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Traditional Immunity Standards are Inadequate for Proving EMC for Functional Safety

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Traditional Immunity Standards are Inadequate for Proving EMC for Functional Safety

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Abstract

The EMC Directive does not cover safety issues, and now that international standards committees are being encouraged to add EMC-for-functional-safety requirements to their safety standards there are a number of draft and new safety standards that include EMC requirements.

Traditionally, EMC performance of equipment has been verified simply by testing a few new samples of an equipment in an EMC test laboratory. However, the safety performance of equipment is verified by quite different means:

- Samples are tested to see if one foreseeable fault (sometimes more) could result in danger;
- Every item of equipment that is manufactured is tested to check that its basic safety features have not been undermined by faulty parts or incorrect assembly;
- The design is inspected against a number of safety design criteria that have been well proven to cope with real-life conditions of service for the foreseeable lifecycle.

Clearly, the traditional approaches to EMC and safety compliance are very different – and this has been causing a great deal of confusion where EMC is important for Functional Safety reasons.

This paper will show why the traditional EMC standards are totally unsuitable, and why EMC testing is inadequate as the sole means of verifying that a design has an adequate EMC performance for Functional Safety reasons. It will conclude that EMC standards for Functional Safety should specify the EMC design techniques that are to be used, and should also specify the use of EMC tests that have more relevance to real-world threats.

Introduction

Electronic devices are being increasingly used in safety-implicated, safety-related and safety-critical applications, especially in industrial, commercial, medical and transportation control and automation applications. The immunity of these electronic devices to electromagnetic interference (EMI) is important for Functional Safety reasons.

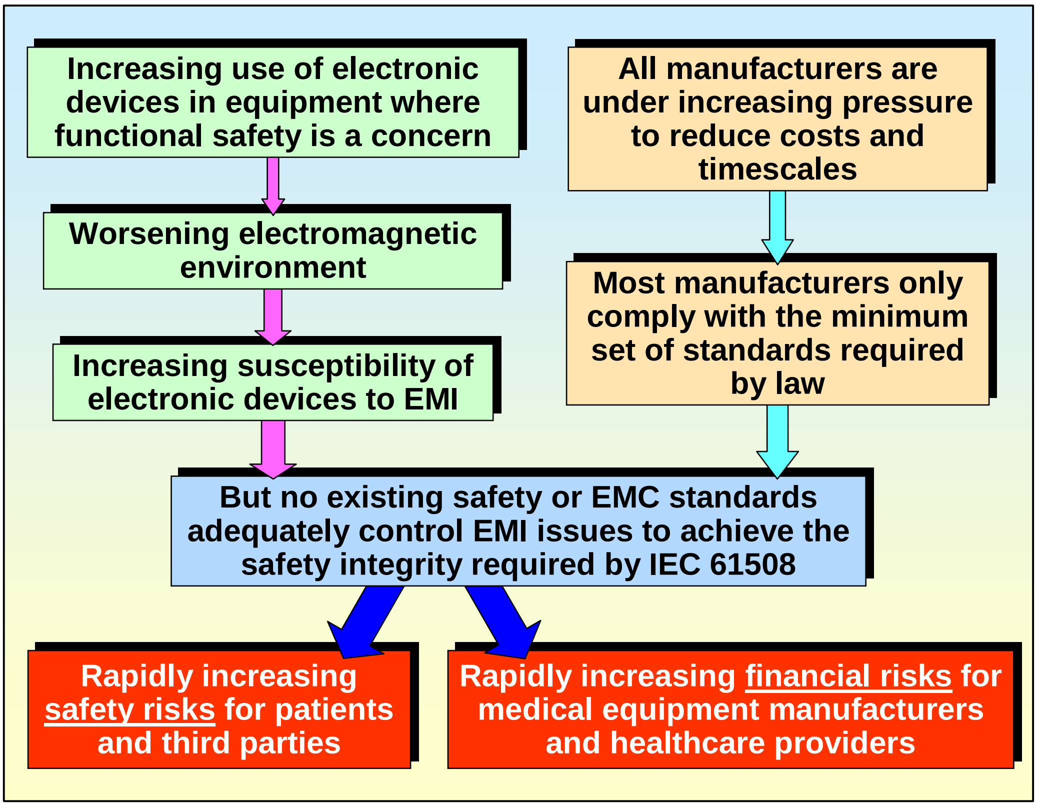
But all electronic technologies inherently suffer from inaccuracy, malfunction, or even permanent damage due to EMI in their operating environments. The continuing shrinkage of the silicon features in electronic devices (responsible for their increasing functionality and reducing cost) requires lower operating voltages, and both of these make the devices more susceptible to EMI.

The intensity and frequency range of EMI in typical real-life environments are getting worse all the time, due to the increasing use of digital, switch-mode, and wireless technologies. Combined with the increasing susceptibility of electronic devices, this means that the reliability of electronic devices is inherently decreasing, which has important consequences for Functional Safety.

Electromagnetic Compatibility (EMC) standards and regulations have grown up around issues of spectrum control. Safety standards and regulations generally have no, or very poor coverage of EMI. Manufacturers employing electronic devices in safety-implicated/related/critical systems have therefore had little in the way of standards and regulations to guide them, and since many of them aim for the lowest possible cost, and compliance with the minimum regulatory requirements, Functional Safety risks are increasing, as shown by Figure 1.

To deal with the above, the IEE (London, UK) set up a Working Group on 'Electromagnetic Compatibility (EMC) and Functional Safety' that produced a 'professional guide' on this topic in 2000 [1]. This adopts a hazards and risk assessment approach to the issue, and has since been utilised by at least one other professional body [2] in formulating its own guidance. In 2004 the IEE started running a series of training courses on "EMC for Functional Safety" [3]. A similar approach to EMC is suitable where high reliability is required for financial or mission reasons, or for legal metrology equipment.

Figure 1



European Union (EU) safety directives that require CE marking are "total safety" directives and so cover any/all Functional Safety problems caused by EMI – but they do not say how this should be accomplished, and until recently none of the harmonised standards they listed had any EMC requirements either. Since the Electromagnetic Compatibility Directives 89/336/EEC and 2004/108/EC and their listed harmonised standards do not cover safety issues [4], this leaves a great big gap in the control of an increasingly important aspect of Functional Safety.

The 'basic IEC standard' for the Functional Safety of electronic and programmable equipment is IEC 61508 [5], but although it requires EMC to be taken into account, it does not say how. EMC is a similar issue to software in that it is very complex and gives rise to systematic faults that are caused by the design (they do not occur at random).

The traditional approach to hardware reliability is to use multiple 'channels', but this only works because hardware faults tend to occur at random, whereas EMC faults tend to be 'common-cause' and can affect all the channels in the same way at the same time. Consequently [5] requires 'EMC for Functional Safety' to be treated similar to the way that it treats software – but whereas [5] devotes the whole of its third part to software design and verification techniques [6], it has no similar guidance for EMC.

IEC/TS 61000-1-2:2001 [7] is a recent IEC Technical Specification that covers EMC for Functional Safety, and is intended by its IEC maintenance team to become a full IEC standard – the basic IEC standard on this topic – that provides the EMC requirements that are lacking from [5]. This IEC/TS employs a hazards and risk assessment and design-based approach, similar to the guidance in [3] and to [5]'s approach to software.

IEC product standard committees have recently begun to add EMI-related Functional Safety requirements to some of their safety standards. But as [8] shows they are all simply adding traditional EMC immunity test requirements, rather than following the lead taken by [7].

However, the first amendment (Sept 2004) to the second edition of EN 60601-1-2 [9] recognizes this error in the medical devices EMC standard and makes it clear that it does not cover EMC as far as safety issues are concerned – for that it references [7] instead. Hopefully all the other safety standards committees will follow suit by referencing [7] wherever EMC for Functional Safety is concerned – instead of trying to use inadequate traditional EMC standards.

EMC compliance is traditionally achieved when one or more new samples of an equipment pass EMC tests in a laboratory. The standards applied do not define any aspects of design or construction, so this type of testing is sometimes called 'black box testing' (because it doesn't ask what is inside the 'black box').

However, the safety performance of equipment is traditionally verified by quite different means:

1. Samples are tested to see if foreseeable faults could result in a dangerous condition. 'Single-fault safety' is a universal requirement, but some critical safety applications also require safety to be maintained despite two (or more) independent faults;
2. Every item of equipment that is manufactured is put through basic tests that check whether faulty parts or incorrect assembly have undermined the basic designed-in safety features;
3. The design is inspected against a number of safety design criteria, well-proven to provide a sufficient level of protection over the foreseeable lifecycle, taking into account the ranges of the physical and climatic environments (e.g. temperature, vibration, pollution, exposure to water) and reasonably foreseeable use or misuse.

The traditional approach taken by EMC standards is very different from the approach taken by safety standards. A number of more detailed explanations of why traditional EMC standards and their test methods are inadequate (on their own) for ensuring Functional Safety follow, taking the above three points in order.

Foreseeable faults are not tested by traditional EMC standards

Point 1 above concerns the need for foreseeable faults not to cause safety hazards. Foreseeable electrical faults can significantly affect susceptibility to normal levels of real-life EMI, causing unreliable operation of safety functions. Some examples of such faults include…

- Dry joints or short circuits (e.g. in a filter)
- Out-of-tolerance components that could affect EM performance (e.g. making feedback circuits unstable)
- Loose fixings or missing parts in the assembly of enclosure or cable shields
- Conductive gaskets missing or damaged during assembly
- Failure of a surge protective device
- Unwitting use of 'die-shrunk' integrated circuits (which have markedly different EMC characteristics to the normal parts although sold under the same part numbers)
- Incorrect values of EMC-related components fitted during assembly
- A broken connection to earth/ground

No Safety or EMC test standards have (so far) ever required the simulation of faults that might cause EMC immunity to reduce to such levels that normal levels of EMI would cause safety hazards to occur. Another possibility is that a fault might cause an item of equipment to start to emit much higher levels of emissions, causing interference with other safety-related equipment nearby.

For example, a failed earth/ground connection could reduce the attenuation provided by a mains filter by tens of dBs, so that (for example) typical transients on the mains supply are now able to corrupt the operation of safety-related software.

Because traditional EMC standards take no account of the possible effects of faults, this alone is sufficient reason for declaring that they are inadequate where EMI could have Functional Safety consequences.

Traditional EMC standards do not test for construction errors

Point 2 above concerns the fact that most of the usual safety standards (e.g. EN 60950, EN 61010-1, EN 60335-1, EN 60601-1, etc.) require routine tests on every manufactured unit, to check whether faulty parts or incorrect assembly have undermined its safety design features.

But so far, no EMC standards contain requirements for routine tests on manufactured units, to check whether faulty parts or incorrect assembly have undermined their EMC design features (for example, whether the correct shielding gasket was competently fitted during assembly). This alone is sufficient reason for declaring that traditional EMC testing methods are inadequate when EMI could have Functional Safety consequences.

Traditional EMC standards do not maintain EM performance in serial manufacture

A related issue to the one discussed above is that most manufacturers test their equipment for EMC, modifying it as required until the tests are passed. But some of them have no real understanding of whether the final version passed because of good EMC design, or because of a fluke that might not be repeated in future manufacture.

Even if the EMC design was indeed good, many manufacturers have no idea whether an altered cable routing, a different batch of ICs or a software ‘bug fix’ could reduce EMC performance by an unacceptable amount. Many companies introduce such ‘small’ changes in production and substitute components without retesting EMC.

The fact that an item of equipment once passed an EMC immunity test proves nothing at all about the quality of its EM design, or the EM immunity performance of the units actually supplied. Performing appropriate EMC checks on the performance of each unit manufactured can help provide the necessary confidence – but such checks are not required by traditional EMC standards. This shortcoming alone is sufficient reason for declaring that traditional EMC testing methods are inadequate when EMI could have Functional Safety consequences.

Traditional EMC standards do not address design methods

Point 3 above concerned the fact that safety standards require that the design is inspected against a number of safety design criteria. Their criteria are well-proven to provide a sufficient level of protection over the expected lifetime, taking into account the ranges of the physical and climatic environments (e.g. temperature, vibration, pollution, exposure to water) and reasonably foreseeable use or misuse (such as terminating cable shields incorrectly).

But traditional EMC standards in the IEC series treat the EUT (equipment under test) as a ‘black box’ and contain no design criteria whatsoever. Most other EMC standards also ignore anything to do with EMC design methods, although there are a few military ones that address some aspects. MIL-STD-464 [10] and DEF-STAN 59-41 Parts 6 and 7 [11] (which are codes of practice or guidelines) include some EMC design methods, but they are almost all aimed at systems and installations and not at the EMC design used in the individual units of equipment.

A consequence of this is that a unit can pass an EMC test with a good margin when it is new, but fail the same test a year or so later because its EMC design was inadequate for the perfectly normal real-world conditions it has been exposed to. Another issue is that although the design requirements in the safety standards are usually based on many decades of experience of how real-world conditions can affect design, EMC standards use tests that only have a very tenuous relationship with the real-world EM environment.

The following are some of the more obvious examples of how traditional EMC standards do not address real-world requirements in either EMC design or EMC testing.

Only one EM threat is tested at a time

The real-world EM environment often contains a number of *simultaneous* EM threats – for example: radiated fields at two or more frequencies; a continuous radiated field plus a fast transient burst, or an electrostatic discharge; etc.

Michel Mardiguian [12] has shown that when one EM disturbance is applied (e.g. a radiated RF field) the immunity of the equipment to another disturbance (e.g. fast transient bursts) can be seriously compromised. It seems that one of the EM threats ‘uses up’ some of the noise margin in the circuit, so that when a simultaneous disturbance occurs, even quite a low level can cause significant interference.

But simultaneous radio-frequency disturbances can cause more unexpected interference problems, by intermodulating within the electronic devices themselves. So, for example, if a unit was known to be susceptible to EM threats around 1MHz, it will be shielded and filtered to protect it from such exposure. And if the unit was not found to be susceptible at very high frequencies, the filtering and shielding might be ineffective above 100MHz.

Then, if this unit was in close proximity to (say) two cellphones, or a cellphone base-station, it might be exposed to two simultaneous frequencies at (say) 900MHz and 901MHz. These high frequencies would not be significantly attenuated by the unit’s shielding and filtering, and would penetrate into the unit’s circuits where intermodulation in the semiconductors would create new threats at 1801MHz and 1MHz (the sum and difference of the original frequencies). The 1MHz ‘intermodulation product’ could then interfere with the unit.

Immunity tests do not simulate real-life exposure

EMC test methods are designed for accuracy, repeatability, and low cost – and may not simulate real life very well. For example: most radiated EM field immunity testing is done in anechoic chambers that create an environment unlike most real-life situations. If the layout of the equipment and related cables in an anechoic chamber test is not identical to its set-up in real life (it usually is not), the test results can differ from the equipment’s real-life radiated susceptibility. Also, there are concerns about the uncertainty in the anechoic chamber test method itself, with some authors suggesting large and unpredictable uncertainties [13], [14]. Tests that use reverberation chambers can be better in these respects [15], [16].

The waveforms used for fast transient burst, surge and electrostatic discharge testing are very simplified versions of the real-world EM disturbances they are supposed to represent. For example [17] shows that, if ESD testing using IEC 61000-4-2 has any correlation with real-life immunity to personnel discharge, it is only an accident (apparently) due to the design of certain ESD simulators.

Immunity test methods are often too simplistic. For example, electronic warfare and munitions EMC experts know that when an EM 'threat' is modulated at a frequency corresponding to the rate of electrical or software activity in the target equipment, the immunity of the target reduces dramatically, maybe by as much as 40dB. Real world sources of EMI have a huge possible range of modulation types and frequencies, but normal immunity standards (e.g. using the basic test method IEC/EN 61000-4-3 or IEC/EN 61000-4-6) only use sine-wave amplitude modulation at a single frequency, 1kHz, therefore they cannot predict the response of the tested equipment to the vast majority of real-life continuous radiated EM threats.

Tests using traditional EMC standards can give an inflated impression of an equipment's real-life EM performance, due to the effects of foreseeable variations in current and temperature. EMC testing standards usually test with just one load setting; at just the nominal value of the mains voltage; and at normal laboratory ambient temperature. Variations in the mains voltage, load current and temperature can all affect the values of the inductors used in EMI filters, and change the effectiveness of the filters.

[18] gives the example of a variable-speed motor drive tested for emissions to IEC 61800-3, at 25°C and 230Vrms with a light load on the motor. When retested at 40°C, +10% supply voltage and full load, the motor drive's mains supply filter performance was 20dB less effective, compromising emissions and immunity.

EMC 'risk analysis' is not done

EM phenomena vary according to some statistical parameters. The question arises of where to set the pass/fail level for an immunity test, within this statistical variation. This level is known as the "Compatibility Level", and traditional EMC standards often seem to set it at the two-sigma level (sigma being the standard deviation) – meaning that 95% of the population of events of a certain type of EM phenomenon should fall below the tested level. But on the other hand this also means that 5% of the EM events can be expected to be higher than the test level.

This might be a suitable compromise between performance and cost for domestic, commercial and industrial equipment that have no impact on safety – but a one-in-twenty chance of malfunction or failure upon exposure to some EM phenomena could be unacceptable where there are safety implications.

Traditional EMC standards also do not cover situations where cellphones and other mobile transmitters are used in close proximity – even though this is now a normal aspect of most EM environments.

As well as their failure to cover the normal EM environments comprehensively enough, traditional immunity standards make no attempt to cover low-probability EM phenomena that could be important for Functional Safety, especially where the consequences for safety risks are high [19]. For example, they test mains power inputs with surges at no more than ±2kV – even though a number of surges of up to ±6kV can be expected each year on normal 230/400V mains supplies throughout most of the developed world [20].

Good safety engineering practice requires a hazard assessment and risk analysis that includes an assessment of the reasonably foreseeable environments and the possible effects they could have on the unit concerned. This is good safety engineering practice for EM environments too.

This type of assessment *is* required by [7], but this Technical Specification and could take years to become a full IEC standard, maybe even longer to be adopted as a harmonised EN and listed under EU safety directives.

So passing tests to the traditional EMC immunity standards cannot give any confidence that the tested example of equipment would be safe enough in its real world EM environment.

Traditional military and automotive EMC standards (the vehicle manufacturers' in-house standards, not the Automotive EMC Directives) tend to base their immunity tests on 'worst-case' EM threats, so are a lot better than in this regard, but since they suffer from many of the other shortcomings described here they are still inadequate, on their own, where Functional Safety is required.

Lifecycle effects of physical and climatic environments on EM performance

Adequate safety performance must be maintained over the entire lifetime of an equipment, so some minimum EM performance must be maintained despite the effects of the physical and climatic environments.

Physical stresses (e.g. from non-flat mounting), vibration, shock, temperature extremes and temperature cycling can all have an immediate bad effect on EM performance – for example by causing poor electrical contact at joints and gaskets and reducing the effectiveness of filtering or shielding.

Lifetime exposure to physical, climatic and operating environments, including condensation, weathering, salt spray, mould growth, air pollution, sand and dust, cleaning solvents and spillages – plus wear and tear caused by multiple operations of controls and the opening and closing of doors and access panels – all contribute to 'ageing'. The inevitable corrosion at metal joints is known to degrade EM filtering and shielding performance and cause immunity to worsen as equipment ages. Ageing *always* degrades EM performance.

Apart from [7] no non-military EMC or safety standards cover this issue [21].

Maintenance, repair, refurbishment, upgrades (e.g. software) are not addressed

Real-world equipment is subject to cleaning, maintenance, repair, refurbishment and upgrades. Safety requires the consequences of these actions to be taken into account as a matter of good safety engineering practice – but they are ignored by traditional EMC standards (with the exception of [10]).

Traditional EMC performance criteria might not be acceptable in a system

The difficulty of testing a system in-situ means that it is preferred to perform EMC tests on individual items of equipment or system sub-assemblies, but if the individual tests do not use immunity test performance criteria derived from the system specifications, great problems can arise [19].

For example, the traditional immunity tests applied to a 24Vdc power supply unit consider it acceptable if it complies with Performance Criterion B during a fast transient burst test (with IEC 61000-4-4 as the basic test method). This allows any amount of momentary degradation during the test, as along as the EUT self-recovers to normal operation immediately afterwards. Power supply units that collapse their d.c. outputs to 0V during the transient test, quickly recovering to 24Vd.c. afterwards, pass this test.

Most specifiers and buyers simply require that the power supply units they purchase for use in their systems pass all of the relevant EMC immunity tests, and they do not enquire about their actual functional performance during their tests. But if in a final system a 24Vd.c. power supply powers a single-board computer or programmable logic controller (PLC), the failure of its d.c. supply during commonplace mains-born transients would probably cause a reboot or a crash. During the reboot (or crash) the system is not under control, and afterwards it might not be in the same state that it was beforehand – requiring manual intervention.

The above example shows that EMC testing individual items of equipment does not necessarily mean that their immunity performance will be acceptable when they are used in a system, especially when the correct performance of the system is important for safety.

Conclusions

The EMC performance that is required for Functional Safety reasons cannot be achieved by applying traditional EMC standards (at least, not on their own).

As for all other safety issues, including software, correct design for the intended lifecycle is the key. EMC standards for Functional Safety should therefore specify the EMC design methods that should be used. Also (as for all other safety issues including software) stricter EMC design methods will be needed as the level of safety required increases.

Design must be verified, so EMC tests that actually simulate real-life EM threats are required. These tests may differ from traditional tests, and should be based on knowledge of the foreseeable real-life EM environment. But the above analysis of the shortcomings of traditional EMC test methods shows that no practical or affordable amount of EMC testing can ever be sufficient, on its own, to prove that the EM performance is adequate for the level of Functional Safety that is required.

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