Another EMC resource
from EMC Standards

Design & mitigation techniques for EMC for Functional Safety

Helping you solve your EMC problems

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EMC Design and Mitigation Techniques for Functional Safety

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We need to *design* EMC for safety

- Where errors or failures in electronics/software could increase safety risks…
  - EM performance must be adequate for the foreseeable worst-case EM environment, over the lifecycle (see my IEEE papers 2001-2003)
- Proving this by EM testing alone is unfeasible…
  - nobody could afford the time/cost of the test plan
  - so we need to employ good EM engineering practices in design and mitigation (see my 2004 IEEE paper)

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The foreseeable 'worst-case' EM and physical environment(s) should be assessed

- to help create the design and test specifications

- Physical environment(s) should be assessed so EM measures can be designed to last the lifecycle
- There is usually no data on statistical variations in these environments…
  - so we must design for the *foreseeable worst-cases*
    - how to do the necessary EM and physical environment assessments was described in my 2005 IEEE paper

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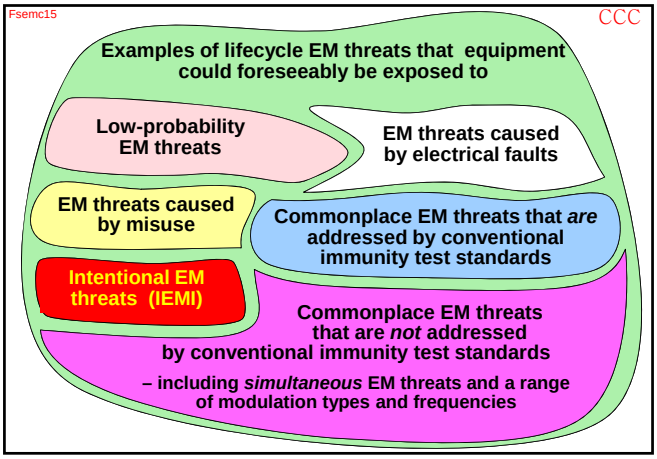

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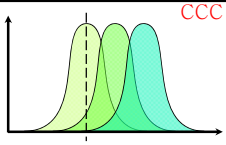
Margins, SILs and confidence
continued…



- There are inherent uncertainties in the…
  - a) Assessments of lifecycle EM & physical environments
  - b) Stresses actually applied during immunity tests
  - c) Performance of individual units (e.g. due to component tolerances, variations in assembly and installation, etc.)
  - e.g. MIL-STD-464 employs a 6dB margin for safety-critical and mission-critical equipment, and a 16.5dB margin for ordnance (missiles, bombs, etc.)

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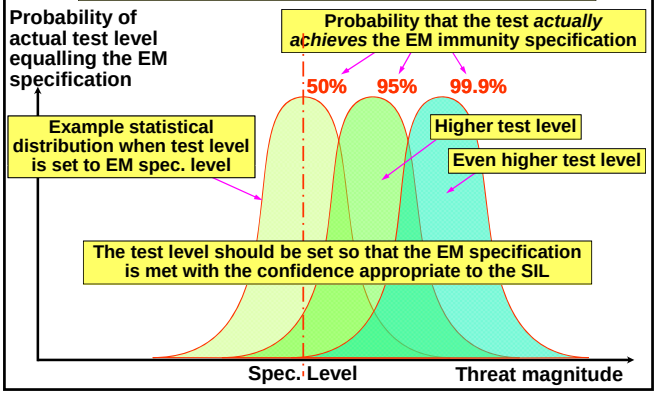
Margins, SILs and confidence



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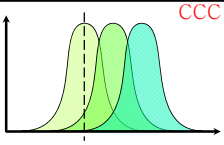
Margins, SILs and confidence continued…



- So, when setting the EM specifications that will be used as the basis for the design, and for the verification tests…
  - an analysis of the various uncertainties is required
  - and the specified EM threat levels increased by the resulting 'test margin', depending on the SIL required
  - for each cell of the threat/performance matrix (see later)
- A similar approach is required for physical stress tests

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Determining the EM performance criteria

- Different functional safety performance criteria will be required for the various safety functions
  - when they are interfered with by the various EM threats
- So it is necessary to create a matrix of safety functions versus EM threats
  - with the functional performance required specified in the resulting cells
    - note that the usual immunity test performance criteria (A, B and C) don't apply – we need to know exactly what happens when interference occurs

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Example of a threat / performance matrix

Function / EM threat	Actuator position error	Pressure error	Warning siren
100V/m 27MHz - 18GHz	< ±0.1mm during / after test	< ±0.1% during / after test	Must *not* operate when *not* required, or fail when required
400V/m 800MHz - 5GHz	< ±1mm during / after test	< ±1% during / after test	Must *not* operate when *not* required, or fail when required
1kV/m 2.35 -2.55GHz	< ±1mm during /after test or fail-safe	< ±1% during /after test or fail-safe	May operate when not required, must not fail when required
Line-to-ground damped oscillatory wave up to ±6kV	< ±1mm during /after test	< ±1% during /after test	May operate < 1s upon each surge, must not fail when required
Etc…	Etc..	Etc..	Etc..

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Determining the 'naturally susceptible frequencies' of hardware and software

- Equipment is *especially* susceptible at certain 'natural' frequencies, including the…
  - full bandwidths of any analogue circuits
  - resonant frequencies of cables, metal structures, transducers or actuators
  - digital clock frequencies, sampling rates, RF carrier and modulation frequencies
    - and all of their harmonics

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Determining the 'especially susceptible frequencies' of hardware and software continued…

- So to achieve a cost-effective and safe design, it helps to analyse or test the effects of radiated and conducted RF on the equipment
  - *without any shielding or filtering fitted*
  - to discover its 'especially susceptible frequencies'
  - then determine how these frequencies *could possibly* be stimulated by the real operational EM environment over the lifetime
    - e.g. by direct interference, demodulation, intermodulation

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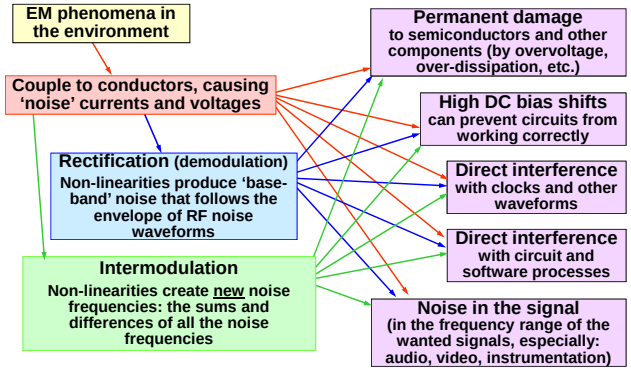
The three interference mechanisms



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Determining the 'especially susceptible frequencies' of hardware and software continued…

- Intermodulation occurs in all semiconductors, and at all corroded electrical joints (known as the 'rusty bolt effect')
  - an important lifecycle consideration
    - (normal EMC RF testing uses single frequencies, so doesn't test intermodulation possibilities)
- To prevent demodulation and intermodulation from causing immunity problems in real life…
  - it may be necessary to shield and filter at frequencies well beyond the 'especially susceptible frequencies'

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Coping with foreseeable faults

- Faults can include…
  - components open/short circuited, or altered parameters
  - broken electrical bonds (e.g. shield joints, filter grounding)
  - increased impedance at shield gaskets, etc.
  - appropriate design for the foreseeable physical environment can reduce likelihood of most faults
- Where a fault can lead to a safety risk, IEC 61508 describes design techniques for achieving the SIL
  - e.g. duplication, triplication, etc.
  - e.g. condition monitoring with safety shut-down, etc.

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EMI mitigation when using multiple redundant channels

- EMC is a systematic (common cause) failure
  - so, where IEC 61508 requires multiple channels to meet the SIL, the use of diverse technologies is required
- But using multiple diverse-technology channels *doesn't mean* each can have low EM performance
  - otherwise, during interference, it could happen that *none* of the digital channels would function correctly
    - and all the analogue channels could be at + / - full scale
    - (a similar issue for common-cause *physical* threats too)

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Interference sensing techniques

- Interference sensors can be used inside or outside equipment
  - to detect EM events which might cause hazards
  - and initiate special protective measures or shut-down the equipment safely
    - e.g. used to protect some military equipment from the pulses caused by nuclear explosions
    - e.g. used by gaming machine manufacturers to protect them from people trying to 'break' the machine with interference (e.g. using cattle prods)

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Interference sensing techniques continued...

- A safety interlock on a door or panel can tell if it has been opened
  - and inhibit the equipment so as to protect people from the possible safety consequences of degraded shielding
    - treating the door like a machine guard that interlocks with an emergency stop function
- But EM sensors can detect *accidentally* degraded shielding or filtering, or *unforeseen* EM threats
  - and could allow doors to be opened *without protective* shut-down (unless EM threats are present)

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A 'layered' approach to EM mitigation

- It is often less costly, and more reliable, to use a number of 'layers' of EM mitigation
  - rather than relying on a single 'layer'…
    - e.g. high-performance shielding and filtering of the equipment's enclosure
- It is recommended to design so that if one 'layer' should fail completely *for some unforeseen reason*
  - e.g. misuse, whether accidental or intentional
  - the equipment will still have adequate EM performance

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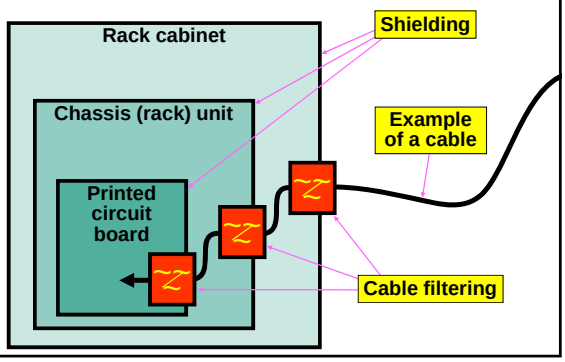
Example of 'layered' EM mitigation (using shielding and filtering)



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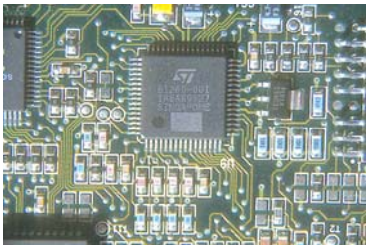
Layers

- Integrated circuits (ASIC, FPGA, custom, etc.) can be designed or chosen for good EM performance
- Circuits, their interconnections and printed circuit boards can be designed for good EM performance



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Layers continued...

- Fibre-optic cables preferred for signal and control
  - or else cables should carry serial digital data protected by a proven robust error correcting protocol (e.g. '1553')
- Shielding, filtering, surge, transient, and ESD protection can be applied at the following levels...
  - individual devices
  - printed circuit assemblies
  - modules and sub-assemblies
  - units (e.g. rack mounted equipment)
  - overall enclosure level (e.g. rack cabinets)
  - and even to rooms, buildings, and sites (campuses)

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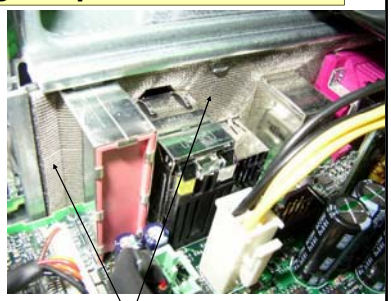
Designing to prevent the physical environment from excessively degrading EM performance

- Static forces on a structure can make joints and gaskets open up
  - reducing shielding effectiveness



Shielding gaskets at the rear panel of a Dell Optiplex PC, 2002

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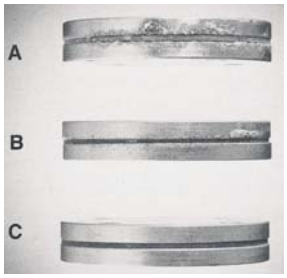
EMC problems caused by the physical environment continued...

- Repetitive stress, shock, vibration, oxidation and corrosion can cause…
  - wear-out of joints / gaskets
  - gaps in cable shields
  - loosened fixings
  - open / short circuits in conductors and component leads
  - connectors to work loose



Results of a test comparing lifetime corrosion for three different types of shielding gaskets

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EMC problems caused by the physical environment continued...

- These physical effects can ruin shielding effectiveness
- They can also cause filters to become less effective
  - e.g. by breaking their ground connections
  - with similar problems for surge, transient and ESD protective devices
- And they can make circuits on PCBs unstable
  - much more prone to causing or suffering EMI

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Protecting from foreseeable "physical EMC problems"

- The equipment must be designed so that its EM performance remains sufficient over its lifecycle
  - despite all foreseeable physical stresses, wear and ageing
- Mechanical structures may need to be designed for forces, shock and vibration with the aid of finite element analysis

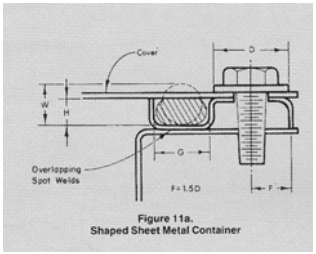

Figure 11a.
Shaped Sheet Metal Container

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Physical mitigation techniques include...

- shock and vibration mountings (active or passive)
- vibration-proof fixings
- encapsulation
- grease, paint, etc.
- cable ties
- anti-condensation heaters
- sealed enclosures
- forced ventilation
- air conditioning
- using more than one 'layer' of physical protection


Underside view of an encapsulated filter

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Preventing degraded EM performance from foreseeable use (or misuse)

- Installation, commissioning or maintenance instructions might not be followed
  - so it is best if these tasks are done by the manufacturer
- Users might open doors, covers or panels when they shouldn't, or make unapproved modifications
  - so we must anticipate what could foreseeably happen, then design, guard and warn accordingly (in that order)
    - sometimes users will need to be trained, maybe even pass an exam, before being appointed a "keyholder"

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EM design/mitigation techniques in system integration/ installation

- Good EM practices should be employed during installation, including techniques for…
  - cable segregation and routing
    earthing and mesh-bonding
    shielding
    filtering
    transient suppression
    - these are described in IEC 61000-5-2 and -6 and other publications

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QA procedures should control…

- Design reviews (independent experts may be required)
- The exact build state that will achieve the EM performance
- The EM performance of suppliers and subcontractors
- Installation, user and maintenance manuals
  - that clearly describe all that should be done to achieve the required EM performance and maintain it over the lifecycle
- The maintenance of EM performance despite upgrades and modifications

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the end

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Some useful references

- *Assessing an Electromagnetic Environment*
  Keith Armstrong, downloadable from the "Publications and Downloads" page at http://www.cherryclough.com
  Note: this was written to help with EMC compliance, not for safety purposes
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Volume 1 - What is EMC?	ISBN 1-902009-05-3
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Volume 4 - Safety of Electrical Equipment	ISBN 1-902009-08-8

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Some references for safety-related software

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Some references for safety-related software continued...

- *Electromagnetic Compatibility of Software*, IEE Colloquium, Thursday 12th November 98, IEE Colloquium Digest: 98/471, sales@iee.org.uk

  NOTE: The software techniques described in the three references below are equally valuable for improving software immunity to all transients, the main causes of EMC problems for software
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