emc STANDARDS

Another EMC resource
from EMC Standards

EMC Testing for Functional Safety

Helping you solve your EMC problems

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EMC Testing for Functional Safety

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Contents of this module

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Special EMC tests are required for safety-related equipment

- No practical tests on the *finished equipment* can give a high degree of confidence in its EM performance over its entire lifetime
  - because such testing would take *much* too long
    - just as it would take much too long to fully test software
- So, *just as for safety-related software*...
  - we must use good EMC design methods, verified as far as possible by *appropriately designed* EMC tests
    - these EMC tests and test plans individually designed by EMC-for-functional-safety experts, for each project

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Two reasons for EMC testing

1 To verify that all critical EM design aspects will maintain the necessary EM performance over their equipment's lifecycle
  - despite the effects of the real physical environment

2 To verify that the finished equipment's EM performance meets its EMC specification
  - EMC tests might not be needed when a performance aspect is *guaranteed* by design (or by design tests)
    - as long as the QC ensures the correct build state

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An example

- It is possible to use highly-shielded cabinets...
    - with anti-vibration, temperature control, etc., if required
  - and flexible shielded conduit for all cabling…
  - and just one 'MIL-Spec' mains filter / surge suppresser...
- To *almost guarantee* adequate EM performance even in the most severe EM environments
  - *without any EMC testing of the final equipment*
    - based solely on calculations, test results and QC for its component parts...
    - plus good EMC design, assembly and installation practices

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An example continued...

- Manufacturers who want to minimise the cost, size, or weight of their equipment...
  - don't like to use such 'brute-force' military-style EMC design techniques
- But if they do not use such techniques
  - then the arguments for EMC testing the finished equipment become stronger
  - especially for high SILs (or SIL-capabilities)

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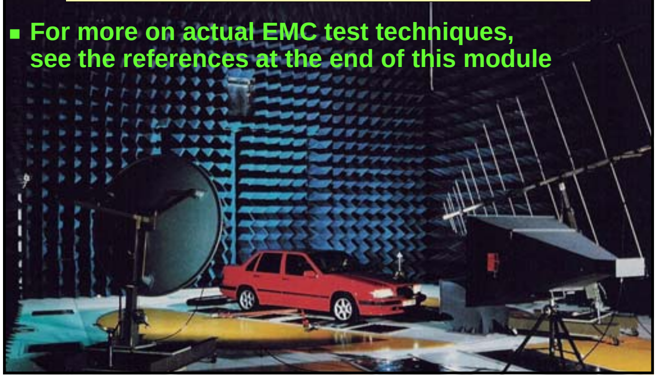
An example continued...

- So the cost, size and weight savings of not using 'brute-force' EMC design
  - must be balanced against the cost and delay of the extra design effort
  - and the cost and delay of verifying the EM performance of the design
    - and of verifying the finished equipment

EMC testing techniques will not be described today

- For more on actual EMC test techniques, see the references at the end of this module



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Verifying the EM performance of aspects of the design

- Verifying the EM performance of all the EMC-critical (at least) design aspects...
  - for the equipment's foreseeable physical, environmental, and electromagnetic stresses...
  - helps to prove good EMC design practices quickly at lowest-cost
  - and makes the achievement of lifetime EMC possible
- This requires EMC testing *during* physical stress tests of the design aspects (and *after* 'ageing' them)

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"HALT" stress testing

- HALT = highly accelerated life testing
  - test to find weaknesses in the design, and the operational limits of the equipment
  - best done on 'risky' design elements early in a project
    - e.g. design of shielding of modules, units and cabinets; filters; surge protectors; sub-assemblies; etc.
- HALT tests are designed individually by mechanical and environmental experts
    - so that they are realistic for the equipment's type of construction and intended use

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HALT testing continued...

- Testing – such as HALT – for mechanical and environmental stresses, ageing, wear-out, etc....
  - is good policy for safety-related equipment anyway
  - and also a good policy for reducing warranty costs
- Adding 'design-proving' EMC testing to them need only add a little extra time and cost
    - where difficulties or high costs seem likely, it is often possible to devise easier and lower-cost alternatives that still provide good confidence in the EM design

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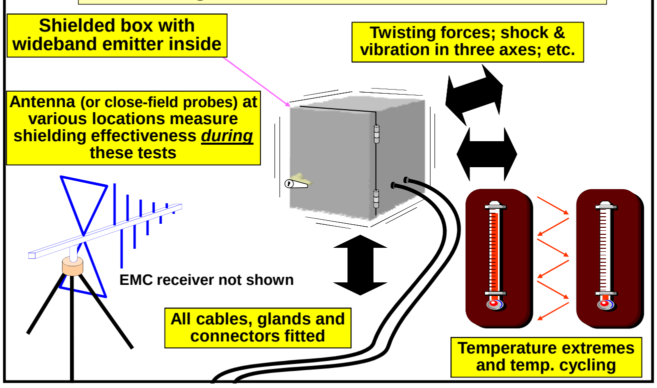
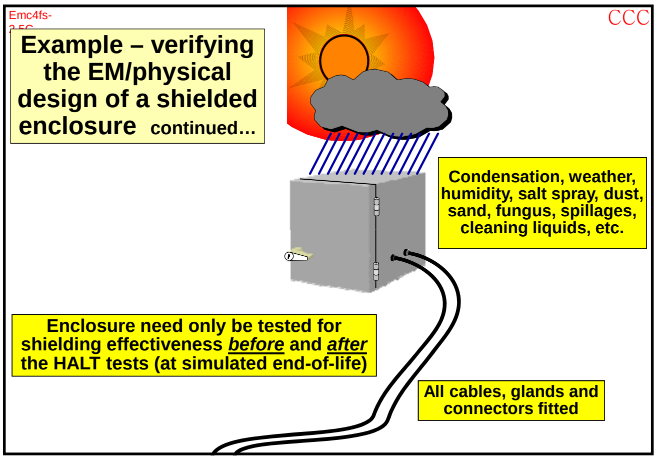
Example – verifying the EM/physical design of a shielded enclosure

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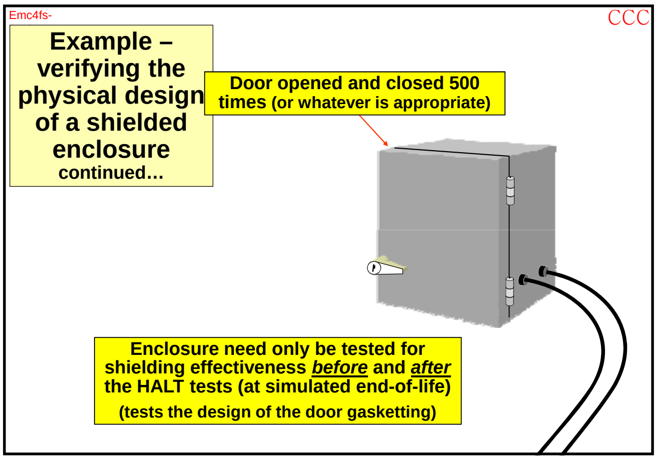
Example – verifying the EM/physical design of a shielded enclosure continued…
Condensation, weather, humidity, salt spray, dust, sand, fungus, spillages, cleaning liquids, etc.
Enclosure need only be tested for shielding effectiveness *before* and *after* the HALT tests (at simulated end-of-life)
All cables, glands and connectors fitted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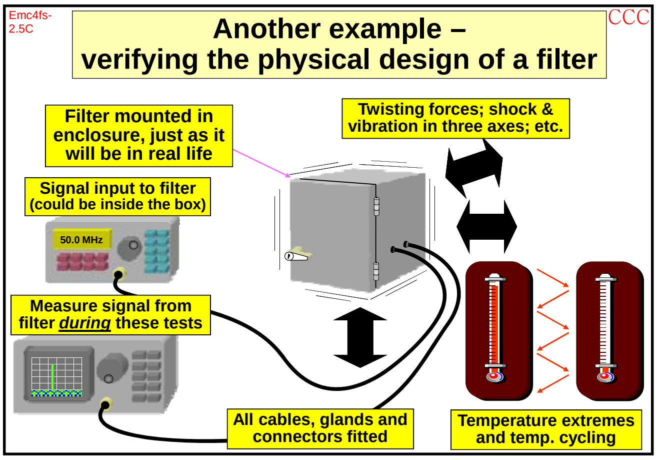
Example – verifying the physical design of a shielded enclosure continued…
Door opened and closed 500 times (or whatever is appropriate)
Enclosure need only be tested for shielding effectiveness *before* and *after* the HALT tests (at simulated end-of-life)
(tests the design of the door gasketting)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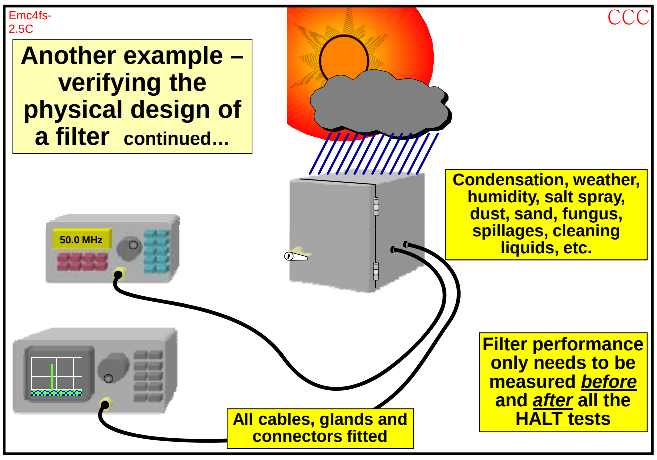
Another example – verifying the physical design of a filter
Filter mounted in enclosure, just as it will be in real life
Twisting forces; shock & vibration in three axes; etc.
Signal input to filter (could be inside the box)
50.0 MHz
Measure signal from filter *during* these tests
All cables, glands and connectors fitted
Temperature extremes and temp. cycling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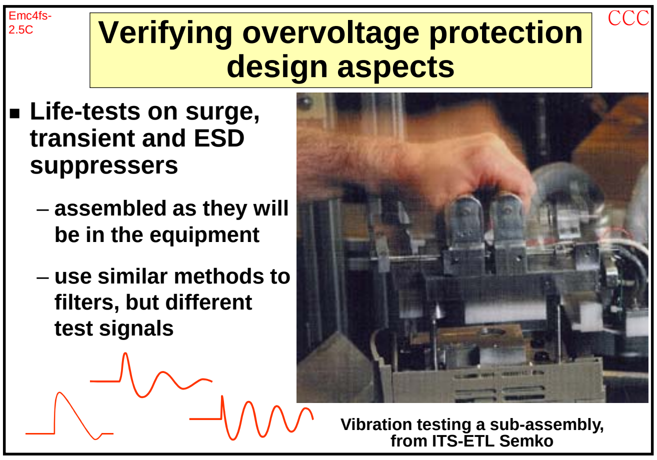
Another example – verifying the physical design of a filter continued…
Condensation, weather, humidity, salt spray, dust, sand, fungus, spillages, cleaning liquids, etc.
50.0 MHz
Filter performance only needs to be measured *before* and *after* all the HALT tests
All cables, glands and connectors fitted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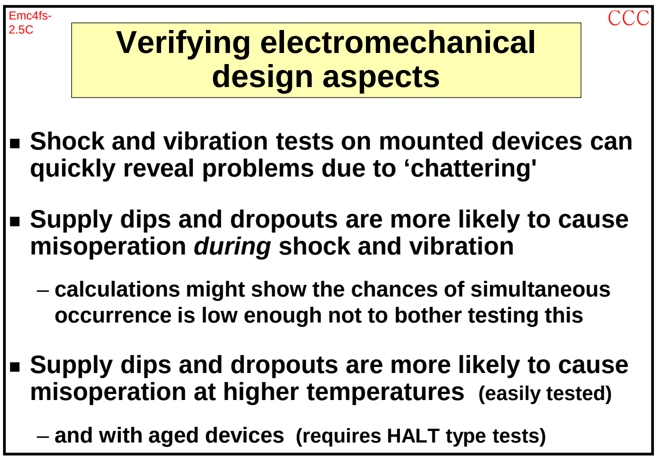
Verifying overvoltage protection design aspects
Life-tests on surge, transient and ESD suppressers
– assembled as they will be in the equipment
– use similar methods to filters, but different test signals
Vibration testing a sub-assembly, from ITS-ETL Semko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Verifying electromechanical design aspects
Shock and vibration tests on mounted devices can quickly reveal problems due to 'chattering'
Supply dips and dropouts are more likely to cause misoperation *during* shock and vibration
– calculations might show the chances of simultaneous occurrence is low enough not to bother testing this
Supply dips and dropouts are more likely to cause misoperation at higher temperatures (easily tested)
– and with aged devices (requires HALT type tests)

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Verifying electromechanical design aspects continued...

- Contact welding due to surge currents is unlikely to be affected by mechanical forces or environmental conditions
  - but the operation of positively-guided contacts might be

Some 'contactor relays' from Moeller

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Verifying the design of electronics and/or software

- These can be susceptible to subtle aspects of their EM environment
  - e.g. the type of modulation used by a radio transmission
    - or the frequency spacings between two or more radio channels (rather than simply the strength of the radio frequency field)
  - e.g. the voltage and current waveshapes of a transient
    - rather than simply its peak overvoltage level

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Verifying the design of electronics and/or software

- So electronics and software need to use more sophisticated EMC tests
  - to verify the lifecycle reliability of their physical realisations

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Continuous immunity testing

- Equipment is especially susceptible at the operating frequencies of its internal hardware and software processes…
  - as described in the previous section on 'Mitigation'
- But high-enough levels of interfering signals can overdrive devices…
  - causing errors, malfunctions, maybe even damage…
  - *at any frequency*

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Continuous immunity testing continued…

- So we test with carrier waves that cover <u>all</u> of the frequencies that could reasonably foreseeably exist in the operating environment over the lifetime
  - with unmodulated CW as well as with modulation at the EUT's 'especially susceptible frequencies'
- The *typical* result is that from 0 to 150kHz we test with CW signals plus a pulse OFF then ON again
  - and at each tested frequency above 150kHz the test signal is a CW period followed by 'chirp modulation' over the range of 'especially susceptible frequencies' below 30kHz, then pulsed OFF for a time then back ON again

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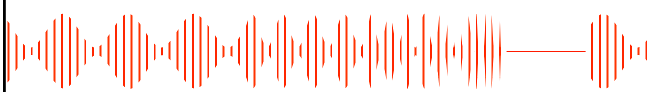
Continuous immunity testing continued…



- The 'CW, chirp and OFF/ON pulse' must be slow enough to be sure of detecting any errors, malfunctions or damage in the functions being tested
  - if necessary, time may be able to be saved by monitoring critical electronic circuits *within* the EUT
    - special probes with high levels of immunity are available for monitoring, but are not always required

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Continuous immunity testing
continued…

- If the 'especially susceptible frequencies' have previously been identified (see the previous section on 'Mitigation')…
  – the testing time may be able to be reduced by modulating only at those frequencies, instead of a full chirp
- Where exposure to pulsed sources is possible (e.g. radars, pulse weapons, etc.)
  – their relevant frequency range should be covered using appropriate pulse modulation waveforms…
    - especially any waveforms with a frequency content that

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Radiated immunity testing

- Anechoic testing is unlike most real-life EM environments, so Reverberation Chamber methods have been developed to give more confidence
    - their results can be correlated mathematically with the reflectivity of the operational EM environment
- Reverb chambers and their RF power amplifiers cost a great deal less than anechoic chambers
  – and they can be very large, and thorough testing can take less time than anechoic
    - because there is no need to test with many angles, and with vertical and horizontal antenna polarisations

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One of Qinetiq's reverberation chambers

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An example of the 'reverberation chamber' test method

- The stirrer rotates over a full revolution, in a series of steps (usually between 20 and 120)
  – at each step, radio fields are generated in the chamber
    - comparable in frequency range and magnitude with the foreseeable radiated threats
- The frequency range is covered in small steps (sometimes as small as 0.1%)
  – at each step the radio field is modulated with the appropriate 'CW, chirp plus OFF/ON pulse'
    - at the appropriate rate (related to the time-constant of the function being tested)

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Conducted immunity testing

- Where equipment is too large, or frequencies too low, radiated testing can be costly or impractical…
  – so alternative conducted coupling test techniques have been developed
  – these should use the methods described in the latest versions of DO160 (or IEC 61000-4-6)
  – using the 'CW, chirp + OFF/ON pulse' modulation at the appropriate RF test frequencies
    - at a slow enough rate to detect errors or malfunctions in the tested functions

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Conducted immunity testing continued…

- But conducted testing of each cable is *not* a true alternative to radiated testing at lower frequencies
- So it may be more realistic to use striplines, TEM cells, Helmholtz coils…
  – or other E and H field immunity tests (e.g. from military or aerospace immunity standards)
  – as before, using the 'CW, chirp + OFF/ON pulse' modulation at the appropriate RF test frequencies, at a slow enough rate to detect errors or malfunctions in the tested functions

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It is difficult to do radiated immunity tests *during* HALT (or similar)

- But it *is* feasible to do conducted immunity tests
  - which can be extended to 1GHz to help identify problems that could compromise radiated immunity

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Sometimes it is not necessary to combine HALT (or similar) with EMC tests

- Where a design aspect can be shown by analysis, calculation or calibrated computer simulation to maintain its EM performance...
  - despite foreseeable shock, vibration, spray, mould growth, condensation, temperature, wear, ageing, etc…
    - or has already been proven by appropriate testing or full-lifecycle experience in a *very similar* application
  - then a case may be made for not doing EMC testing during HALT tests
    - *on that design aspect*

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Dealing with multiple *simultaneous* EM threats

- Where each individual threat affects a particular circuit or unit in exactly the same way
  - the worst-case is to assume their effects are *additive*
- Then, for continuous threats (e.g. radio transmissions on a number of frequencies)…
  - or for continuous threats plus one transient threat…
  - test with each threat in turn at a level *equivalent to the combined threat*
    - requires calculations

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Where significant intermodulation possibilities remain in the final design…

- The EUT should be tested with the full range of frequencies that it can experience
  - modulating them with the 'especially susceptible frequencies' to simulate the results of intermodulation
    - even if the threats at those RF frequencies would not normally be modulated in such a way
- Alternatively, monitoring points within the EUT to see if the IM products will be negligible enough

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Where significant intermodulation possibilities remain in the final design… continued…

- But where these techniques still leave an untested area, testing with simultaneous RF frequencies might be required
  - it might be possible to test with simultaneous frequencies at lower levels than real life…
  - measuring and analysing the results for the susceptible circuits (e.g. using 'calibrated' analysis techniques)
  - hopefully avoiding the need for full-power intermodulation testing

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Other testing issues

- Tests should be carried out at the maximum level expected over the lifecycle…
    - increased as described earlier to allow for uncertainties
  - and also tested at lower levels (because the devices have non-linear behaviour, so lower might be worse)
    - for both transient *and* continuous threats
- All transient tests should be carried out often enough to be sure to coincide with vulnerable software states
  - and to confirm the ratings of the protection devices

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Where each EM threat causes a *different* error or malfunction…

- ***And*** where those errors or malfunctions could not possibly affect the same safety functions…
  - e.g. a machine starting up when supposed to be in standby, plus a failure in the guarding circuit that prevents access to the machine
    - real-life example of a packaging machine that, after lightning struck the building it was in, ran at full speed backwards with all of its guards open
  - then it is probably enough to test with each EM threat individually, at the specified level

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Where each EM threat causes a *different* error or malfunction… continued…

- ***But*** where these errors or malfunctions *could possibly* affect the same safety function(s)
    - e.g. an overspeed, plus failure of the overspeed detector
  - then it may be necessary to test a number of times, with one problem permanently simulated each time

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The designer should be able to show that there is no point in EMC testing the finished equipment

- because he/she has already proven that the EMC design aspects will reliably protect the equipment from its foreseeable EM environment…
- over its foreseeable lifecycle

HMS Sheffield on fire during the Falklands war. Poor EMC was a major cause of this disaster

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But EMC testing of the final equipment is always required

- At least using pristine equipment in a benign environment
    - testing after HALT is better, and may be necessary
  - the EMC procedures and test methods used for safety-related equipment should be similar to those described earlier

EMC testing a refurbished self=propelled gun, at ABRO, Bovington

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Final EMC testing should…

- be performed at the highest practical level of assembly
  - e.g. on-site testing of systems and installations
- replicate, as far as possible, the foreseeable EM environment
- operate the equipment as it will be in real life
- with all performance degradations detected and assessed from the point of view of functional safety
  - or reliability or measurement accuracy, where they are the main concern

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the end

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Some EMC testing references

- ***On-Site Testing Methods,*** **Keith Armstrong, downloadable from the "Publications and Downloads" page at http://www.cherryclough.com**
  - ***Note:*** **this was written to help with EMC Directive compliance, not for safety purposes**
- ***Directivity of Equipment and its Effect on Testing in Mode-Stirred and Anechoic Chamber*****,**
  Jansson, L., and M. Bäckström, IEEE International Symposium on EMC, Seattle, August 99
- ***An Introduction to Reverberation Chambers for Radiated Emission/Immunity Testing*****,**
  Freyer, G.J., and Hatfield, M.O., ITEM 1998, www.rbitem.com
- ***Coupling to Devices in Electrically Large Cavities, or Why Classical EMC Evaluation Techniques are Becoming Obsolete*****, John Ladbury, IEEE International Symposium on EMC, Minneapolis, Aug 02**

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Some EMC testing references
continued...

- ***Low Level Coupling Techniques for the HIRF Clearance of Air Systems*****, A Wraight et al, EMC-Europe 04, Eindhoven, Sep 6-10, pp 776-780, ISBN: 90-6144-990-1**
- ***The Case for Combining EMC and Environmental Testing*****,**
  William H Parker, Wayne Tustin, Tony Masone, ITEM 2002 pp 54-59, www.rbitem.com
- ***REO booklets on EM Phenomena and EN Test Methods***
  free from http://www.reo.co.uk
  - **as well as describing how to perform tests to the IEC/EN basic EMC test methods, these booklets describe the various types of EM disturbances, where they might occur, their possible magnitudes, and what effects they might have on electrical and electronic equipment**

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Some EMC testing references
continued...

- **RTCA/DO-160E**
  Civil aerospace EMC standards, from www.rtca.org
- **DEF STAN 59-41, from www.dstan.mod.uk/home.htm**
- **MIL STD 461E, ask Google for sources**
- **ITU 'K' Recommendations on 'resistibility' and immunity, International Telecommunications Union, www.itu.org**
- **GR-1089-CORE *Electromagnetic Compatibility and Electrical Safety - Generic Criteria for Network Telecommunication Equipment***
  Search the Technical Document Centre at http://telecom-info.telcordia.com

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Some EMC testing references
continued...

- ***EMC Testing*** **(in seven parts),**
  Tim Williams and Keith Armstrong, EMC & Compliance Journal 2001-2, www.compliance-club.com/KeithArmstrongPortfolio

  This series is based on the IEC 61000-4-x basic test methods, but it also describes 'do-it-yourself' methods which have a variety of uses. E.g. it describes close-field probing methods which can be used check gaskets and joints for 'EM leaks' when subjected to physical stresses.
- **The IEC 61000-4-x series**
  Basic immunity test methods for residential, commercial, industrial environments, from the bookstore at www.iec.ch
- **Don't forget that using the IEC 61000-4-x series *as they are* is not recommended for proving a design is safe enough**