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from EMC Standards

Tutorial on EMC for Functional Safety part 1

Helping you solve your EMC problems

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Tutorial on EMC for Functional Safety

Including an introduction to IEC 61000-1-2

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&
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Tutorial Contents

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Introduction to EMC for Functional Safety

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Contents of this module

1. How EMC can affect functional safety
2. IEC 61508's EMC requirements
3. EMC testing is inadequate for safety
4. Shortcomings in Directives and their standards
5. How to control EMC for functional safety

The word "equipment" as used in this module generally means: devices, units, appliances, systems and installations

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This module covers all appliances, equipment and machinery

- Used in...
  - households, commerce, industry, fairgrounds
  - medical and healthcare
  - all vehicles and transportation systems (road, rail, marine, air, etc.)
  - military, security, police and emergency services
- None of these areas yet employs standards that correctly deal with EMC for Functional Safety

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How EMC can affect functional safety

- When electronics is used in equipment which, if it went wrong, could create health or safety risks...

  ...then it is very important to have confidence in the performance of those electronics

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How EMC can affect functional safety
continued...

- Unfortunately, ***all electronics*** can suffer from inaccuracy, mis-operation or damage…
  - due to electromagnetic interference (EMI)
    - and electromechanical devices can suffer from EMI too
- So EMI can be bad for health and safety
  - where a safety-related system employs electronics or electromechanics

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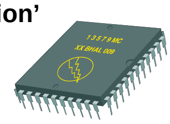
EMC is increasingly important, because...

- Mobile radio transmitters (e.g. cellphones, walkie-talkies) used everywhere, creating powerful fields nearby
- Modern electronics technologies (e.g. digital, switch-mode, wireless) emit more EM 'pollution'
- Semiconductor 'chips' or 'ICs' use ever-smaller features



  - and consequently are more likely to suffer damage or mis-operation due to electromagnetic (EM) threats
- Electronics is being used to control *everything*

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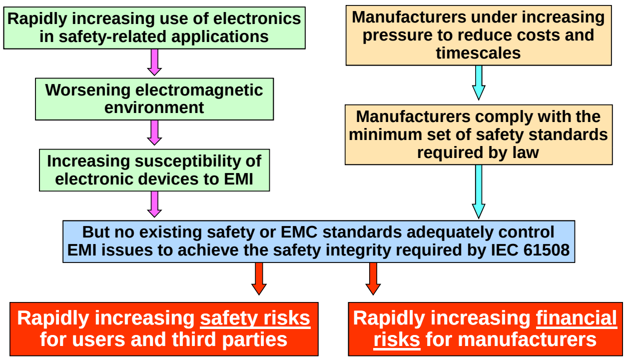
Increasing risks caused by EMC-related functional safety



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IEC 61508
Functional safety of electrical / electronic / programmable electronic safety-related systems

- This basic IEC standard on Functional Safety requires EMC to be taken into account
  - but does not say how to do this
  - we hope IEC 61000-1-2 will eventually fill this need
- Remember: all safety directives require all relevant standards and appropriate expertise to be used to achieve a high level of human protection
  - not simply slavishly following safety standards

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Safety standards are always based on the use of well-proven safety *engineering* techniques…

- ….that take account of….
  - all credible faults
  - environmental extremes and ageing
  - reasonably foreseeable use, or misuse
- This is *quite different* from the 'black box' testing that is normally all that is used for EMC
  - which *ignores* design, construction, foreseeable faults, physical environment, ageing, foreseeable use or misuse

Some safety standards employ
(or are are beginning to add)
'EMC for functional safety' requirements

- But instead of employing the IEC's basic standard on EMC for Functional Safety, IEC 61000-1-2...
  - they follow the approach used for the safety of medical devices and automobiles instead...
  - treating the equipment as a 'black box' and simply applying EMC immunity tests in much the same way as for compliance with the EMC Directive
- ***This approach is totally inadequate for safety***

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Normal immunity testing only covers one type of disturbance at a time

- **In real life, equipment is usually subjected to a number of electromagnetic disturbances (threats) *simultaneously***
- **Tests have shown that when one disturbance is applied (e.g. a radiated RF field)…**
  - **the immunity to a *simultaneous* disturbance (e.g. fast transient burst, ESD, etc.) is often *seriously compromised***

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Normal immunity testing does not simulate real-life EM exposure

- **Traditional EMC test methods are designed for accuracy and repeatability**
  - **they do not simulate real life exposure very well**
- **E.g. normal radio frequency (RF) immunity testing uses a single *modulation* frequency (e.g. at 1kHz)**
  - **but an equipment is much more vulnerable to radio-frequency (RF) threats when they are modulated with a frequency that is close to one of its control frequencies**
  - **or when they use a different type of modulation**

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Normal immunity testing does not simulate *foreseeable* EM exposure

- **Normal immunity tests cover 'normal' EM environments**
  - **not low-probability EM threats or unusual environments**
- **But where safety integrity levels are high, even very low-probability risks may be unacceptable**
  - **and low-probability EM threats will need to be considered**

A high current fault (courtesy of Powertech)

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Normal immunity testing might use inappropriate compatibility margins

- **Electromagnetic events have statistical distributions**
  - **and normal immunity tests set compatibility limits that are appropriate for commercial and industrial reliability**
    - **e.g. IEC 61000-2-2 permits 5% of EM events to exceed the tested levels**
- **These compatibility levels will probably not be tough enough where safety is a concern**
  - **depending on the safety integrity required by the application**

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Faults are not addressed by normal immunity testing

- **The normal EM activity in an environment must be withstood *all of the time***
- **But normal 'black box' immunity testing does not simulate common faults that can affect EMC, e.g.…**
  - **a broken joint in a filter capacitor, or in a filter's ground bond**
  - **a short-circuit or out-of-tolerance component that makes a circuit more unstable at RF**
  - **a broken spring finger gasket (not an uncommon fault)**

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Effects of the physical environment on EMC

- **Shock, vibration, condensation, dust, exposure to liquids, ageing, temperature extremes and cycling, bending and twisting (e.g. non-flat mounting), etc.**
  - **can all have a bad effect on EM vulnerability, e.g…**
    - **reducing shielding through poor contact at EMC gaskets**
    - **reducing filtering by ageing of filter capacitors and temperature variations of inductors' values**
- **But normal 'black box' EMC tests take no account of the foreseeable physical environment, or ageing**

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Normal immunity testing performance criteria might be inappropriate

- Degraded performance during interference that is considered to be perfectly acceptable for an individual item of equipment…
  - might result in unsafe behaviour of the system it is employed in
- So the performance criteria for the individual items of equipment are *application dependent*
  - they must satisfy the needs of the final safety system
    - as identified by a hazard assessment and risk analysis

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Safety requires good EMC techniques in *design* , *assembly* and *maintenance*

- …in the same way that well-proven safety design methods are required ***for all other safety issues***
  - including software (e.g. IEC 61508-3)
- EMC testing is necessary for verifying the EMC techniques that were used (or are to be used)
    - but the normal "EMC Directive" test methods (e.g. IEC 61000-4-x series) are inappropriate on their own
  - special test methods are required, which take the foreseeable EM *and physical* environments into account

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Safety shortcomings in EU EMC directives

- The EMC Directive (EMCD) ***does not cover safety***
    - EMC-related functional safety is covered by safety directives instead (see CENELEC R0BT-004:2001)
- The Radio and Telecommunication Terminal Equipment Directive (R&TTE) *does not* cover safety-related communications systems
- The various vehicular EMC Directives are inadequate for EMC-related functional safety
  - because they rely solely on 'black box' immunity testing; as do the EMCD's EN 50121 series of railway standards

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Examples of shortcomings in typical immunity standards

- EN & IEC 55024 EN & IEC 55014-2
  EN & IEC 61000-6-1 EN &IEC 61000-6-2
  EN & IEC 61326-1 EN & IEC 50130-4
  - all state that they ***do not*** cover safety issues
- Most of these also state that they ***do not cover*** the close proximity of hand-held radio transmitters
  - *even though this is now a normal part of most operational EM environments*

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EMC shortcomings in the EU Medical Directives and their standards

- Medical equipment is covered by…
    - Medical Device Directive 93/42/EEC
    - Active Implantable Medical Devices Directive 90/385/EEC
    - In-Vitro Diagnostics Directive 98/79/EEC
- The relevant standard for the EMC-related safety of medical devices and equipment is EN 60601-1-2
  - but amendment 1 to its 2nd Edition makes it clear that it is <u>not a safety standard</u>
    - for EMC for Functional Safety it references IEC 61000-1-2

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EMC shortcomings in EU Safety directives

- The Low Voltage Directive (LVD) doesn't even mention functional safety at all
    - although as a 'Total Safety Directive' it does cover it
- The Machinery Directive and its listed standards attempt to cover 'EMC for functional safety'
  - but does so only in the most general terms and fails to be explicit about what work it really requires
- Result?
  - contradictory guidance from experts and Notified Bodies

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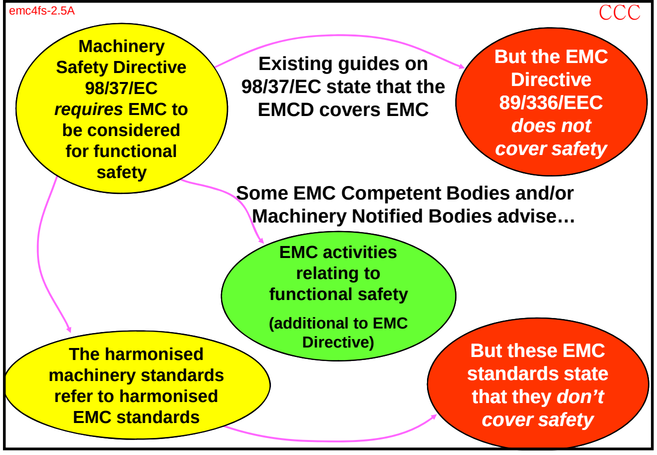

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Examples of shortcomings in safety standards

- EN & IEC 60950:2000 (computers and telecom's)
  EN & IEC 61010-1:2001 (measurement and control)
  - say they ***do not cover functional or performance issues***
- EN & IEC 60204-1 (electrical equipment of machines) *tries* to cover EMC-related functional safety
  - but is not comprehensive, and simply refers to EMC immunity standards which ***don't*** cover safety

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We can't afford to rely solely on immunity testing for safety

- There are much better immunity test standards…
  - e.g. D0160E (civilian aircraft, www.rtca.org) includes much more comprehensive test methods…
  - but still doesn't cover most of the safety issues
- Proving adequate safety by using immunity testing alone would require a test programme that no-one could afford…
  - so we need to be ***cleverer*** — to achieve the safety required with reasonable costs and timescales

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How EM performance should be controlled to achieve functional safety

- Use an established safety engineering type of approach, as follows….

A) What EM threats could the equipment foreseeably be exposed to?

B) What could foreseeably happen as a result of the EM threats identified by A) above?

C) Could the foreseeable EM emissions from the equipment affect other equipment?

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How EM performance should be controlled to achieve functional safety continued...

D) What are the foreseeable implications of A) - C) above for functional safety?

E) What actions are needed to achieve the required level of functional safety over the lifecycle? e.g. design and verification; Quality Control

F) What documentation is required to show that due diligence has been applied?

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A) What EM threats could the equipment (reasonably foreseeably) be exposed to?

- EM 'threats' are more correctly called: EM disturbances, or EM phenomena
- An 'EM threat assessment' is required
  - for the foreseeable EM environment of the equipment's intended operational site
  - taking into account low-probability EM threats over the whole lifecycle of the equipment
    - i.e. the worst-case possibilities

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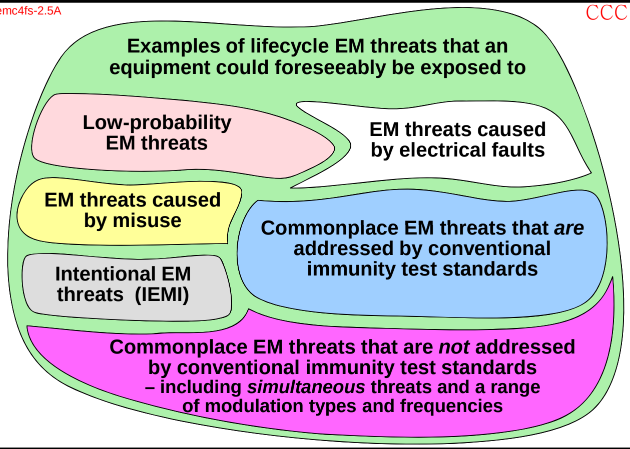

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Modified trams in Helsinki interfered with equipment in a hospital along their route

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B) What could (reasonably foreseeably) happen ?

- Follow the usual safety engineering approach, based on a hazards and risks assessment…
  – taking into account that…
- *Electromechanical* devices can malfunction, or be damaged
  – e.g. a problem for 'hard-wired' safety systems
- *Analogue circuits* can be upset, or damaged
  – e.g. a cause of errors in instrumentation

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B) What could (reasonably foreseeably) happen ? continued…

- *Digital circuits* and programmable devices can malfunction, or be damaged
  – e.g. errors in control and automation
    - note especially that crashing can leave the control outputs in any random states while rebooting occurs, which may not be acceptable in some applications
    - and clever software techniques don't work when a processor is damaged

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Erection of the Millennium Wheel (London Eye) was delayed by interference from outside broadcast vehicles' satellite dishes

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C) Foreseeable effects of equipment emissions

- Emissions standards are *not* intended to protect nearby radio receivers or other sensitive circuits
  – and some permit very high levels in specified circumstances, enough to...
    - be a direct hazard to human health
    - cause serious interference with electronic devices
- So the foreseeable effects on existing equipment of the *emissions* from the new equipment...
  – should be considered in the hazards assessment and risk analysis

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D) What are the (reasonably foreseeable) functional safety implications?

- This should take into account the severity of the possible safety hazard
  - and the scale of the risk
- It is best to employ the approach of IEC 61508
  - based on Safety Integrity Levels (SILs) and 'SIL-capability'

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Some early ABS systems were interfered with by powerful CB radios in trucks

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E) What actions are needed to achieve the required level of safety?

- Five kinds of actions are needed, carried out in the following order...

E1) Hazard reduction by design

- Design so that the safety functions have less demanding requirements
  - for the equipment's whole lifecycle

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E2) Risk-reduction by EM design

- Determine what foreseeable physical, climatic, chemical, biological, etc. stresses the equipment will be subjected to over its lifecycle….
- Specify the EM performance required, taking all the foregoing stages into account
- Then design to achieve the EM specification despite the application of the physical (etc.) stresses over the whole lifecycle
- This topic is covered later, in: "EMC Mitigation Techniques"

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E3) Verification of the EM design

- A test plan that proves the EM design will be at least adequate…
  - for the foreseeable EM environment…
  - plus the foreseeable physical (etc.) environment, faults, misuse, etc., over the whole lifecycle
- This is covered later, in: "EMC Testing"
  - but it is important to note that appropriate design and test verification planning can help avoid lengthy and costly test programmes

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E4) Maintain safety performance in serial manufacture, maintenance, and repair

- EMC performance can be degraded by (for e.g)...
  - a different batch of ICs
  - the surface conductivity of metalwork and its fixings
  - an altered cable routing
  - other small changes in assembly
  - 'form, fit and function' replacement parts
  - changed suppliers for parts, and processes (e.g. painting)

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E4) Maintain safety performance in serial manufacture, maintenance, repair continued...

- So a Quality Assurance (QA) system is required that controls all of the EM-safety aspects of the equipment *during* and *after* manufacture
- This QA system should control…
  - components, sub-assemblies, software (whether bought-in, or made-in-house)
  - in-house processes (e.g. plating) and subcontractors
  - manufacturing concessions, design changes
  - the build standard of the equipment
- This topic is not covered today (insufficient time)

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E5) Maintenance of safety performance despite modifications and upgrades

- A Quality Control (QC) procedure is required that controls all of the safety aspects of the equipment, including EMC-related safety for the above activities
  - it will be very similar to the procedure used to ensure that EMC-related safety aspects were correctly addressed during the equipment's original design
- This topic is not covered today (insufficient time)

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Safety design and verification activities over the "equipment's lifecycle" should take into account…

- design and development
- manufacture
- storage
- transport
- installation
- commissioning
- operation
- maintenance
- repair
- refurbishment
- decommissioning
- disposal

The steering of an Australian Navy minesweeper was affected by the radar of a nearby ship, nearly causing collision

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F) What documentation is required to show due diligence?

- If it isn't written down… the law assumes it didn't happen
- So the project records should show that steps A) to E) above were carried out in full
  - that the required EMC performance was determined and 'designed-in'
    - for all safety-related areas, from the start of a project
    - and verified at the end of a project

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the end

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Some useful references

- *Guide on EMC & Functional Safety*
  The IEE (London, UK) 2000,
  http://www.iee.org/Policy/Areas/Emc.index.cfm
- *Assessing an EM Environment*
  useful tables, procedures, sources, and simple calculations
  via "Publications & Downloads" at http://www.cherryclough.com
- The EMC & Compliance Journal's "*2005 Yearbook*"
  available on CD-ROM from http://www.compliance-club.com
  contains a wealth of useful information including the following…
  - Designing for EMC (6 parts)
  - EMC for Systems and Installations (6 parts)
  - EMC Testing (7 parts) (from low-cost D-I-Y to full compliance)
  - The "Banana Skins" Compendium (EMI anecdotes)
- *List of Resources on EMC and Functional Safety*,
  http://www.iee.org/OnComms/PN/emc/EMCandFunctionalSafety.cfm

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Some useful references continued…

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  IEE (London, UK) training course (2004, 2005), http://www.iee.org.uk
- IEC/TS 61000-1-2:2001 *Electromagnetic Compatibility (EMC) – Part 1-2: General – Methodology for the achievement of the functional safety of electrical and electronic equipment with regard to electromagnetic phenomena*
- *Functional Safety and EMC*
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- IEC 61508-3, *Functional Safety of Electronic/Electronic/ Programmable Electronic Safety-Related Systems – Part 3: Software Requirements*

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  Keith Armstrong, 2001 IEEE EMC International Symposium, Montreal, Canada, August 13-17 2001, Conference Proceedings: ISBN 0-7803-6569-0/01, pp. 774-779
- *New Guidance on EMC and Safety for Machinery*
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- *Review of Progress with EMC-Related Functional Safety*
  Keith Armstrong, 2003 IEEE EMC Symposium, Boston, USA, August 18-22 2003, ISBN 0-7803-7835-0, pp 454-460
- *Why EMC Immunity Testing is Inadequate for Functional Safety*
  Keith Armstrong, 2004 IEEE International EMC Symposium, Santa Clara, USA, August 9-13 2004,ISBN 0-7803-8443-1, pp 145-149
  — also in Conformity, March 2005 pp 15-23, http://www.conformity.com

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  Keith Armstrong, EMC-Europe 2004 (6th International Symposium on EMC), Eindhoven, The Netherlands, September 6-10 2004, ISBN: 90-6144-990-1, pp 348-353
- *Introduction to EMC for Functional Safety*
  Keith Armstrong, EMC-UK 2004, Newbury, UK, 12-13 October 2004, pp 116-123 — also in the EMC Society of Australia Newsletter, June 2005, Issue No. 30, pp 8-16, http://www.emcsa.org.au
- *Specifying Lifecycle Electromagnetic and Physical Environments – to Help Design and Test for EMC for Functional Safety*
  Keith Armstrong, 2005 IEEE International EMC Symposium, Chicago, USA, August 8-12 2005, ISBN: 0-7803-9380-5, pp 495-499
- *EMC Performance of Drive Application Under Real Load Condition*, F Beck, J Sroka, Schaffner EMV AG application note, 11th March 1999

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Some useful references continued…

- *Combined Effects of Several, Simultaneous, EMI Couplings*
  Michel Mardiguian, 2000 IEEE International Symposium on EMC, Washington D.C., August 21-25 2000, ISBN 0-7803-5680-2, pp. 181-184
- *Occurrence of Low-Frequency Noises in Electronic Systems Under Action of Two-Tone High-Frequency Electromagnetic Excitation*
  J Nitsch, N Korovkin, E Soloveyna and H-J Scheibe, , IEEE 2005 International Symposium on EMC, Chicago, Aug 8-12, ISBN 0-7803-9380-5, pp 618-621
- *The Case for Combining EMC and Environmental Testing*
  W H Parker, W Tustin and T Masone, ITEM 2002, pp 54-60, http://www.rbitem.com
- *Wireless Interference in a Central Office Environment*
  David A Case, Compliance Engineering 2005 Update pp 42-44, www.ce-mag.com