029 and 223067 are all suitable for alarm systems. A 10% transmit duty cycle limit applies being specifically no more than 6 seconds per minute. None of the section 223 allocations are license free and so each caravan site using this product would have to apply for a license from the Bundesnetzagentur and would presumably be assigned a frequency to use on a case by case basis.

Example 2

Desktop radio paging transmitters also have to be licensed for use on an individual basis.

National Notification Requirements

Article 6.4 of the Radio and Telecommunications Terminal Equipment (RTTE) directive[12] requires that the national spectrum authority be notified of a wireless product that uses a non-harmonised frequency allocation at least four weeks prior to its introduction into that EU member state.

Article 6.4 applies to both of our examples 1 and 4 even if we have self-declared these products to appropriate harmonised standards. The notification form can normally be downloaded from the national spectrum authority’s website. A full list of authorities worldwide with links to all those authority’s websites is available at **http://www.cellular-news.com/regulator/**.

In the UK the notification form[13] can be either completed online or downloaded. Alternatively we could use the One Stop Notification (OSN) procedure on the Europa website[14] to notify the UK along with other EU member states in a single process.

Market Access Standards for Radio Performance

As we saw in part 1 of this paper the RTTE directive takes precedence over the EMC directive for all products containing wireless devices. In addition to meeting EMC requirements*, article 3.2 of the RTTE directive requires intentional radiators (the term used for radio transmitters) to meet certain radio performance requirements in order to protect the radio spectrum. These requirements are standardised by ETSI.

Both ERC REC 70-03 and IR 2030 specify the applicable radio performance standards. ERC REC 70-03 specifies the applicable standards in ‘additional information’ at the end of each annex, whereas IR 2030 specifies the standard in the extreme right column of each allocation’s table entry.

Examples 1, 3 and 4 are required to be compliant to ETSI EN 300 220. Example 2 (RFID) has to comply with ETSI EN 300 330[15] for its LF function and ETSI EN 302 208[16] for its UHF communications function. Since these specifications are published in the Official Journal of the EU (OJ) manufacturers can self-declare compliance.

The LBT function we met when considering example 3 is fully defined in ETSI EN 300 220 section 9. AFA is simply a matter of switching to alternative channel(s) if the channel we intended to use is busy. Whereas this is easy for the transmitter to do, it’s not easy for a remote receiver to keep in sync with. The situation is made worse if the receiver only wakes up periodically – a technique frequently used in battery powered applications to save power. With that thought in mind I think we’ve finished exploring our topic and are in danger of drifting off onto a new one.

Special thanks to Robin Donoghue of OfCom and Dietmar Ost of the German Federal Network Agency for help in answering my odd-ball questions during the preparation of this paper.

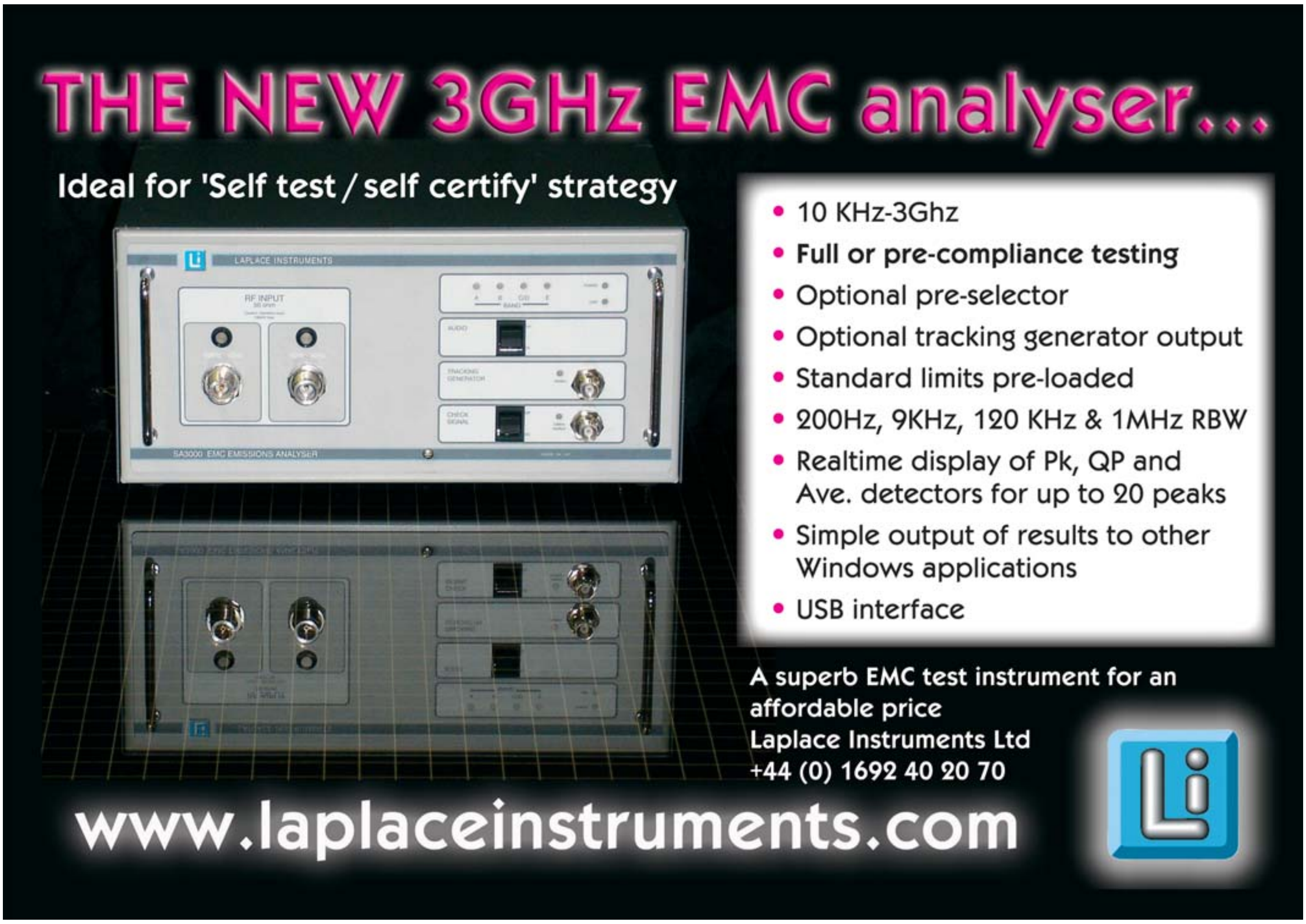
References

[1] ERC RECOMMENDATION 70-03 (Tromsø 1997 and subsequent amendments) RELATING TO THE USE OF SHORT RANGE DEVICES (SRD) Recommendation adopted by the Frequency Management, Regulatory Affairs and Spectrum Engineering Working Groups - Version of 9 February 2011.

* For all our examples ETSI EN 301 489-3 is that applicable standard for EMC.

[2] IR 2030 - UK Interface Requirements 2030 Licence Exempt Short Range Devices - December 2011 – OfCom
[3] http://standards.ieee.org/findstds/standard/802.15.4-2011.html
[4] MPT 1329 PERFORMANCE SPECIFICATION - Transmitters and receivers for use in the UHF band allocated to low power telemetry and telecommand 458.5 MHz to 458.95 MHz – Radiocommunications Agency Archive.
[5] http://www.npl.co.uk/science-technology/time-frequency/time/products-and-services/msf-radio-time-signal
[6] DIRECTIVE 2004/40/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (electromagnetic fields) (18th individual Directive within the meaning of Article 16(1) of Directive 89/391/EEC) - L 159/1 EN Official Journal of the European Union 30.4.2004
[7] ITU-R M.584-2 1 - RECOMMENDATION ITU-R M.584-2 - Codes and Formates for Radio Paging (Question ITU-R 12/8), 1982-1986-1997.
[8] ETSI EN 300 220-2 V2.3.1 Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 25 MHz to 1 000 MHz frequency range with power levels ranging up to 500 mW; Part 2: Harmonized EN covering essential requirements under article 3.2 of the R&TTE Directive
[9] EN 300 224-2 V1.1.1 Electromagnetic compatibility and Radio spectrum Matters (ERM); On-site paging service; Part 2: Harmonized EN under article 3.2 of the R&TTE Directive
[10]http://www.bundesnetzagentur.de/
[11]"Bundesnetzagentur frequenznutzungsplan – gemäß TKG über die Aufteilung des Frequenzbereichs von 9 KHz bis 275 GHz auf die Frequenznutzungen sowie über die Festlegungen für diese Frequenznutzungen.
[12]DIRECTIVE 1999/5/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity - L 91/10 EN Official Journal of the European Communities 7.4.1999
[13]http://stakeholders.ofcom.org.uk/spectrum/spectrum-management/research-guidelines-tech-info/rtte/form/
[14]https://webgate.ec.europa.eu/enterprise-portal
[15]ETSI EN 300 330-2 V1.5.1 Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment in the frequency range 9 kHz to 25 MHz and inductive loop systems in the frequency range 9 kHz to 30 MHz; Part 2: Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive
[16]ETSI EN 302 208-2 V1.4.1 Electromagnetic compatibility and Radio spectrum Matters (ERM); Radio Frequency Identification Equipment operating in the band 865 MHz to 868 MHz with power levels up to 2 W; Part 2: Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive

Tim Jarvis graduated from The University of Hull in 1983. He started his career designing RF circuitry for naval sonar systems. In 1988 he moved into the telecommunications sector. In 2001 he set up RadioCAD Limited as an independent RF and EMC consultancy www.radiocad.com. Tim approaches EMC engineering and approvals as an RF engineer with a practical knowledge of electromagnetic phenomenon and good design practice. Tim is a chartered engineer (CEng) and has been a member of the IET and IEEE for many years, and he sits on ETSI ERM committee TG26. Tim presents at conferences and has published a number of technical EMC papers (www.radiocad.com/downloads/articles.html).



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

Suppressing RF emissions from inputs and outputs *(continued)*

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 – 98 of The EMC Journal carried earlier 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; whether they are used in modules, 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., will also be covered.

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

I will generally not repeat stuff I have already published, instead providing appropriate references to material published in the EMC Journal [14] and my recently-published books based on those articles [15].

7 Suppressing RF emissions from inputs and outputs

I will discuss suppressing low-frequency emissions (mains harmonics and other noise emissions below 150kHz) in a later article.

7.3 Designing or choosing effective filters

Subsections 7.1 -7.3 of this topic appeared in Issue 98 of the EMC Journal [72], and this Issue completes subsection 7.3 and covers 7.4 too. The remainder of section 7 is intended to appear in a later article.

7.3.5 Combining capacitive and inductive (choke) RF filtering *(continued from [72])*

Sorry, but I forgot to include this in section 7.3.5 in the previous Issue of the EMC Journal [72].

As I mentioned in section 7.3.4 of [72] it is usual to wind CM chokes bifilar, to minimise their DM inductance. But for AC and DC power filtering we often need DM inductance as well as CM inductance, and some manufacturers (e.g. Murata) make "leaky" CM chokes that create high CM and DM (leakage) inductances at the same time, and using them helps save PCB area and cost.

Now we get to the bit that I meant to include last time – it's the situation that faces many circuit designers when they have to run a number of DC/DC converters to provide power rails at different voltages from a common DC bus (e.g. +5V), or when they have to run a number of DC/DC converters in parallel (e.g. multi-phased, see section 2.10 in [42]) from a common DC bus.

Figure 7.3-9 shows the use of CM + DM chokes to help prevent the emissions from the DC/DC converters from adding up in their common DC bus and making it too noisy.

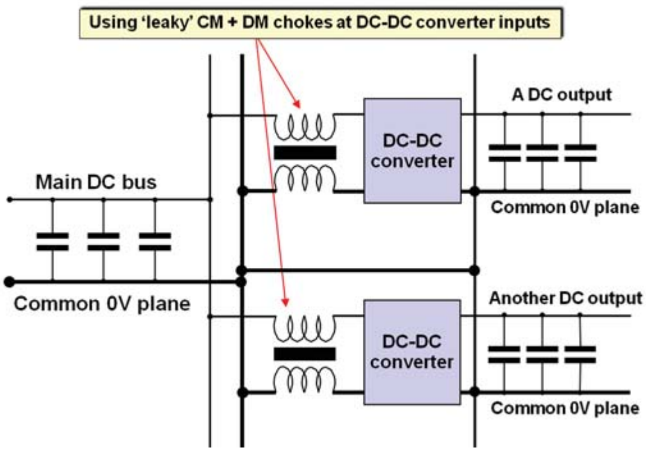


Figure 7.3-9 Example of using 'leaky' CM chokes at DC-DC converter inputs

7.3.6 Many different kinds of proprietary mains filters

Figures 7.3-10 and 7.3-11 show a variety of items, all of them different kinds of power filters suitable for AC mains or DC power.

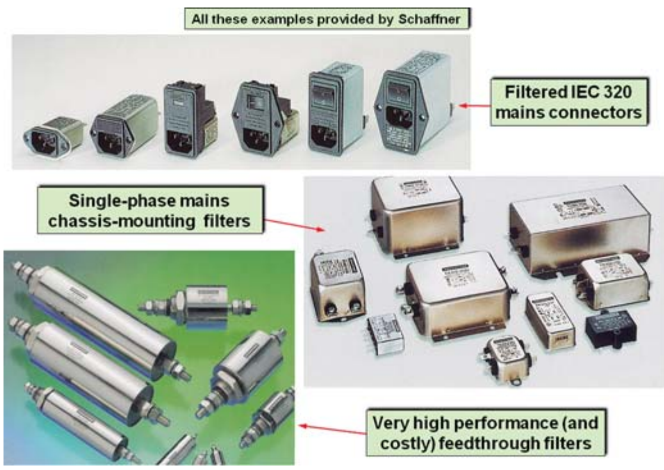


Figure 7.3-10 Some examples of power filters

Figure 7.3-11 Some more examples of power filters

Some of the filters in these two figures are very expensive, and some are very low-cost. We would all like to use the low-cost ones, of course, but we can't rely on most filter manufacturer's data sheets to tell us how they will perform in real life. Sections 7.3.7 through 7.3.9 below discuss the reasons for this, and how to deal them.

7.3.7 Basics of filter resonance and damping

Power input (AC or DC) filters are constructed from inductors and capacitors, so they can all suffer from resonances, amplifying some frequencies instead of attenuating!

Figure 7.3-12 shows a simple low-pass filter made with passive components – the basic building block of most EMI suppression filters intended for AC or DC power inputs or outputs.

A certain value of load resistor (R) is required for critical damping, which has no gain and is -3dB at the resonant frequency f_{res}. Lower values of R cause overdamping, and higher values cause some gain to occur around f_{res}.

Theoretically, an open-circuit for R would mean an infinite gain at f_{res}, but in practice the Ls and Cs have some intrinsic resistance, as do the conductors that connect them together, and the open-circuit has some stray capacitance, so infinite gain is never realised.

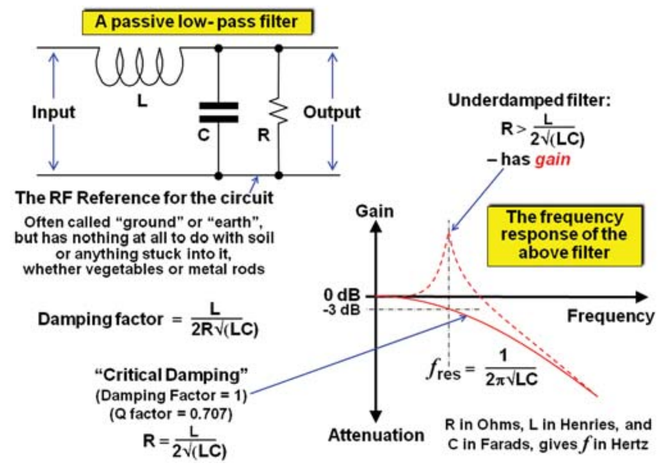


Figure 7.3-12 Underdamped low-pass filters have gain

Circuit values of 1H and 1F give f_{res} = 1Hz, and would be critically damped by a resistance of 0.5Ω. Values of L =1mH and C = 1µF give an f_{res} of just over 5kHz, critically damped by R =15.8Ω.

Filters are generally measured using test equipment with 50Ω inputs and outputs, so filter design usually starts with a load resistor of 50Ω and selects the values of L and C depending on the value required for f_{res} and for the damping factor. So, for example, if we wanted to achieve a damping factor of 1 and an f_{res} of 5kHz with a load resistance of 50Ω, we would choose L = 3.19mH and C = 0.319µF. Of course, in practice we would choose the nearest standard values that got us closest to our design goals. For more on the equations for filter design and damping, see section D.6 of [71] and [73].

In real life, of course, AC and DC power filters are almost *never* working into 50Ω resistive loads. Indeed, their loads are generally complex impedances that vary – and also vary their phase angles between capacitive and inductive – over the frequency range being filtered.

Here are some very generalised examples of AC and DC power source and load impedances (don't use these figures for design!)….

Domestic 50Hz mains supply at wall socket:

Differential Mode (DM): 2Ω to 2kΩ depending on the frequency, varying as other loads on the distribution network are switched off or on.

Common Mode (CM): 1MΩ to 20Ω depending on the frequency, varying as other loads on the distribution network are switched off or on.

Bridge-rectifier and storage capacitor AC power input:

DM: Either <10mΩ or >1MΩ depending on the frequency, switching between them at 100Hz as the rectifiers switch on/off.

CM: 10MΩ to 100Ω depending on the frequency, and varying at 100Hz as the rectifiers switch on/off.

Dedicated traction battery with cables < 2m long:

DM: 1mΩ to 1kΩ depending on frequency and state of charge, temperature and age of the battery.

CM: 10MΩ to 100Ω depending on the frequency.

48V DC supply distribution (e.g. telecoms central office, data centre using blade servers):

DM: 20mΩ to 2kΩ depending on frequency and location in network, and on the state of charge, temperature and age of the battery.

CM: 1MΩ to 100Ω depending on the frequency and location in network.

Both also depend on what loads are connected to the DC distribution, and where they are located, so can change with time.

CISPR 17 [74] is the test standard for the attenuation of mains filters, and requires tests to be done with 50W resistive source and load, known as "matched 50/50" tests. Because this is the standard test, filter manufacturers design their filters to look good on this test, and most designers will choose the filters that look the best on these tests whilst costing the least – but this is a big mistake.

Because AC and DC power filters almost never have resistive 50Ω inputs and outputs, we cannot reliably choose cost-effective filters on the basis of their "matched 50/50" measurement data!

7.3.8 How to deal with filters that are insufficiently damped in real life

CISPR 17 [74] recognises the problem of non-50Ω source and load impedances, and includes optional tests using 100Ω source with 0.1Ω load, and 0.1Ω source with 100Ω load, known as "mismatched 100/0.1" and "mismatched 0.1/100" tests respectively.

A complete set of filter attenuation curves covers both DM (known as "symmetrical") and CM (known as asymmetrical"), for all of the CISPR 17 matched and mismatched tests, making 6 curves in all.

Figure 7.3-13 shows three of these curves taken from the datasheet of a standard volume-manufactured proprietary single-stage (hence low-cost) mains filter. The single mismatched curve included shows a gain of nearly 20dB around 250kHz.

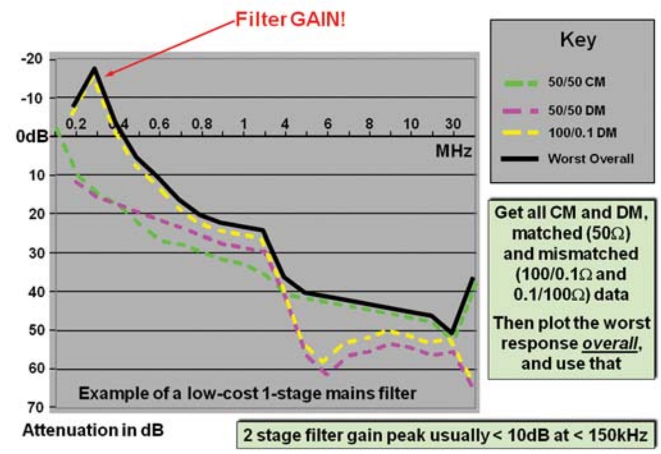


Figure 7.3-1 Example of a single-stage mains filter, matched and mismatched attenuation

In general, filters with two or more stages have mismatch resonances that are lower in amplitude and lower in frequency than single-stage filters such as the example in Figure 7.3-12, although this will not be evident from their matched 50/50 test results and they will cost more.

Figure 7.3-13 indicates how to deal with this problem: we obtain all six CM and DM, matched and mismatched attenuation curves, plot their overall worst case, and use that as our guide to the real-life performance of the filter.

The result of this exercise isn't *really* the worst-case, because all the CISPR 17 tests use resistive sources and loads rather than complex impedances, and also they aren't as extreme as what will occur in real life – so it is best to allow an "engineering margin" for filter performance, say by assuming they are worse by a further 10dB.

Some filter manufacturers publish the mismatched figures for their filters as a matter of course, although of course they don't appear in short-form catalogues or distributors' data. Some filter manufacturers will test their products for mismatch upon request.

Figure 7.3-14 through 7.3-19 shows the results I received in May 2011 from MPE Ltd when I requested a complete set of attenuation full test data for one of their high-performance mains filters whilst choosing the filters for the 2,000 or more control and instrumentation cabinets for ITER [75]. They provided me with the data within 24 hours of my request.

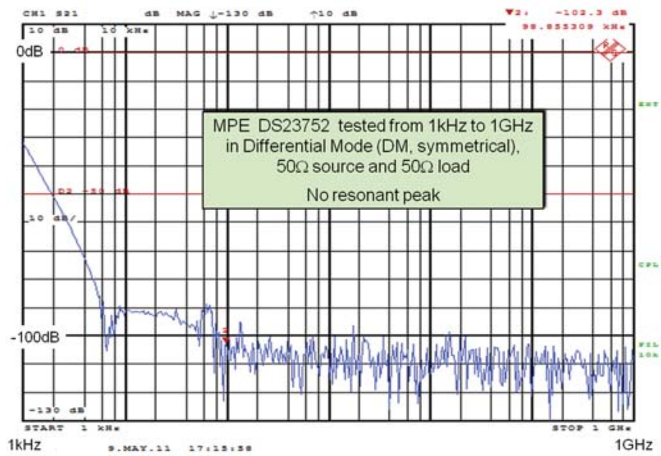


Figure 7.3-14 Example of high-performance mains filter, DM, matched 50/50

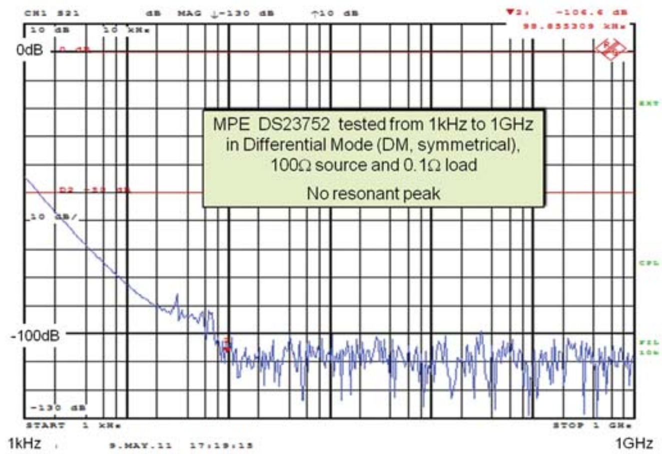


Figure 7.3-15 Example of high-performance mains filter, DM, mismatched 100/0.1

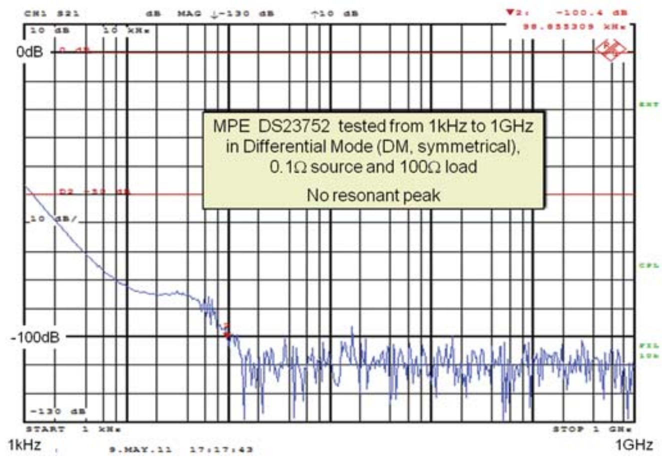


Figure 7.3-16 Example of high-performance mains filter, DM, mismatched 0.1/100

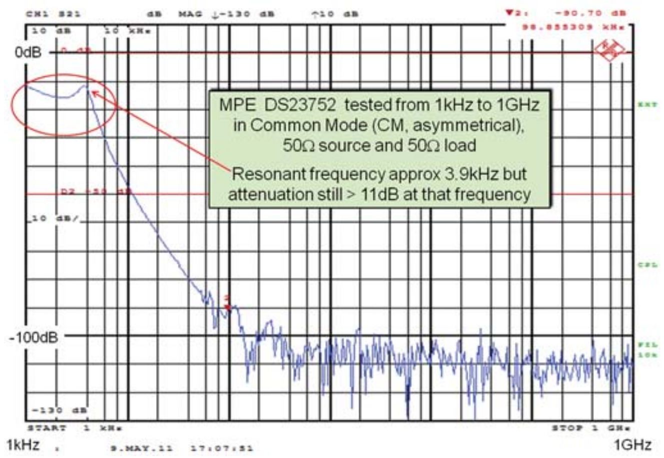


Figure 7.3-17 Example of high-performance mains filter, CM, matched 50/50

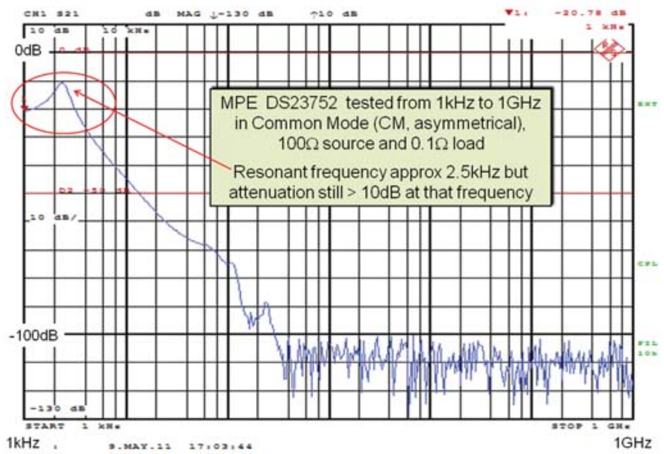


Figure 7.3-18 Example of high-performance mains filter, CM, matched 100/0.1

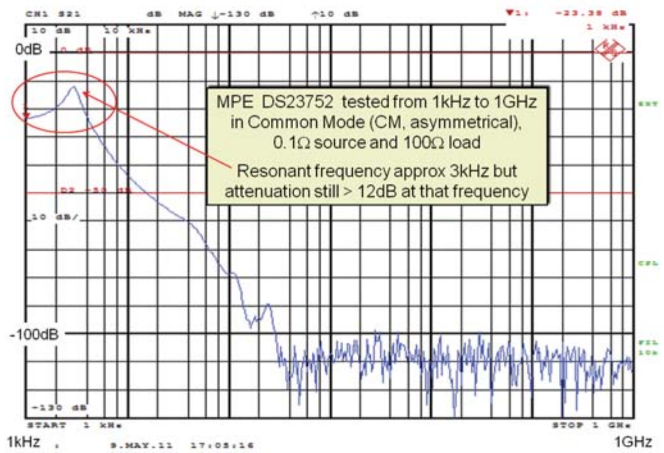


Figure 7.3-19 Example of high-performance mains filter, CM, mismatched 0.1/100

More information on choosing mains filters and dealing with real-life impedances that are not 50Ω *and* resistive is given in Chapters 5.2.8 and 5.2.9 of [5], and its Chapter 5.2.11 discusses how to dampen down mains filters so they don't produce quite so much "negative attenuation" (gain) when mismatched.

I had an interesting example of filter resonances some years ago when I was asked to "fix" the excessive emissions from a winch fitted to the outside of a Navy submarine. The winch was driven by a variable-speed motor and drive that switched at 1kHz, both inside a waterproof pressure housing that mounted on the outside of the submarine's hull.

Full marks to the designers for combining the drive and motor inside one metal box – the DC Link and motor cables were so very short and so well shielded that they were unlikely to cause any problems at the harmonic frequencies created by this drive. The problem was that the military EMC conducted emissions standard that applied, measured from 200Hz to 100MHz, and the 1kHz drive had a virtually flat emissions spectrum about 10dB above the limit line, for every 1kHz spacing from 1kHz to 100MHz.

Filtering to reduce emissions by 20dB or more is an easy job, so I expected to finish the work in a morning, but by the end of the first day I had gone through dozens of filter designs using nearly all my samples of inductors, chokes and capacitors with no solution in sight.

What was keeping me from a quick solution, was that I could easily make filters that reduced the conducted emissions almost to the noise floor from 50kHz to 100MHz, but they all had a gain peak below that frequency, sometimes as low as a few kHz, and that gain peak boosted the emissions failure from 10dB to 20 or 30dB around its frequency. It was most frustrating!

If the drive had switched at 10kHz I could have arranged the filter resonance to either lie below 10kHz, or mid-way between 10 and 20kHz, but with 1kHz-spaced harmonics I couldn't make the filter's Q high enough not to amplify the harmonics on either side of it. And I didn't have large-enough values of components to get the resonance below 1kHz (nor did I want to use such large and costly parts anyway).

That night, eating dinner in my hotel, I remembered section 7.1 in [72] (well, actually, I remembered its basic premises, because I hadn't written that article at that time).

So at the start of the next day I asked the customer to dismantle the pressure housing so I could get at the drive itself. He wasn't very pleased, because it took over an hour to remove all the bolts and separate the two gasketted halves, but he did it, and it then took me five minutes to solder a single 470nF polypropylene capacitor across the DC link and reduce all the conducted emissions by 20dB. No mains filter was required at all, saving weight and cost. By lunchtime he had reassembled the pressure housing and we had confirmed that from 200Hz to 100MHz all the 1kHz-spaced emissions were now 10dB below the limit line and the winch complied with its conducted emissions standard.

As 7.1 says (see [72]) it is much better in every way to design a converter that has low emissions and only needs a little filtering and/or shielding (if any), than it is to design a converter without using good EMC engineering and expect to be able to suppress its excessive emissions by filtering and/or shielding.

With civilian emissions standards ceasing to measure conducted emissions at frequencies below 150kHz, it is not too hard to design or choose filters with resonances below 150kHz and pass the tests. But where power converters are switching below 150kHz these filters can easily amplify converter noise below 150kHz and risk causing interference problems in real life.

Remember, compliance with the EMC Directive means compliance with its Essential Requirements. Passing tests to all relevant standards listed under the EMC Directive is the usual method of being legally permitted to sign a Declaration of Conformity and applying the CE-Marking (although not the only method) – but if our products cause interference in real life, when used as intended, they don't comply with the Essential Requirements and are not legal to supply or use, even though they pass all the tests.

I had a good example of this a few years ago when a shiny new machining centre was installed in a factory that made metal fixings (nuts, bolts, screws, nails, etc.). The machining centre took sheet metal in, and spat finished fixings out, under computer control. When it was working it sounded like a heavy machine gun, and most of the other equipment on the factory malfunctioned.

A quick look at the mains waveform with an oscilloscope showed that whenever the new machining centre operated, about 20V pk-pk at around 15kHz appeared on the mains distribution for the entire factory.

EMC Directive-listed immunity standards only test conducted RF down to 150kHz, so the equipment had not been designed to withstand significant levels of mains noise at 15kHz.

The machining centre used a 55kW Siemens motor drive, and it was this that was causing the 15kHz mains noise, either the 5th harmonic of its 3kHz switching rate or the 3rd harmonic of its 5kHz switching rate – I don't remember which. The machining centre's manufacturer had not used the drive filter recommended by Siemens, instead they had had a lower-cost one made that still passed the conducted emissions test limits – at 150kHz and above.

But this filter resonated at 15kHz and – being underdamped – *amplified* the already large drive emissions at that frequency, causing mayhem in the rest of the factory.

All we had to do was get the machining centre manufacturer to replace the custom filter with the more costly one recommended by Siemens, which had a resonant frequency below the lowest drive emission frequency, and the 15kHz noise level fell to below 0.5V pk-pk and the rest of the factory was then unaffected.

Figure 7.3-20 is a photograph of this actual drive with its Siemens filter fitted, in its cabinet. I often use it as an example of good EMC engineering in industrial cabinet design, because its manufacturers had done a very good job indeed – except for assuming that complying with the emissions test standards would be sufficient for preventing interference in real life.

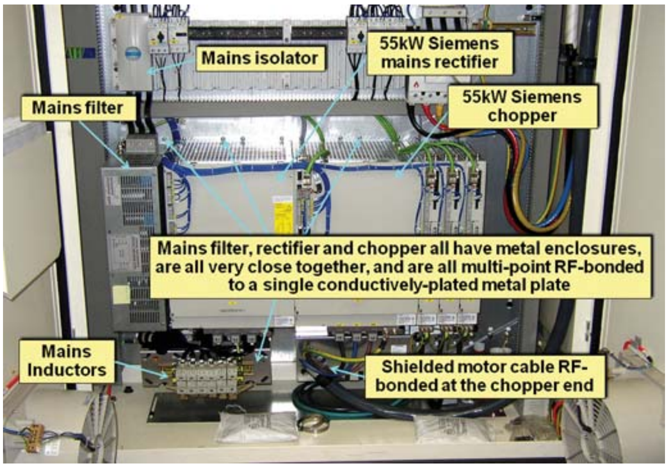


Figure 7.3-20 The Siemens 55kW drive with its associated mains filter, from the story above

7.3.9 Filter resonances caused by the negative impedances of power converter inputs

All types of switch-mode power converters draw more current from the supply as the supply voltage decreases, and this means they have a negative input impedance.

Negative input impedances can cause resonances when the supply is via filters with significant series inductance, and they can be severe enough to damage the converters, and possibly even other equipment connected to the same power supply distribution network.

Solutions are to reduce the series inductance in the filter, and/ or increase the value of capacitance that is connected across the power converter's input terminals.

For more on this issue, see [76]. Many more useful references can be found on the Internet.

7.3.10 Filter construction and installation

These issues are fairly comprehensively discussed in EMC Journal articles [14], books and guides I have written, so I won't duplicate their text here, but I have copied some of their figures as 7.3-21 to 7.3-33, covering (in order):

- Filters mounted on PCBs, see Chapters 2.6 of [37] and 5 of [5] for a lot more on these good EMC design techniques
- Filters mounted in the walls of small enclosures, such as personal computers (PCs), see Chapter 3.1 of [37] and 5.3 of [5] for a lot more on these good EMC design techniques
- Filters mounted in equipment cabinets, see [68] and Chapter 5 of [5] for more on these good EMC design techniques
- Filters installed in systems and installations, see Chapter 8 of [70] and Section 5.10 of [69].

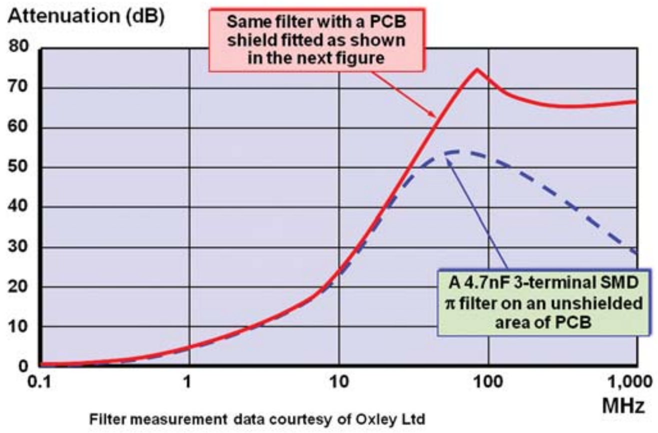


Figure 7.3-21 PCB filters benefit from shielding

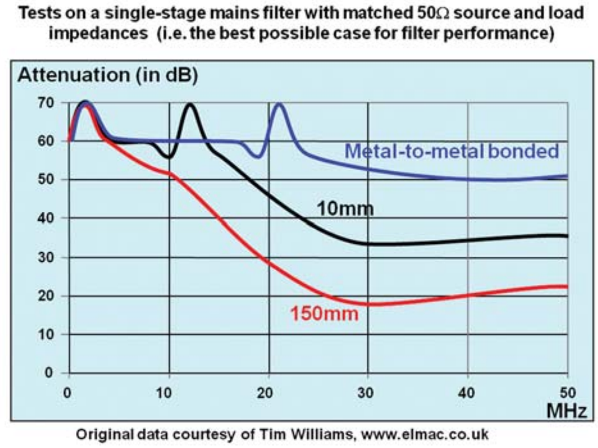


Figure 7.3-24 Comparison of two lengths of filter RF-bonding wire

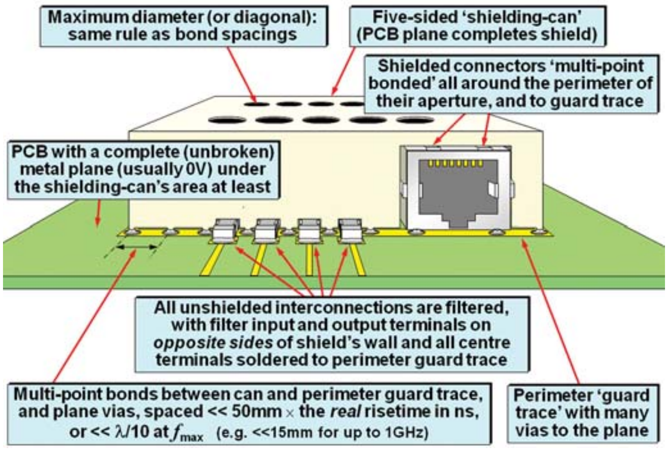


Figure 7.3-22 Overview of good EMC design by combining PCB shielding with filtering

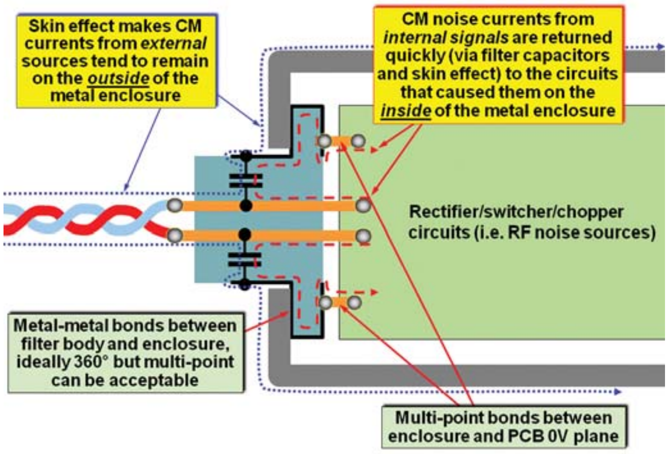


Figure 7.3-25 Example of filter RF-bonding to control surface currents

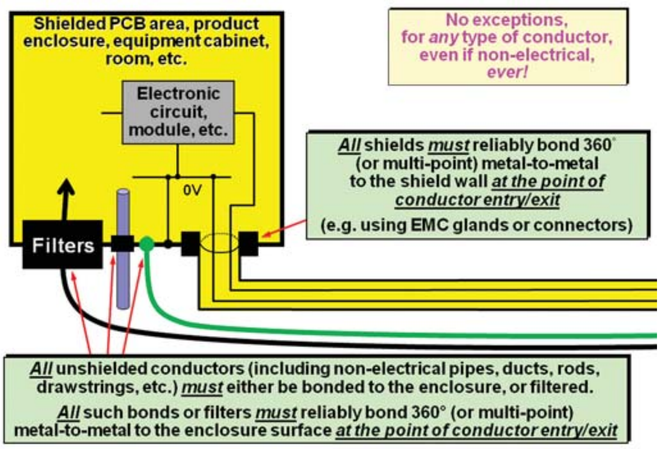


Figure 7.3-23 Dealing with conductors entering shielded enclosures/areas

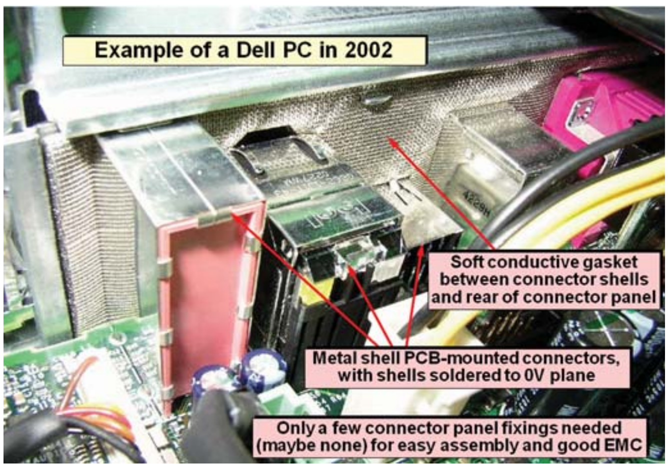


Figure 7.3-26 Easily making good 0V plane – chassis bonds by using conductive gaskets

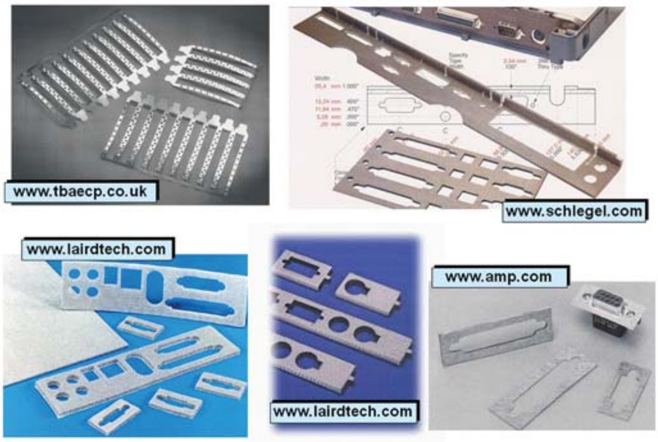


Figure 7.3-27 Examples of die-cut conductive gaskets suitable for bonding to PC chassis

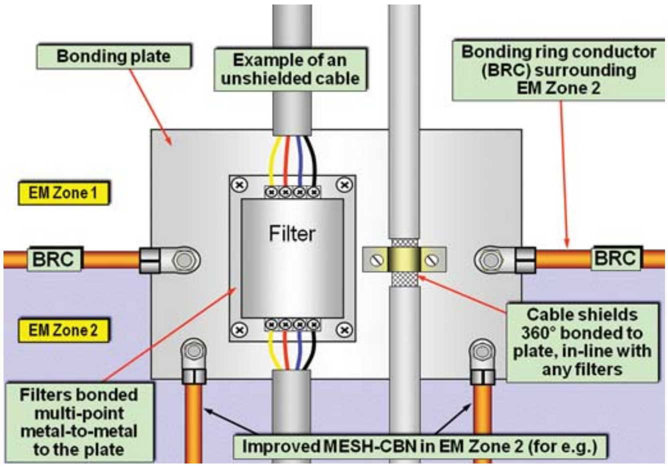


Figure 7.3-30 Example of direct and indirect RF-bonding (via a filter) at a Bonding Ring Conductor, using a bonding plate

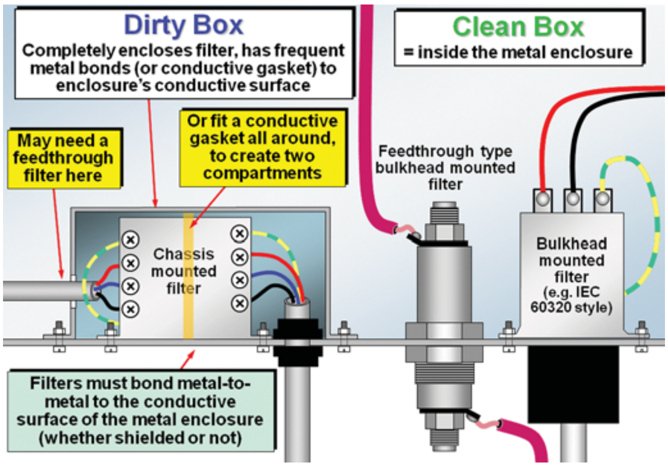


Figure 7.3-28 Good assembly techniques for filters in metal enclosures

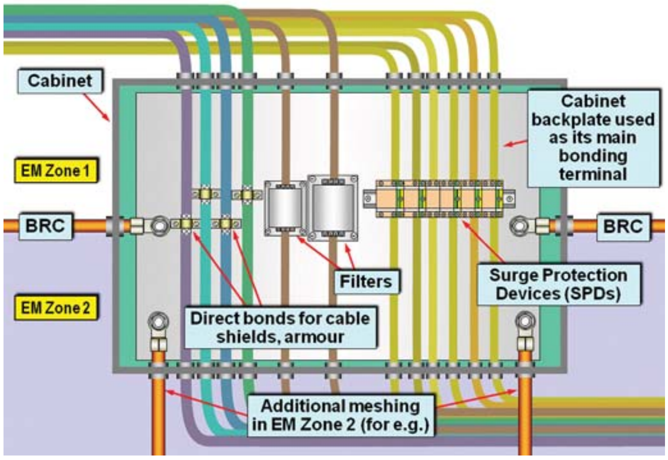


Figure 7.3-31 Example of direct and indirect RF-bonding (via filters and/or surge arrestors) at a Bonding Ring Conductor, using a cabinet backplate

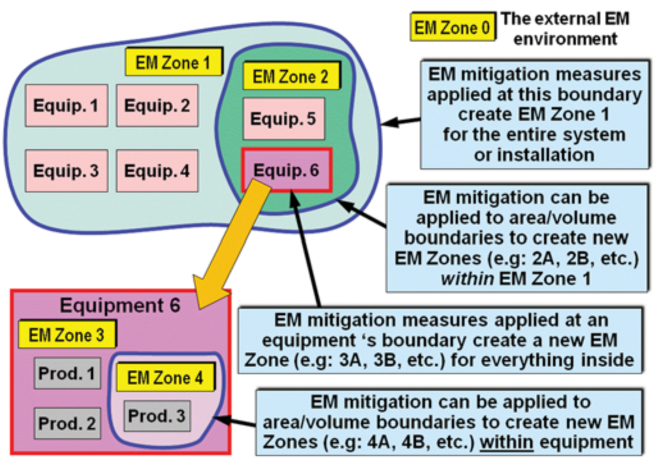


Figure 7.3-29 Using EM Zoning techniques to control EM environments

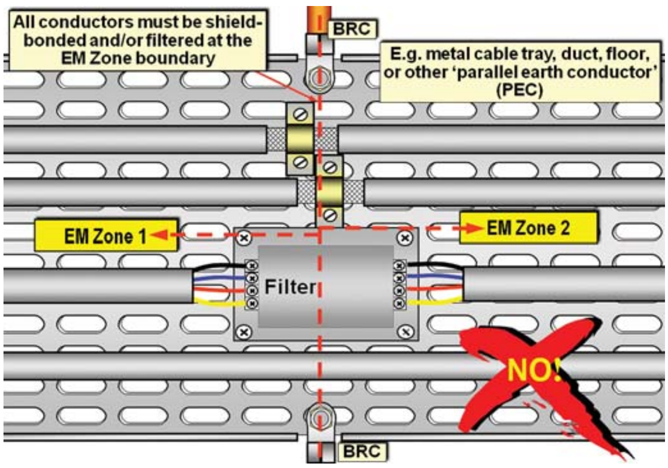


Figure 7.3-32 Example of direct and indirect RF-bonding (via a filter) at a Bonding Ring Conductor, using a cable tray

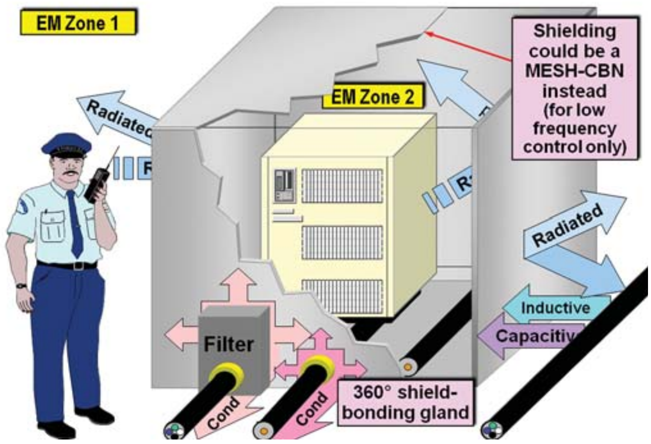


Figure 7.3-33 Shielded EM Zones need filtering too, for all unshielded cables

7.3.11 Filter reliability over time

Issues covered in the text of the articles, books and guides that are not covered in the above figures include the variations in component values (hence filtering effectiveness) and reliability with variations in temperature, voltage and load current. Getting this wrong has been shown to reduce the attenuation of filters by 20dB, when they are used within their maximum ratings (see [78]).

So it is necessary to ensure that, for worst-case combination of load current, supply voltage and ambient temperature, the current rating is adequate, and the attenuation and expected lifetime of the filter remains adequate.

Surge transients can damage power supply filter capacitors, so it is best to complete all surge tests before testing RF emissions and immunity. Real-life surges on all 115/230/400V single-phase supplies worldwide can exceed 6kV (line-line and line-earth/ground) [79]. For three-phase supplies that power only three-phase distribution systems with IEC 60309 or similar three-phase mains sockets, anecdotal evidence suggest allowing for surges of up to 15kV.

Some X2 capacitors lose 10% of the value every 1000 hours of operation, which means they can lose 90% over just 3 years (100nF capacitors degrading to 9nF over 3 years of continuous use have been seen in practice, and were not considered unusual by their manufacturers), and it might be thought surprising that this is permitted by their safety test standard, IEC 60384-14.

This loss of capacitance value is caused by "inception" (i.e. partial discharge or corona discharge that eats away at their very thin metallised layers) – which would start at 200V AC rms unless the air in the capacitor was replaced by resin or oil – or by using two capacitors in series.

IEC 60384-14 requires using two capacitors in series for all Y1 caps – but not because of inception – so that if one goes short-circuit there is another in series to prevent safety risks caused by high levels of earth/ground leakage current. Of course, it has the benefit that all Y1 capacitors used on their rated mains supplies do not suffer inception.

To achieve very high reliability, capacitor manufacturers such as MPE make all their filter capacitors (X and Y) as two capacitors in series, so they suffer no corona discharge and hence no reduction in capacitance value over years of use. As an example, MPE recently received over 20 of their mains filters from a military base that was being refurbished after nearly three decades of continual use, and found by re-measuring them, that they all still met their original specifications.

So, because we want our filters to maintain their performance for their operational lifetime, we should choose X capacitors that are rated for twice the AC voltage, and/or that have an acceptable specification for their rate of capacitance loss based on the results of actual tests performed by their manufacturers.

7.3.12 Filter attenuation depends upon the impedance of its RF Reference

A filter's RF Reference is a conductor that is shared with the circuit to be filtered, to control the RF surface currents so they flow in smallest size current loops and so create the least efficient "accidental antennas".

An RF Reference is generally at a circuit's 0V potential, and/or at earth/ground potential (but not necessarily!), and its impedance should be <<1Ω (preferably <10mΩ, ideally <1mΩ) over the entire frequency range to be suppressed by filtering and/or shielding (which often need to be used together, as figures 7.3-21 – 7.3-33 above show.

What should we use as the RF Reference?

- For a single PCB
  At least a "solid" (i.e. continuous copper with no gaps) 0V plane, better still a 0V plane that is RF-bonded to a metal chassis/enclosure, with the best performance achieved using a well-shielded metal enclosure. For more detail, see Chapter 4 of [37].

- For a product containing several PCBs
  At least a metal chassis/enclosure, better still one that is RF-bonded, with the best performance (once again) achieved using a well-shielded metal enclosure. For more information, see Chapters 5.2 of [5] and 2 of [68].

- For an electronic cabinet
  Its metal backplane area, or its metal cabinet (shielded cabinets being the best). For more detail, see Chapter 2 of [68].

- For a distributed system, installation or site
  Its "common-bonding network" (CBN), which means the site's metal structure, which is usually (although not necessarily) safety earthed/grounded. Two-dimensionally-meshed areas are better, with three-dimensionally-meshed areas being better still. A shielded enclosure, room or building (yes, they are used) is the very best. For more detail, see Chapters 3.4 and 5.5.3 of [69] and 5.3 of [70].

When using a metal volume (box) as a filter's RF Reference, it only provides a low enough impedance over the frequencies for which its RF-bonding and/or shielding has been designed to be effective (see later).

Poorly shielded / unshielded boxes create impedances that depend upon their detailed design, and *will* suffer from high-impedance resonances at some frequencies (see our module on shielding) at which filters will not work well at all.

Shielding techniques are described in more detail for PCBs in Chapter 2.6 of [37]; for products in Chapter 6 of [5]; for equipment cabinets in Chapter 5 (starts on page 55) of [68], and for systems and installations in Chapters 5.12 (starts on page 134) of [69] and 6 of [70].

When using a metal area as a filter's RF Reference, a single sheet of metal (one with no seams or joints) maintains low impedance to many GHz, but suffers "patch antenna" high-impedance resonances at some frequencies due to its dimensions, and at these frequencies filters will not provide much attenuation.

A seamed or jointed metal area will suffer from high-impedance resonances at frequencies that depend on detailed design aspects, once again degrading filter attenuation at these frequencies.

A larger metal area and thicker material extends an RF Reference's low impedances to lower frequencies (but its patch antenna frequencies will also reduce).

PCB 0V planes and other metal sheets or meshed-conductor area structures are only effective as RF References, for components/conductors closer than λ/10 to the plane, preferably < λ/100, and further from any plane edge than their height above the plane.

λ is the wavelength of the frequency to be filtered, and we generally base our designs on the highest frequency, f_{max} (i.e. the shortest λ) at which we want out filters to be effective – which is almost always the same as the highest frequency we need to suppress by any means, whether by filtering or shielding. It is easy to calculate λ for conductors in air or vacuum, as $300/f_{max}$ metres, where f_{max} is given in MHz (f_{max} in GHz gives λ in millimetres).

When using a metal mesh or meshed structure of any size as a filter's RF Reference, for example perforated metal sheet, "weldmesh", wire mesh, electrically-bonded conductors and/or metal structures, etc., they are only effective at all up to 30/L MHz, where L is the dimension of the largest mesh diagonal in metres (if L is given in mm, 30/L gives results in GHz).

Meshes only provide a good low-impedance below 3/L, and 0.3/L is much better (sheet metal is best).

All meshes *will* suffer from high-impedance resonances at frequencies above 50/L, where filter attenuation will be significantly degraded.

For more information on using meshes or meshed structures as RF References, see Chapter 5.5.3 (starts on page 71) of [69] and Chapter 5.3 of [70]. Figures 7.3-34 through 7.3-27 are examples taken from [69].

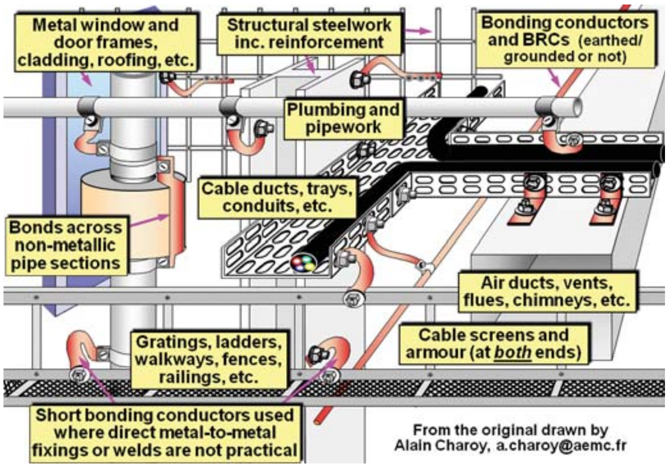


Figure 7.3-34 Creating a meshed RF Reference using existing ("natural") metal structures

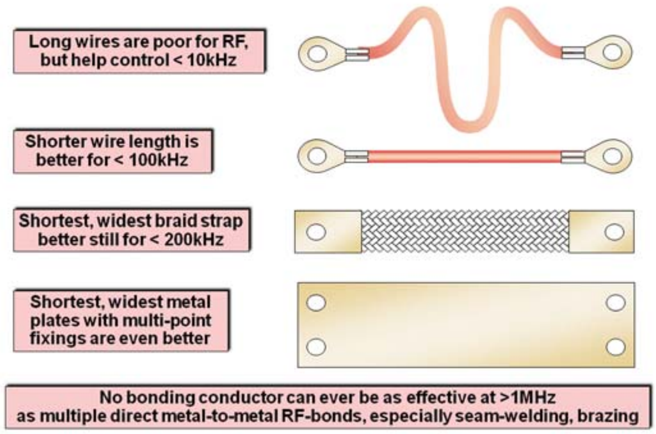


Figure 7.3-35 Some RF-bonding conductors

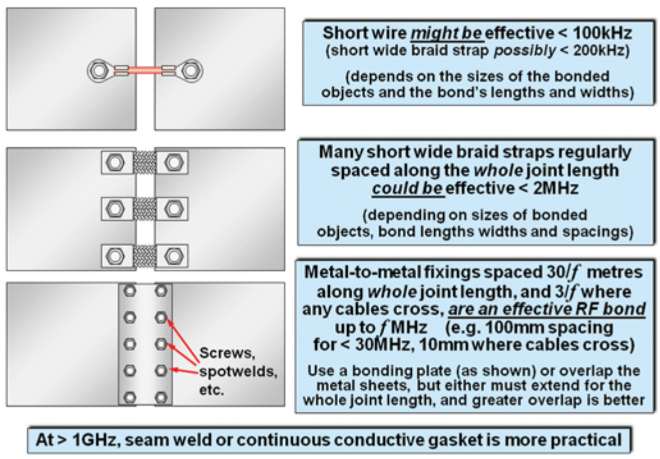


Figure 7.3-36 Some RF-bonding methods

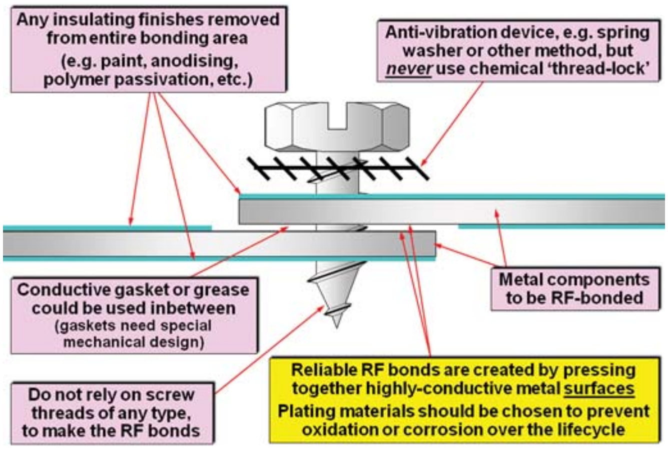


Figure 7.3-37A direct metal-to-metal RF bond (using a self-tapping screw as an example, and shown partially disassembled)

7.3.13 Filter attenuation also depends upon the impedance of its bond to the RF Reference

A filter's RF bonding to its RF Reference (see 7.3.12) must *also* be <<1Ω (preferably <10mΩ, ideally <1mΩ) over the range of frequencies it is to suppress – and this applies also to the circuit being filtered.

The RF bonding method used must control the surface currents so they flow in smallest loops, hence creating least efficient "accidental antennas". Ideally, we use 360° direct metal-to-metal contact or multipoint direct metal-metal contacts with spacing <<λ/10 at f_{max}, preferably < λ/100. However, bonding with a few millimetres of wire or braid might be acceptable where the frequencies to be filtered are <100kHz and the filter attenuation required is <20dB (see figure 7.3-24).

The green, green/yellow or clear insulated, or plain, metal wires or braids used for filter safety earthing/grounding are almost always unsuitable as their RF bonds, because they are much too long.

(Braids or straps with a length-to-width ratio of less than 5 are often mentioned in texts on EMC as if they have magical low-inductance properties. Trying to discover where this fallacy originated leads to military documents that appear to have been written before 1980, but can no longer be identified. Anyway, there is no physical basis for this ratio being special in any way. The most important thing with any conductor used for RF bonding is to make its length as short as possible. The next most important is to increase its surface area to as large as practicable, a 5:1 length to width ratio is OK, but 3:1 is better and 2:1 better still. And where the dimension of the joint that is being RF-bonded is longer than λ/10 at f_{max}, use multi-point bonding with such conductors spaced <<λ/10 at f_{max} apart.)

RF-bonding techniques are described in more detail for PCBs in Chapter 3 of [37]; for products in Chapter 5.3 of [5]; for equipment cabinets in Chapter 4 (starts page 45) of [68], and for systems and installations in Chapters 5.7 of [69] and 5.2 of [70].

7.3.14 Filter frequency range and shielding

I must mention a very important point here, which is that a converter's AC or DC power input or output cables contribute to radiated emissions, and "leakages" from imperfect shields contribute to conducted emissions. So any filtering and/or shielding has to be effective over the full range of frequencies that need to be suppressed.

Many designers think that mains cables only need filtering over the range of conducted emissions to be tested (typically 150kHz to 30MHz for the EU's EMC Directive), so they think they only need filters that attenuate to 30MHz, which means that most low-cost filter manufacturers only design and specify their filters to be effective up to an f_{max} of 30MHz – causing many problems for radiated emissions above 30MHz. They know that good filtering is required to higher frequencies than this, but can't justify the added cost when their customers can't see the need.

If radiated emissions are to be measured to, say, 1GHz, then the mains cable filters generally need to be effective up to 1GHz too. This is why the mains filters in figures 7.3-14 to 7.3-19 were tested from 1kHz to 1GHz.

However, power converters that do not incorporate microprocessor circuits, and are not enclosed in the same boxes as microprocessors, generally have a limited ability to generate frequencies above a few hundred MHz, meaning that their input and output filters do not have to provide much attenuation at higher frequencies. High-power converters use larger switching devices that switch more slowly, and might not emit much noise above, say, 20MHz.

7.3.15 Special issues for filtering power converter *outputs*

Converter AC or DC power output filters are similar in construction to their power input filters, and all of the previous good EMC design and installation practices for power input filters apply in exactly the same way to power output filters, and ordinary mains filters can be used for DC outputs.

But there are some special considerations for converters with AC outputs (e.g. PWM). Mains filters designed for 50Hz can generally be used with little/no derating up to 400Hz sine-wave (it is best to check with the manufacturer) but some power converters directly output kHz rectangular waves or PWM, that have switching rates from up to several hundred kHz with harmonics up to more than 100 times higher.

Variable-speed motor drives for AC motors are often described as having outputs from 0Hz to 100Hz (say) but in fact these numbers refer to the sine-wave modulation frequency of the PWM waveform. They rely on the integration of the PWM waveform in the magnetic core of the motor's stator to create the sine-wave flux at 0 to 100Hz that spins the rotor.

Similarly, variable-speed DC drives output a PWM waveform with a mark-space ratio that corresponds to the DC voltage specified when the PWM has been integrated by the motor winding's iron core.

Similar issues apply to other motor drives, for example for stepper-motors or reluctance motors, because they all use rectangular output waveforms generated by power switching semiconductors.

It is not surprising that the PWM outputs of choppers (and the like) are extremely large sources of EMI. A 10kW variable-speed motor drive connected to an AC or DC motor is essentially a 10kW radio transmitter emitting its RF power at many dozens of discrete frequencies into a mismatched cable connected to a mismatched motor, so exceeding emissions limits is easy!

PWM and similar types of converter outputs are generally suppressed by shielding, which I intend to cover in a future article. But filtering is a powerful technique that is generally not used enough. [82] might be interesting here.

PWM (and similar) converter output filters must be designed or chosen for the PWM frequency taking account of the chopper's design, so as not to make the chopper unreliable, so where a proprietary chopper is to be filtered I always recommend checking with the manufacturer whether the type of filter that is proposed is acceptable. Some converter manufacturers might list suitable output filters in their EMC installations manuals.

When we are designing our own power converters, we should ensure that any output filters we add do not cause the voltages/currents in the power switches to behave in ways that might cause unreliable operation – over the whole range of operating conditions that are possible.

Output filters can be used to just "round off" the sharp edges of the output waveform and thereby reducing levels of RF emissions at higher frequencies. These are often called dV/dt filters, and they are available in different strengths – providing greater or lesser degrees of rounding. These filters are often used to assist output cable shielding in meeting emissions specifications.

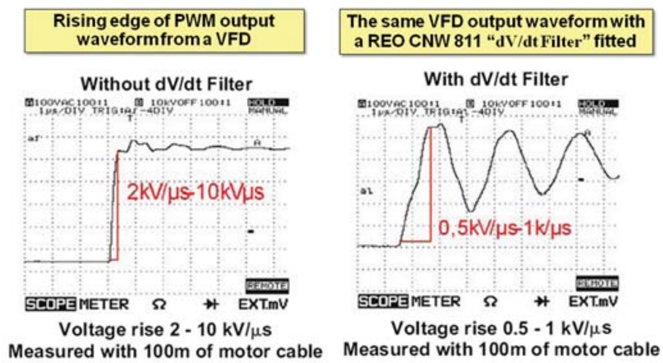


Figure 7.3-38 Example of the effect of a dV/dt output filter

Figure 7.3-38 shows a proprietary dV/dt filter slowing the rising edge of a converter's output waveform from 2kV/µs to 0.5kV/µs, thereby reducing the levels of high frequencies in its emitted spectrum. Note that the dV/dt filter causes strong ringing at about 350kHz, that was not present in the original waveform, and which might possibly cause a new problem at that frequency.

One important purpose of dV/dt filters has nothing to do with suppressing EMI – they can be used to reduce the overshoot voltage that occurs at the motor terminals due to the impedance mismatch between the cable and the motor windings – the "Faraday Effect" – and can damage the motor winding's insulation.

Modern choppers switch so rapidly that motor overvoltages of 200% of the nominal motor AC voltage rating can now arise with cables as short as 13 metres or less [80] – which is a problem, because most AC motors use insulation that is only rated for twice the nominal 50 or 60Hz AC rms voltage and so can be damaged by such high levels of overshoot. [81] shows that overvoltages of 300% or more can also be caused in situations where 200% at most might be expected.

DV/dt filters also help reduce the level of RF "bearing currents" – caused by the stray capacitance between the stator windings with their PWM waveforms and the rotor, that can cause sparking in the bearings that wear them out in one-tenth the normal lifetime.

We can go a long way beyond dV/dt PWM filters, to use what are often called "output reconstruction filters".

These integrate the PWM in their inductors and capacitors, instead of leaving it to the motor or other load, at the end of a long and mismatched cable, to do the integration. The output of a reconstruction filter is the low-frequency sine-wave or variable DC level that the converter's front panel controls say it is providing (e.g. 0Hz to 100Hz).

Most filter manufacturers who supply output reconstruction filters, supply types that reconstruct only the DM waveform, and this is very good for entirely preventing overvoltaging motor winding insulation. They also have *some* benefits for reducing bearing RF currents and suppressing EMI.

But to greatly reducing bearing currents and greatly suppressing EMI requires output reconstruction filters that that reconstruct both the DM *and CM* waveforms from the PWM. These are costly filters, and at the time of writing are only available from a few manufacturers, but they are generally cost-effective (especially so when long output cables are necessary) because the Faraday Effect and EMI emissions become much worse with longer cables, and the only alternative method – shielded cables – is even more expensive.

Reconstruction filters for variable-speed AC motor drives are sometimes called "sine-wave output filters", or "Sinus output filters", and are available from REO, Siemens, and a few other filter manufacturers. Some of them require a connection to the converter's DC Link.

Types that reconstruct the DM and CM waveforms are given a variety of unhelpful names by their manufacturers, which do not help when web searching for their suppliers. I tend to call them "sine-wave CM + DM PWM output reconstruction filters" so that their design and purpose is evident, but this description isn't very helpful as a search term either. [83] is a guide to their use, from REO (UK) Ltd.

7.4 Filters and safety

A very important issue associated with AC mains filters is the safety of the earth/ground leakage currents caused by their filter capacitors – *which might continue to flow even when the equipment is switched off by its front panel control*.

Figure 7.4-1 is the filter for the Dipole Magnet Power supply for a synchtrotron. Its leakage current of 3A meant that special safety precautions needed to be taken to prevent electric shock in the case of a broken protective earth (safety ground) conductor.

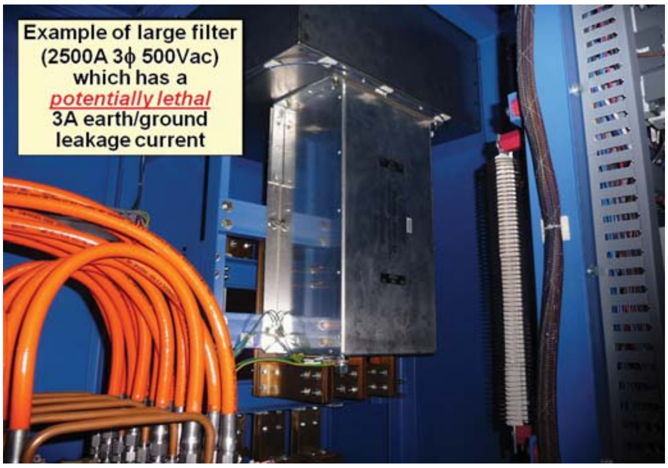


Figure 7.4-1 Example of a filter with a very dangerous earth/ ground leakage current

The safety issues associated with filter earth/ground leakage currents are all discussed in Chapter 5.2.12 of [5], and I won't duplicate its text here other than to say that most (if not all) national wiring/installation regulations, such as the UK's BS7671 [77], require items of equipment with excessive earth/ ground leakage currents to be installed in a special way.

(There is an interesting non-safety story associated with the 3A leakage current from the filter in figure 7.4-1. Because the system used single-point earthing (ugh!) and the safety earth/ ground cable from the dipole magnet power supply was routed back to the distribution room with a 500mm spacing from the three-phase AC supply cables, the resulting magnetic field from the leakage current coupled with the beam position monitor cables and put a lot of 50Hz noise onto the synchroton's electron beam position, reducing the synchrotron's usefulness for the science experiments it was intended to perform for several years. Of course, the electrical installers had no idea that this could be the result, they just routed the cables where they seemed easiest. They also didn't fit any mains filters to the dozens of 100kW inverter drives in the plant room, despite them being required by the drive manufacturer's installation instructions, resulting in high levels of noise up to 10MHz all over the large site, with a peak at 2MHz – the site's resonant frequency. But these are stories for a different article!)

Mains distribution systems protected by residual current circuit breakers (RCCBs), sometimes called earth-leakage circuit breakers (ELCBs) , residual current detectors (RCDs) or ground-fault interrupters (GFIs), will have reliability problems when using mains filters.

Transients and surges on the mains cause unbalanced transient currents in the filters, which can trip the breakers, as can the higher leakage currents of larger filters, which can also trip main breakers during switch-on or transients/surges.

The lowest-cost solution may be to omit the RCCBs (ELCBs, RCDs, GFIs, etc.), and use high-integrity safety earthing/ grounding techniques instead.

But it is possible to use RCCBs (ELCBs, RCDs, GFIs, etc.) with mains filters (however high their leakage current) by passing the mains power through an isolating transformer before the mains filter. The isolated neutral should not be earthed/ grounded, or else the centre tap should be grounded (e.g. supplying 230V as 115-0-115), and the same safety earth/ground must be used for both sides of the transformer.

As mentioned in 7.3.9 above, power converters work best when their supply comes from big fat capacitors, which is also best for EMC too, but Chapter 5.2.12 of [5] doesn't discuss the design of the discharge resistors needed for filter capacitors that can be charged at hazardous voltage.

When designing and building our own mains filters and off-line rectifiers we mustn't forget to fit all capacitors over 0.1µF with discharge resistors independently safety-approved to IEC 60065 clause 14.1.a), so that they will handle the peak value of voltage surge expected on the mains supply without damage or safety problems. Filter manufacturers should be well aware of this (but it is worthwhile checking with them, to make sure).

I have always used VR37 resistors for discharging all mains filter and off-line storage capacitors, regardless of value, but I often see products that use a single 1206 resistor for this purpose. Of course, when they have been used for a few months these resistors are always failed open-circuit, having been destroyed by mains surges, exposing users to dangerous shocks from the pins of their mains plugs – possibly for days or weeks after disconnection from the mains supply.

How did such products ever pass their surge tests to IEC 61000-4-5? Well, when these surge tests are done, the functionality of the product is checked afterwards – no-one checks that the mains filters are still discharging as they should when unplugged from the supply.

Test labs should now perform a quick re-check of the conducted and radiated emissions after a surge test, to check that the mains filter is undamaged, but it seems that some EMC test labs don't always do this. But even when they do, they don't check that the filter capacitor discharging resistors have not been damaged by the surges, and even if they were not damaged by the standard surge test, it only tests with surges to a kV or two, whereas we know that real-life surges can exceed 6kV a few times each year.

Inadequate mains filter discharge resistors should, of course, have been identified during product safety testing, but many manufacturers do their own safety tests. It appears that the necessary ruggedness (and standards compliance) of mains filter discharge resistors is an issue that is sometimes overlooked.

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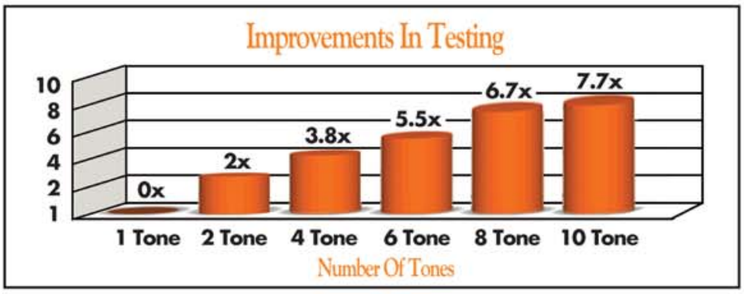

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