DD IEC/TS 61000-1-2:2008

BSI British Standards

Electromagnetic compatibility (EMC) —

Part 1-2: General — Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena

raising standards worldwide™

British Standards

National foreword

This Draft for Development is the UK implementation of IEC/TS 61000-1-2:2009. It supersedes DD IEC TS 61000-1-2:2001 which is withdrawn.

This publication is not to be regarded as a British Standard.

It is being issued in the Draft for Development series of publications and is of a provisional nature. It should be applied on this provisional basis, so that information and experience of its practical application can be obtained.

Comments arising from the use of this Draft for Development are requested so that UK experience can be reported to the international organization responsible for its conversion to an international standard. A review of this publication will be initiated not later than three years after its publication by the international organization so that a decision can be taken on its status. Notification of the start of the review period will be made in an announcement in the appropriate issue of Update Standards.

According to the replies received by the end of the review period, the responsible BSI Committee will decide whether to support the conversion into an international Standard, to extend the life of the Technical Specification or to withdraw it. Comments should be sent to the Secretary of the responsible BSI Technical Committee at British Standards House, 389 Chiswick High Road, London W4 4AL.

The UK participation in its preparation was entrusted by Technical Committee GEL/210, EMC - Policy committee, to Subcommittee GEL/210/12, EMC basic, generic and low frequency phenomena Standardization.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

ISBN 978 0 580 60245 0

ICS 33.100.99

This Draft for Development was published under the authority of the Standards Policy and Strategy Committee on 30 April 2009

Amendments issued since publication

Date	Text affected

IEC/TS 61000-1-2

Edition 2.0 2008-11

TECHNICAL SPECIFICATION

BASIC SAFETY PUBLICATION

Electromagnetic compatibility (EMC) –
Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **XC**

ICS 33.100.99

ISBN 2-8318-1019-5

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with an IEC Publication.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical specification when

- the required support cannot be obtained for the publication of an International Standard, despite repeated efforts, or
- the subject is still under technical development or where, for any other reason, there is the future but no immediate possibility of an agreement on an International Standard.

Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC/TS 61000-1-2, which is a technical specification, has been prepared by technical committee 77: Electromagnetic compatibility. It has the status of a basic safety publication in accordance with IEC Guide 104.

This second edition cancels and replaces the first edition published in 2001 and constitutes a technical revision.

The main changes are the following.

- For safety-related systems that use electrical, electronic or programmable electronic technologies, the technical information, definitions, terminology and text of this second edition have been aligned to IEC 61508.
- Risk assessment requirements and methodologies have been deleted from this document, so as not to duplicate or clash with IEC 61508.
- It now makes a clear distinction between complete safety-related systems and items of equipment that might be used in such systems, and clarifies its application by the different types of end-users.
- This technical specification focuses more on appropriate design methods, and their verification and validation.
- The methodology for assessing and specifying electromagnetic environments has been extended.
- The combination of electromagnetic and physical/climatic influences are taken into account.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
77/356/DTS	77/359A/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

IEC 61000 is published in separate parts according to the following structure:

Part 1: General

General considerations (introduction, fundamental principles)

Definitions, terminology

Part 2: Environment

Description of the environment

Classification of the environment

Compatibility levels

Part 3: Limits

Emission limits

Immunity limits (insofar as they do not fall under the responsibility of the product committees)

Part 4: Testing and measurement techniques

Measurement techniques

Testing techniques

Part 5: Installation and mitigation guidelines

Installation guidelines

Mitigation methods and devices

Part 6: Generic standards

Part 9: Miscellaneous

Each part is further subdivided into several parts, published either as international standards, technical specifications or technical reports, some of which have already been published as sections. Others will be published with the part number followed by a dash and completed by a second number identifying the subdivision (example: IEC 61000-3-11).

Particular considerations for IEC 61000-1-2

The function of electrical or electronic systems should not be affected by external influences in a way that could lead to an unacceptable risk of harm to the users, other persons, animals or property. A comprehensive safety analysis should consider various factors of climatic, mechanical, electrical nature and reasonably foreseeable misuse. Electromagnetic disturbances are present in most environments and should therefore be considered during such an analysis.

The purpose of this document is to provide guidance relating to the achievement of functional safety of electrical or electronic systems exposed to electromagnetic disturbances.

With respect to consistency within IEC, the document makes use, as far as appropriate, of existing relevant basic IEC standards. It considers the work of SC 65A relating to functional safety concepts of the IEC 61508 series and of TC 77, its subcommittees and CISPR relating to the electromagnetic environments. For details on these subjects reference should be made to the standards of these committees.

IEC 61508 has the status of a basic safety publication and it deals with the topic of functional safety of electric/electronic/programmable electronic (E/E/PE) safety-related systems. It sets the overall requirements to achieve functional safety. Sufficient immunity to electromagnetic interference is one of those requirements. However, it is limited in scope to systems that carry out safety functions that have integrity requirements assessed in the range of safety integrity level (SIL) 1 to SIL 4 range, and it does not give detailed requirements relating to electromagnetic immunity. This part of IEC 61000-1 gives guidance to achieve adequate immunity of the safety-related systems and equipment that are intended to be used in safety-related systems.

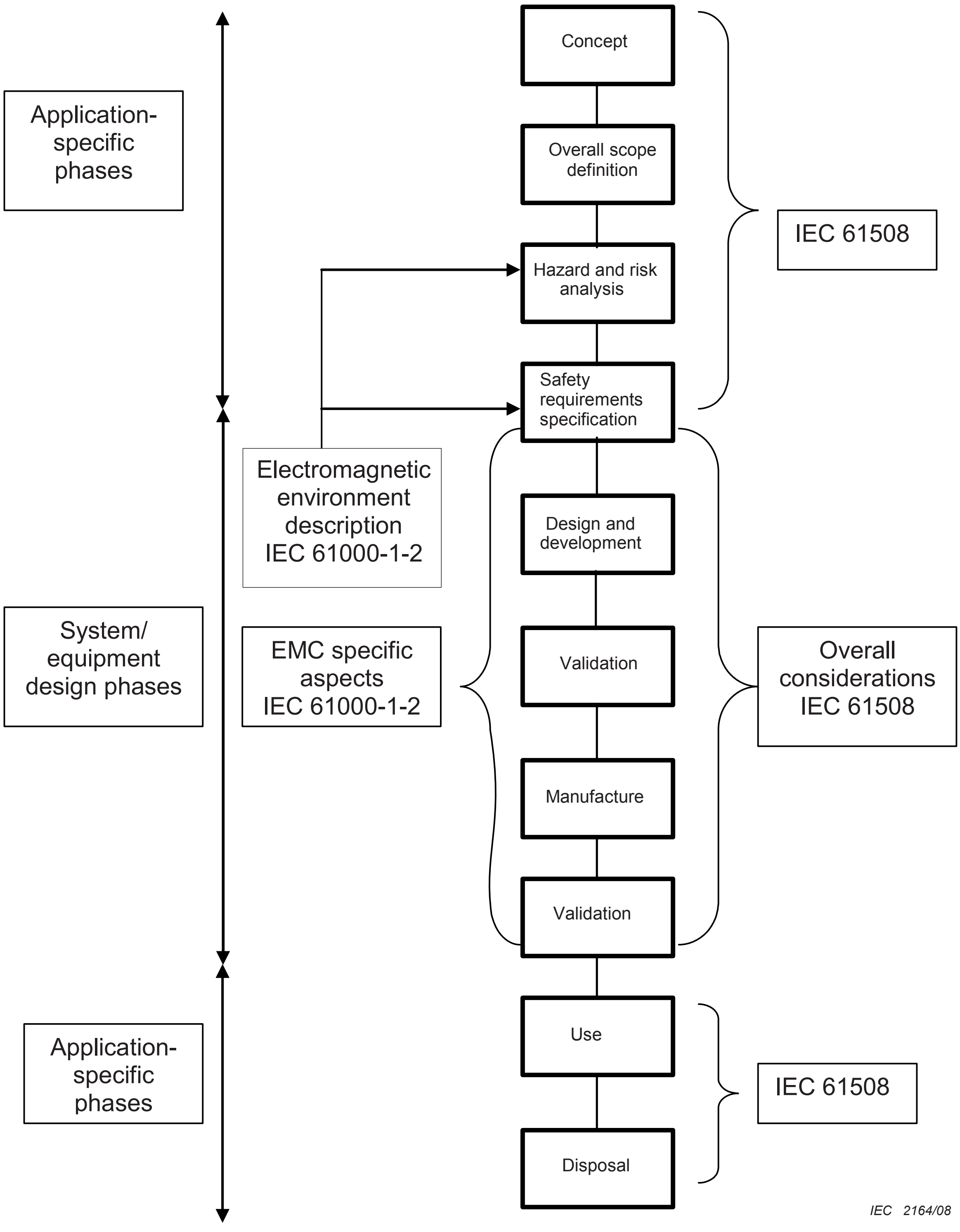
The concept of IEC 61508 is based on a lifecycle model (see Figure 1). The concept comprises application-specific activities and activities relating to the design of the equipment. The application-specific activities are contained in phases both before and after the phases for equipment design. The interface between the earlier application-specific phases and the equipment design phases is the safety requirements specification (SRS), see Table 1. It specifies all relevant requirements of the intended application(s):

a) definition of the safety-related function(s), based on a risk assessment of the intended application(s) (which function(s) may cause a hazard in case of failure).
b) selection of appropriate safety integrity level (required) based on a risk assessment of the intended application(s).
c) definition of the environment in which the system will work.

The safety-related system intended to implement the specified function(s) has to fulfil the safety requirements specification (SRS). Equipment intended for use in that system has to fulfil the relevant requirements derived from the safety requirements specification (SRS).

Table 1 – Safety requirements specification, interfaces and responsibilities according to IEC 61508

Functional safety	
Safety-related system (IEC 61508)	
Application (system level)	Safety requirements specification (SRS) a) Definition of safety-related function, based on a risk assessment of the intended application (IEC 61508) (which function may cause a dangerous failure) b) Selection of appropriate safety integrity level (required) based on a risk assessment of the intended application (IEC 61508) c) Definition of the environment in which the system will work (IEC 61508, IEC 61000-1-2, IEC 61000-2-5)
E/E/PE equipment intended for use in a safety-related system	Equipment manufacturer has to fulfil the relevant requirements of the safety requirements specification (SRS). This includes: ensuring that there is adequate confidence that electromagnetic disturbances will not result in dangerous systematic failures (systematic capability with respect to electromagnetic disturbances); and producing evidence that appropriate methods and techniques have been employed.



NOTE 1 The diagram shows a simplified overview of the relationship between IEC 61508 and IEC 61000-1-2. It should be noted that EMC issues may need careful consideration during lifecycle stages other than those covered by IEC 61000-1-2, e.g. maintenance activities for EMC characteristics may be required during the "use-of-equipment" phase to ensure continued safety-related system performance.

NOTE 2 Verification is not shown in the diagram but it is relevant to all lifecycle phases.

Figure 1 – Relationship between IEC 61000-1-2 and the simplified lifecycle as per IEC 61508

ELECTROMAGNETIC COMPATIBILITY (EMC) –

Part 1-2: General – Methodology for the achievement of functional safety of electrical and electronic systems including equipment with regard to electromagnetic phenomena

1 Scope and object

This part of IEC 61000 establishes a methodology for the achievement of functional safety only with regard to electromagnetic phenomena of electrical and electronic systems and installations, as installed and used under operational conditions. This methodology includes the implication it has on equipment used in such systems and installations.

This technical specification:

a) applies to safety-related systems incorporating electrical/electronic/programmable electronic equipment;

b) considers the influence of the electromagnetic environment on safety-related systems; it is intended for designers, manufacturers and installers of safety-related systems and can be used as a guide by IEC committees;

c) is not concerned with direct hazards from electromagnetic fields on living beings nor is it concerned with safety related to breakdown of insulation or other mechanisms by which persons can be exposed to electrical hazards.

It mainly covers EMC related aspects of the design phase of safety-related systems and equipment used therein, and deals in particular with

– some basic concepts in the area of functional safety,
– the various EMC specific steps for the achievement and management of functional safety,
– the description and assessment of the electromagnetic environment,
– the EMC aspects of the design and integration process taking into account the process of EMC safety planning on system as well as on equipment level,
– the validation and verification processes regarding the immunity against electromagnetic disturbances,
– the performance criterion and some test philosophy considerations for safety-related systems and the equipment used therein,
– aspects related to testing of the immunity of safety-related systems and equipment used therein against electromagnetic disturbances.

This Technical Specification is applicable to safety-related systems intended to comply with the requirements of IEC 61508 and/or associated sector-specific functional safety standards.

For safety-related systems covered by other functional safety standards, a consideration shall be made of the requirements of this Technical Specification in order to identify the appropriate measures that shall be taken with relation to EMC and functional safety.

This Technical Specification may also be used as a guide for considering EMC requirements for other systems having a direct contribution to safety.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050(161), *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

IEC 61000-2-5, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 5: Classification of electromagnetic environments*

IEC 61000-2-13, *Electromagnetic compatibility (EMC) – Part 2-13: Environment – High-power electromagnetic (HPEM) environments – Radiated and conducted*

IEC 61000-4 (all parts), *Electromagnetic compatibility (EMC) – Part 4: Testing and measurement techniques*

IEC 61000-4-1, *Electromagnetic compatibility (EMC) – Part 4-1: Testing and measurement techniques – Overview of IEC 61000-4 series*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety-related systems*

IEC 61508-1, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 1: General requirements*

IEC 61508-2, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 2: Requirements for electrical/electronic/programmable electronic safety-related systems*

IEC 61508-4, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 4: Definitions and abbreviations*

IEC Guide 104:1997, *The preparation of safety publications and the use of basic safety publications and group safety publications*

3 Terms, definitions and abbreviations

For the purposes of this document, the definitions contained in IEC 60050(161) as well as the following apply.

3.1
degradation (of performance)
undesired departure in the operational performance of any device, equipment or system from its intended performance

NOTE The term "degradation" can apply to temporary or permanent failure.

[IEV 161-01-19]

3.2
electrical/electronic/programmable electronic
E/E/PE
based on electrical and/or electronic and/or programmable electronic technology

NOTE The term is intended to cover any and all devices or systems operating on electrical principles.

EXAMPLE Electrical/electronic/programmable electronic devices include

– electro-mechanical devices (electrical);
– solid-state non-programmable electronic devices (electronic);
– electronic devices based on computer technology (programmable electronic).

[IEC 61508-4]

3.3
electromagnetic compatibility
EMC
ability of an equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

[IEV 161-01-07]

3.4
electromagnetic compatibility level
specified electromagnetic disturbance level used as a reference level for co-ordination in the setting of emission and immunity limits

NOTE 1 By convention, the compatibility level is chosen so that there is only a small probability that it will be exceeded by the actual disturbance level. However, electromagnetic compatibility is achieved only if the emission and immunity levels are controlled such that, at each location, the disturbance level resulting from the cumulative emissions is lower than the immunity level for each device, equipment and system situated at the same location.

NOTE 2 The compatibility level may be phenomena-, time- or location-dependent.

[IEV 161-03-10]

3.5
electromagnetic disturbance
any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

NOTE An electromagnetic disturbance may be an electromagnetic noise, an unwanted signal or a change in the propagation medium itself.

[IEV 161-01-05]

3.6
electromagnetic environment
totality of electromagnetic phenomena existing at a given location

[IEV 161-01-01]

3.7
electromagnetic interference
EMI
degradation of the performance of an equipment, transmission channel or system caused by an electromagnetic disturbance

NOTE Disturbance and interference are respectively cause and effect.

[IEV 161-01-06]

3.8
equipment
part of system

NOTE Equipment as used in this specification is a very general term that refers to a wide variety of possible subsystems, modules, devices and other assemblies of products. It does not include people.

3.9
equipment under control
EUC
equipment, machinery or plant used for manufacturing, process, transportation, medical or other activities

3.10
equipment requirements specification
ERS
equipment specification covering safety-related requirements only with regard to electromagnetic phenomena

NOTE An equipment requirements specification (ERS) is created for each item of equipment within the safety-related system. Included in each equipment requirements specification is an electromagnetic performance specification based upon the maximum electromagnetic environment expected over the lifetime for that particular item of equipment.

3.11
failure
termination of the ability of an item to perform a required function

NOTE 1 The definition in IEV 191-04-01 is the same, with additional notes.

NOTE 2 For further information, see IEC 61508-4.

NOTE 3 Performance of required functions necessarily excludes certain behaviour, and some functions may be specified in terms of behaviour to be avoided. The occurrence of such behaviour is a failure.

NOTE 4 Failures are either random (in hardware) or systematic (in hardware of software).

[ISO/IEC 2382-14-04-11, modified] [IEC 61508-4]

3.12
fault
abnormal condition that may cause a reduction in, or loss of, the capability of an item to perform a required function

NOTE IEV 191-05-01 defines “fault” as a state characterised by the inability to perform a required function, excluding the inability during preventative maintenance or other planned actions, or due to lack of external resources.

[ISO/IEC 2382-14-04-06, modified]

3.13
functional safety
part of the overall safety relating to the Equipment under Control (EUC) and the EUC control system which depends on the correct functioning of the E/E/PE safety-related systems, other technology safety-related systems and external risk reduction facilities

[IEC 61508-4]

NOTE In the context of this EMC document, functional safety is that part of the overall safety relating to the electromagnetic environment in which the safety-related system exists.

3.14
installation
combination of equipment, components and systems assembled and/or erected (individually) in a given area; for physical reasons (e.g. long distances between individual items) it is in many cases not possible to test an installation as a unit

3.15
EMC planning
engineering method by which EMC aspects of a project are systematically considered and investigated in order to achieve EMC; all activities connected to it are described in an EMC plan

3.16
EMC safety planning
EMC planning which also considers functional safety aspects

3.17
safety integrity
probability of a safety-related system satisfactorily performing the required safety functions under all the stated conditions within a stated period of time

[IEC 61508-4, modified]

3.18
safety integrity level
SIL
discrete level (one out of a possible four) for specifying the safety integrity requirements of the safety functions to be allocated to the E/E/PE safety-related systems, where safety integrity level 4 has the highest level of safety integrity and safety integrity level 1 has the lowest

NOTE The target failure measures for the four safety integrity levels are specified in Tables 2 and 3 of IEC 61508-1.

[IEC 61508-4]

3.19
safety-related system
designated system that both implements

– the required safety functions necessary to achieve or maintain a safe state for the equipment under control, and

– is intended to achieve, on its own or with other E/E/PE safety-related systems, other technology safety-related systems or external risk reduction facilities, the necessary safety integrity for the required safety functions

NOTE 1 A safety-related system includes all the hardware, software, human operators and supporting services (for example, power supplies) necessary to carry out the specified safety function (sensors, other input devices, final elements (actuators) and other output devices are therefore included in the safety-related system).

NOTE 2 For further information, see IEC 61508-4.

[IEC 61508-4, modified]

3.20
safety requirements specification
SRS
specification containing, for each safety function, the safety function requirements (what the function does), and the safety integrity requirements (the likelihood of the safety function being performed satisfactorily) that have to be performed/met by the safety-related systems

3.21
system
combination of equipment and/or active components constituting a single functional unit and intended to be installed and operated to perform (a) specific task(s)

NOTE Safety-related systems are specifically designed equipment that both

– implement the required safety functions necessary to achieve or maintain a safe state for a controlled equipment,

– are intended to achieve on their own or with other safety-related equipment or external risk reduction facilities, the necessary safety integrity for the required safety requirements.

[IEC 61508-4]

3.22
E/E/PE system
system for control, protection or monitoring based on one or more electrical/electronic programmable electronic (E/E/PE) devices, including all elements of the system such as power supplies, sensors and other input devices, data highways and other communications paths, and actuators and other output devices

[IEC 61508-4]

3.23
systematic capability
measure (expressed on a scale of 1 to 4) of the confidence that equipment will not fail due to relevant systematic failure mechanisms (see Note 2) when the equipment is applied in accordance with the instructions specified in its safety manual

NOTE 1 Systematic capability is determined with reference to the requirements for the avoidance and control of systematic faults (see IEC 61508-2 and IEC 61508-3). This technical specification specifies the requirements for systematic capability as it relates to electromagnetic disturbances.

NOTE 2 Determination of a relevant systematic failure mechanism depends on the nature of the element. For example, for an element comprising solely software, only software failure mechanisms will need to be considered. For an element comprising hardware and software it will be necessary to consider both systematic hardware and software failure mechanisms.

NOTE 3 This document only specifies what needs to be done to claim a level of systematic capability for an item of E/E/PE equipment, in so far as electromagnetic disturbances are concerned.

3.24
testing
demonstration by empirical means that an implemented solution conforms to its specification

3.25
validation
confirmation by examination and provision of objective evidence that the particular requirements for a specified intended use are fulfilled

NOTE 1 Adapted from ISO 8402 by excluding notes.

NOTE 2 Validation is the activity of demonstrating that the safety-related system under consideration, before or after installation, meets in all respects the safety requirements specification for that safety-related system.

[IEC 61508-4]

3.26
verification
confirmation by examination and provision of objective evidence that the requirements have been fulfilled

NOTE 1 Adapted from ISO 8402 by excluding the notes.

NOTE 2 In the context of this technical specification, verification is the activity of demonstrating for each phase of the relevant life cycle, that, by analysis and/or tests, for the specific inputs, the deliverables meet in all respects the objectives and requirements set for this phase.

NOTE 3 Example: verification activities include:

- reviews on outputs (documents from all phases of the safety life cycle) to ensure compliance with the objectives and requirements of the phase taking into account the specific inputs to that phase;
- design reviews;
- tests performed on the designed products to ensure that they perform according to their specification;
- integration tests performed where different parts of a system are put together in a step-by-step manner and by the performance of immunity tests against electromagnetic disturbances to ensure that all parts work together in the specified manner.

[IEC 61508-4]

3.27
radiated HPEM environment
high power electromagnetic fields with peak electric field levels that typically exceed 100 V/m

[IEC 61000-2-13]

3.28
conducted HPEM environment
high power electromagnetic currents and voltages that are either coupled or directly injected to cables and wires with voltage levels that typically exceed 1 kV

[IEC 61000-2-13]

4 General considerations

Electromagnetic disturbances can influence the performance of equipment and the functional safety of systems.

The aim of this document with regard to EMC and functional safety is to address the possible effects of electromagnetic disturbances on safety-related systems and to specify requirements for the relevant phases of the lifecycle of a safety-related system to achieve the systematic capability due to electromagnetic aspects as specified in the safety requirements specification (SRS).

The correct operation of a safety-related system depends on several factors. IEC 61508 contains the overall consideration for safety-related systems. The specific aspects related to electromagnetic disturbances are considered in this technical specification.

These aspects comprise:

- the electromagnetic environment (see Clause 6);
  - assessing environment information,
  - deriving test levels and methods,
  - considerations on electromagnetic phenomena and safety integrity levels (SILs);
- the EMC aspects of the design and integration processes (see Clause 7);
  - system level,
  - equipment level;
- electromagnetic immunity verification/validation for functional safety (see Clause 8);
  - verification and validation processes,
  - performance criteria and test philosophy;
- immunity testing with regard to functional safety (see Clause 9);
  - considerations on test methods and levels,
  - considerations on immunity testing with regard to systematic capability.

Figure 2 shows the mutual relationship between these aspects as well as to those treated within IEC 61508. Though the safety requirements specification (SRS) is primarily an aspect of IEC 61508 it shall consider the outcome of an assessment of the electromagnetic environment in which the safety-related system is intended to be operated.

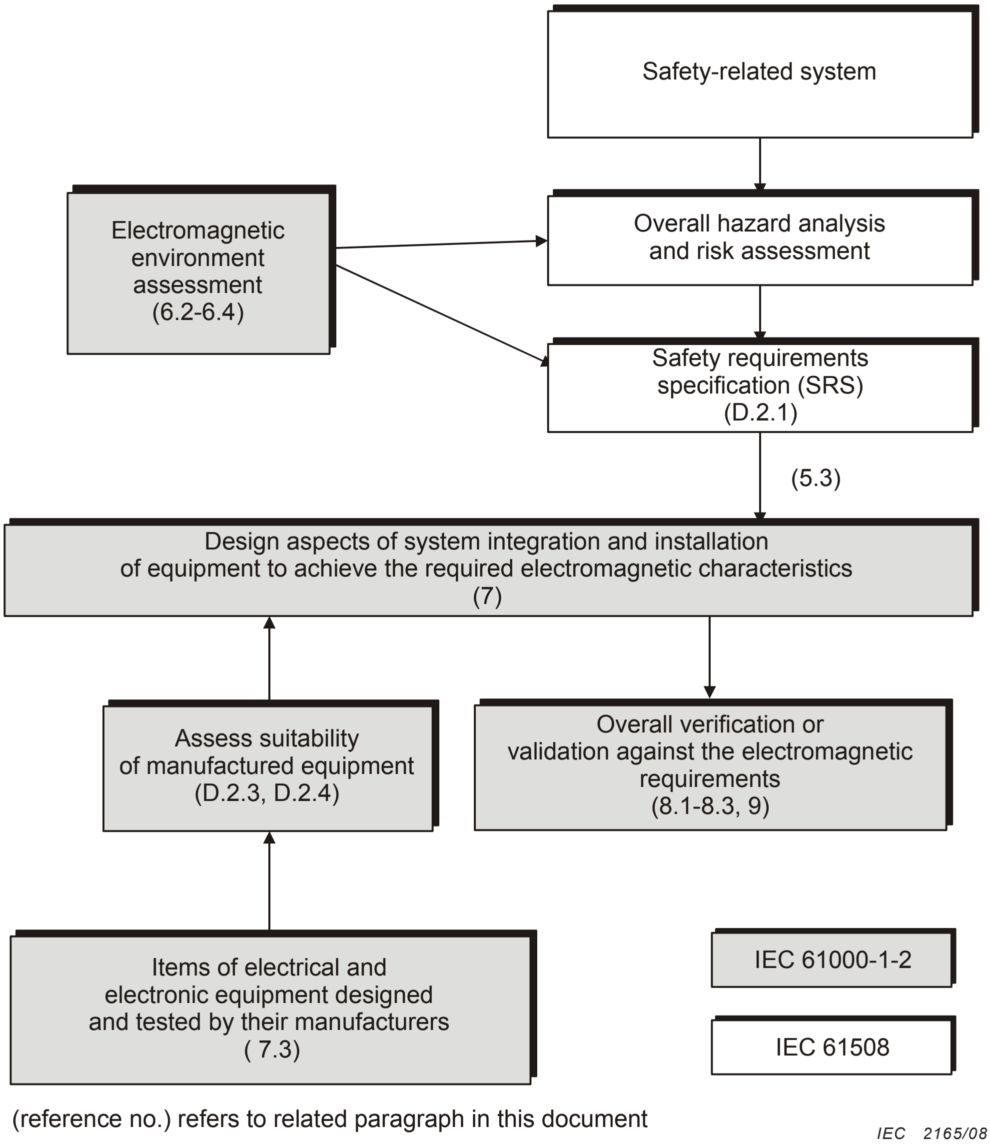


Figure 2 – Basic approach to achieve functional safety only with regard to electromagnetic phenomena

5 The achievement of functional safety

5.1 General

The achievement of functional safety represents a process which contains technical as well as management activities. As a precondition, this process requires an understanding of some basic terms and concepts within the area of functional safety, these being:

– safety life cycle: necessary activities involved in the implementation of safety-related systems, occurring during a period of time that starts at the concept phase and finishes when the safety-related system is no longer available for use (see 5.2);

– safety integrity: it is the probability of a safety-related system to satisfactorily perform the required safety functions under all stated conditions within a stated period of time (see 5.3).

NOTE IEC 61000-1-2 does not deal with all the phases of the whole lifecycle (see also Figure 1).

Taking into account those basic terms and concepts, 5.4 gives guidance on those steps for the achievement of functional safety which are related to the impact of electromagnetic disturbances. Corresponding procedures on the management level are described in 5.5.

5.2 Safety life cycle

The overall lifecycle relevant for the functional safety of safety-related E/E/PE systems is defined in IEC 61508, and shown in Figure 1. The lifecycle starts with the concept phase followed by the definition of the considered application and the hazard and risk analysis. The hazard and risk analysis and consideration of the overall safety requirements result in a specification of the requirements on the safety-related system. These phases of the lifecycle are within the scope of IEC 61508.

The safety requirements specification (SRS) is the interface to the E/E/PE system-related consideration. For safety-related E/E/PE systems, the safety requirements specification (SRS) is within the scope of IEC 61508 and it is also partly within the scope of IEC 61000-1-2 for the specification of the electromagnetic environmental conditions.

The overall design process and the necessary design features to achieve functional safety of safety-related E/E/PE systems are defined in IEC 61508. This includes requirements for design features that make the system tolerant against electromagnetic disturbances.

The phases of design, implementation, validation, commissioning and modification of safety-related E/E/PE systems are covered by the scopes of both IEC 61508 and IEC 61000-1-2. IEC 61508 comprises all aspects relevant for functional safety and IEC 61000-1-2 deals with the aspects related to electromagnetic phenomena.

Use, maintenance and decommissioning of safety-related E/E/PE systems are within the scope of the IEC 61508 series.

For E/E/PE equipment used in safety applications within the scope of IEC 61508, the approach to deal with aspects related to electromagnetic phenomena is different from that used for safety-related systems.

An important consideration for equipment is its specified behaviour. This is the state/condition that equipment goes to and/or maintains upon the occurrence of a fault. This behaviour shall be specified by the equipment manufacturer. For example, this specification could be simply a statement that the equipment will provide a specified output signal upon detection of an equipment fault.

This specified behaviour of equipment shall be considered during several of the lifecycle phases of the equipment. These include the concept, overall planning, design and development, integration, operation and maintenance, validation, and modification phases. The hazard and risk analysis, overall safety requirements, and safety requirements allocation phases do not apply at the equipment level.

5.3 Safety integrity

The safety requirements specification (SRS) contains two types of requirements:

– safety function requirements (what the safety-related system is required to do); and
– safety integrity requirements (the required likelihood of each safety function being performed satisfactorily).

IEC 61508 introduces the concept of a safety integrity level (SIL). This is a discrete level (one out of a possible four), corresponding to a range of safety integrity values either expressed as a dangerous failure rate per hour or an average probability of dangerous failure on demand, where SIL4 has the highest level of safety integrity and SIL1 has the lowest, see Table 2.

Table 2 – Safety integrity levels

Safety integrity level	Average probability of dangerous failure on demand (x) [a]	Frequency of dangerous failure of the safety function per hour (y) [b]
4	$10^{-5} \leq x < 10^{-4}$	$10^{-9} \leq y < 10^{-8}$
3	$10^{-4} \leq x < 10^{-3}$	$10^{-8} \leq y < 10^{-7}$
2	$10^{-3} \leq x < 10^{-2}$	$10^{-7} \leq y < 10^{-6}$
1	$10^{-2} \leq x < 10^{-1}$	$10^{-6} \leq y < 10^{-5}$

NOTE See IEC 61508-1, 7.6, for further details.

[a] Low demand mode of operation: where the safety function is only performed on demand, in order to transfer the equipment under control (EUC) into a specified safe state, and where the frequency of demands is no greater than one per year.

[b] High demand mode or continuous mode of operation: where the safety function is only performed on demand, in order to transfer the EUC into a specified safe state, and where the frequency of demands is greater than one per year. Continuous mode of operation: where the safety function retains the EUC in a safe state as part of normal operation.

The safety integrity of a safety-related system is determined by its hardware safety integrity and its systematic safety integrity.

Hardware safety integrity relates to dangerous failures of hardware due to physical degradation (which will occur randomly in time). The hardware safety integrity of a safety-related system can be determined quantitatively based on the hardware safety integrity of its constituent elements (which depends on their random failure rates).

Systematic safety integrity (which includes software safety integrity) relates to dangerous failures that will always occur given a particular set of circumstances. Systematic safety integrity is difficult to quantify accurately. The safety integrity level allocated to the safety-related system (as a result of its safety integrity requirements) will affect the degree of rigour necessary when meeting requirements for controlling or avoiding systematic failures. Some of these requirements are explicitly graded according to safety integrity level (see Table 4).

The failure or malfunction of a safety-related system due to an electromagnetic disturbance with a given strength is systematic as long as the duration of the disturbance is longer or equal to the operating cycle of the safety-related system. In this document, it is therefore assumed that the duration of the disturbance is such, moreover the influence of given electromagnetic disturbances on a given safety-related system is considered the same for each occurrence. At system level, appropriate mitigation techniques increase immunity of the safety-related functions and shall be considered as part of the systematic capability.

Any equipment that has been developed to fully meet the requirements of the IEC 61508 series concerning systematic safety integrity for a given safety integrity level (SIL) is said to have the corresponding systematic capability. Alternatively, the systematic capability of equipment can be demonstrated through proven in use evidence according to the strict requirements of IEC 61508-2.

In general, all equipment used in a safety-related system shall have a systematic capability of at least the safety integrity level (SIL) allocated to the system.

Therefore, the suitability of equipment for safety-related systems is in general determined by both the random hardware failure data for the equipment and by its systematic capability.

5.4 EMC specific steps for the achievement of functional safety

To achieve functional safety the following actions with regard to electromagnetic influences shall be undertaken:

a) consider the structure, design and intended functions of the projected or existing safety-related system;
b) describe the relevant electromagnetic environment in which the safety-related system is intended to be used over its lifecycle (see 6.1);
c) consider the physical and climatic environments and the degradation due to normal use and foreseeable misuse with respect to electromagnetic aspects in which the safety-related system is intended to be used over its lifecycle;
d) implement EMC aspects in the design process (see Clause 7) of safety-related systems (see 7.3);
e) perform verification/validation of immunity against electromagnetic disturbances for functional safety (see Clause 8);
f) modify the design or installation measures, if necessary, in order to achieve the required immunity;
g) produce EMC specific operation and maintenance instructions to ensure the specified functional safety over time (these instructions would be added to the safety manual).

5.5 Management of EMC for functional safety

The requirements of this subclause are reproduced from IEC 61508-1, showing those requirements that are particular applicable to achieving EMC for safety-related systems with regard to functional safety.

An organisation with responsibility for EMC of a safety-related system or equipment, or for any of the activities within the scope of this document, shall appoint one or more persons to take overall responsibility for

– the system or equipment, or for all relevant activities,
– coordinating the EMC-related activities,
– the interfaces between those activities and other activities carried out by other organisations,
– carrying out all the requirements of this subclause,
– ensuring that EMC is sufficient and demonstrated in accordance with the objectives and requirements of this document.

NOTE 1 Responsibility for EMC-specific safety-related activities may be delegated to other persons, particularly those with relevant expertise, and different persons could be responsible for different activities and requirements. However, the responsibility for coordination, and for overall EMC for functional safety, should reside in one or a small number of persons with sufficient management authority.

For those activities for which the organisation is responsible, the policy and strategy for achieving EMC for functional safety shall be specified, together with the means for evaluating their achievement, and the means by which they are communicated within the organization.

All persons, departments and organizations responsible for carrying out EMC-specific safety-related activities shall be identified, and their responsibilities shall be fully and clearly communicated to them. Where appropriate other persons, departments and organizations which could influence the safety-related performance achieved by the system shall be made aware of these responsibilities.

Procedures shall be specified for defining what information is to be communicated, between what parties, and how communication will take place.

NOTE 2 See Clause 10 for documentation requirements.

Procedures shall be specified for ensuring that reported EMC-related hazardous situations are analysed for their relevance to safety-related systems, equipment or activities for which the organisation is responsible, and that recommendations are made to minimise the probability of a repeat occurrence.

Procedures shall be specified for ensuring prompt follow-up and satisfactory resolution of recommendations relating to EMC of safety-related systems, including those arising from verification, validation and incident reporting and analysis. Organisations shall maintain a system to initiate changes as a result of EMC-related defects being detected in safety-related systems or equipment for which they are responsible and, if they are unable to make the changes themselves, to inform users of the need for modification in the event of the defect affecting safety.

Those individuals who have responsibility for one or more of the activities within the scope of this document, shall, in respect of those activities for which they have responsibility, specify all management and technical activities that are necessary to ensure the achievement and demonstration of EMC for functional safety of the safety-related systems or equipment. This includes the selected measures, techniques and tests used to meet the requirements of this document.

Procedures shall be specified for ensuring that all persons involved in any activity within the scope of this document shall have the appropriate training, technical knowledge, experience and qualifications relevant to the specific duties that they have to perform.

The procedures specified as a result of the requirements of this clause shall be implemented and monitored.

Suppliers providing products or services to an organization having overall responsibility for one or more activities within the scope of this document, shall deliver products or services as specified by that organization and shall have an appropriate quality management system.

6 The electromagnetic environment

6.1 General

The electromagnetic environment is defined as the totality of electromagnetic phenomena existing at a particular location. These phenomena may be time dependent. Information on the electromagnetic environment shall be provided to the system designer/specifier as an input to the safety requirements specification (see Figure 2).

The electromagnetic environment is produced by, for example:

- fixed and moving sources of electromagnetic energy,
- low, medium and high voltage equipment,
- control, signalling, communication and power systems,
- intentional radiators,
- physical processes (e.g. atmospheric discharges, switching actions),
- random or infrequent transients

which all can produce disturbances potentially affecting the safety-related system under consideration.

Table 3 gives an overview of the principal electromagnetic phenomena, which shall be considered for the achievement of functional safety for safety-related systems. This list is not necessarily complete, but it shall be used to begin the consideration of electromagnetic environments that can impact functional safety.

NOTE In some particular electromagnetic environments, the occurrence of several electromagnetic phenomena at the same time, for example harmonics and unidirectional transients, can have some influence on the immunity of safety-related systems and should be taken into account.

Table 3 – Overview of types of electromagnetic phenomena

Conducted low frequency phenomena	Harmonics, interharmonics Signalling voltages Voltage fluctuations Voltage dips and interruptions Voltage unbalance Power frequency variations Induced low frequency voltages d.c. in a.c. networks
Radiated low frequency field phenomena	Magnetic fields [a] Electrical fields
Conducted high frequency phenomena	Directly coupled or induced continuous voltages or currents Unidirectional transients [b] Oscillatory transients [b]
Radiated high frequency field phenomena	Magnetic fields Electrical fields Electromagnetic fields – continuous waves – transients [c]
Electrostatic discharge phenomena (ESD)	Human and machine
Phenomena of conducted and radiated HPEM environment [d]	
High altitude electromagnetic pulse (HEMP) [d]	

[a] Continuous or transients.

[b] Single or repetitive (bursts).

[c] Single or repetitive.

[d] To be considered in case of special conditions (see IEC 61000-2-13).

NOTE There is no abrupt change between the low frequency domain and the high frequency domain but a soft transition between 9 kHz and 150 kHz. For formal applications the limit is set at 9 kHz (scope of CISPR).

6.2 Electromagnetic environment information

Many publications include basic descriptions of electromagnetic environments considering the electromagnetic phenomena and disturbance levels typically expected in such environments. General information about the description and the levels of electromagnetic disturbances in various locations can be found in the standards or technical reports of the IEC 61000-2 series. Examples of descriptions of various environments are given in IEC 61000-2-5. These descriptions, however, are given in terms of compatibility levels (which by definition are lower than immunity levels required in such environments).

IEC 61000-4-1 gives applicability assistance and provides general recommendations concerning the choice of relevant tests described in the IEC 61000-4 series. It is noted that standards designed for the achievement of EMC, which are based primarily on technical/economic factors, may not describe the electromagnetic environment sufficiently for the achievement of functional safety for safety-related systems.

Table A.2 in Annex A provides a list of electromagnetic environment levels, which can be considered as examples of the maximum electromagnetic levels for each of the phenomena for two exemplary types of electromagnetic environments. Since it has been accepted that the electromagnetic environment itself does not vary with respect to the safety integrity level (SIL) of systems placed in an installation, these maximum electromagnetic environments shall be considered for all electromagnetic functional safety situations. While some examples are provided in Annex A, it is recognized that it is difficult to ensure that the maximum levels cannot be exceeded. It is therefore the responsibility of the system designer/specifier to ensure that the proper electromagnetic disturbances and levels are considered for functional safety.

It is stressed that the levels of electromagnetic disturbances indicated in various EMC standards, reports or technical specifications shall be considered very cautiously with regard to their implications for functional safety. In particular:

a) The electromagnetic disturbance levels vary according to a statistical distribution (see Figure A.1), and the levels shown as examples in Table A.1 can be exceeded in some particular circumstances. However, such circumstances may only exist infrequently or at particular sites. It is important to establish the levels of these disturbances for functional safety purposes.
b) The standardised immunity test methods, test levels and performance criteria found in the immunity test standards are related to operational requirements and not to functional safety. If tests based on these test methods are being performed, safety-related test levels and performance criteria shall be defined for each of the electromagnetic phenomena.
c) The electromagnetic characteristics of equipment and systems can worsen with ageing, for example through physical degradation of protection measures. This life cycle aspect of electromagnetic influences should be considered.

6.3 Methodology to assess the electromagnetic environment

Relevant and significant information exists within the EMC body of publications regarding the electromagnetic environment present where most electrical or electronic equipment operates.

In cases where insufficient information can be derived from EMC publications, alternative activities are recommended to be carried out in order to obtain appropriate knowledge about the electromagnetic environment at locations of interest. Such activities are

- to perform literature surveys to determine the amount of information available,
- to perform a survey directly related to the location of interest; such a survey could involve both a measurement campaign to determine the characteristics of the electromagnetic phenomena present and an analysis effort to assess the data and the characteristics of electromagnetic phenomena produced by known emitters.

The information obtained about the electromagnetic environment shall be assessed in such a way that data can be derived regarding

- the electromagnetic phenomena that are expected to occur at the locations of interest,
- the characteristics of those electromagnetic phenomena, for example their levels, frequency, modulation, rise time, etc.

NOTE 1 For automotive and aerospace applications, there are groups working within the ISO that have produced relevant information regarding EMC of those applications. This information should be used as a starting point to describe a set of electromagnetic environments appropriate for functional safety aspects.

NOTE 2 With respect to surveys it should be recognized that any survey is limited in time and locations, and therefore some considerations should be made to improve the confidence in the maximum electromagnetic environment.

6.4 Deriving test levels and methods

After the electromagnetic characteristics have been established for a particular environment, these shall be used to design the safety-related systems. While good design is a critical part of the overall process, it is well established that realistic tests are required to ensure that the safety-related systems achieve their requirement specifications. As the IEC EMC community has developed a significant number of immunity tests for equipment and small systems, these shall be considered as a starting point for testing of electromagnetic characteristics for functional safety.

For each electromagnetic phenomenon established for a particular environment, the system specifier shall include the phenomenon in the safety requirements specification (SRS) and examine the existing IEC immunity test method (using IEC 61000-4-1 as an initial guide) to determine whether the test method is appropriate. The system specifier shall also check to see if the parameters required to test to the electromagnetic characteristics of the environment are within their suggested ranges for the basic immunity test standards (refer to the IEC 61000-4 series of standards).

Immunity requirements, as defined for example in the generic standard IEC 61000-6-2, aim at supporting and achieving sufficient operation under normal conditions. Corresponding immunity test levels are derived for the most frequent electromagnetic phenomena and on a technical/economic approach taking into account issues of availability of the equipment or system under consideration. Consequently, it can be expected and it is accepted by all parties involved that the equipment or system may be disturbed in a few cases.

NOTE This approach can be accepted for normal functions of an equipment or system, but it is not acceptable for safety-related functions. Hence aspects of functional safety cannot be considered to be covered by the usual immunity requirements, as for example defined in IEC 61000-6-2, without a particular consideration of the electromagnetic environment in which the equipment or system is intended to be used.

In order to be able to justify the test method and test parameters, the system designer shall be aware of the uncertainty of the immunity testing. The uncertainty due to the test equipment can be calculated using test equipment data. It may be necessary to evaluate the significance of the skills of test personnel and those environmental conditions, which are not defined by the standards. After the complete evaluation of uncertainty, one or more of the following approaches may be used to compensate for this testing uncertainty depending on the factors of uncertainty.

a) If the available immunity test equipment is suitable, and if testing to levels above the electromagnetic disturbance level is used, then the system requirement specification shall determine the margin to failure and the description of how the safety-related system reacts to an electromagnetic induced failure.

b) If the available immunity test equipment is not suitable due to the unavailability of the required test parameters (for example amplitude, frequency, modulation, repetition rate, etc.) then

   – the system designer shall request the appropriate test equipment be obtained and used;

   and/or

   – the system designer shall specify that electromagnetic mitigation methods be applied at the system level so the safety-related equipment is assigned a reduced electromagnetic specification to parameters that can be tested by the available test equipment (for example through the use of shielded racks, surge protection devices for wire and cable entries, fibre optic data lines, power line isolation techniques, etc.). IEC 61000-5-6 provides examples of these types of mitigation methods. The applied mitigation methods (shields, surge protection devices, isolation methods, etc.) shall become a permanent part of the system design, and they shall be separately tested to ensure that they reduce the external electromagnetic environments to the specified test levels.

7 EMC aspects of the design and integration process

7.1 General

EMC safety planning shall be carried out (EMC safety control, EMC safety management) taking into account functional safety considerations. It is a strategy to ensure EMC of a safety-related system with respect to other systems in the vicinity and with respect to the environment of the outside world (see Annex F). The aim of EMC safety planning is to provide

EMC at acceptable cost by meeting target requirements during all development stages of project implementation. This means considering, investigating and assessing all the EMC issues which might arise during the project schedule. All these activities and steps will be described in an EMC safety plan (including EMC safety control and EMC safety management). The depth and extent of the EMC safety planning depends on the complexity of the system and the safety integrity level (SIL) required in the safety requirements specification (SRS).

NOTE In many cases EMC planning will be performed already due to requirements beside safety; in this case it can be extended in order to include aspects of functional safety. Further information about the process of EMC safety planning is given in Annex F.

During electromagnetic design management, one or more identified persons shall be responsible for creation and execution of the EMC safety plan. They shall establish a procedure for maintaining lifetime electromagnetic performance during maintenance, repair and refurbishment (where these are not carried out by the manufacturer). Also, they are responsible for information on any restrictions concerning future changes to the electromagnetic environment. This information shall be given to the user.

7.2 EMC aspects on system level

The electromagnetic environment in the place where the safety-related system is used shall not unacceptably affect its functional safety. This requires that the level of immunity of the safety-related system is sufficient for the intended safety integrity and electromagnetic environment, over its lifetime.

Any electromagnetic disturbances generated inside of a safety-related system shall not unacceptably affect the functional safety of the other parts of the safety-related system.

Electromagnetic disturbances generally cause systematic or “common cause” faults. This ability of an electromagnetic disturbance to affect multiple items of equipment of a safety-related system is due to the system design and therefore shall be addressed by the measures and techniques presented below and in Annex B.

All the EMC measures shall be designed and implemented in such a way that they are effective taking into account the physical environment (which includes mechanical, climatic, chemical, biological and other stresses and strains) over the lifetime of the safety-related system. This is because emissions and immunity can be altered over the lifetime of a safety-related system by exposure to its physical environment. The design of the safety-related system shall be such that it maintains its required electromagnetic performance over its lifetime.

One approach to achieving system immunity against electromagnetic disturbances shall consider the immunity of each individual item of equipment. For this purpose the following procedure shall be used.

– The entire system is formally divided into items of equipment.
– All the items of equipment of the system are to be described in terms of their EMC characteristics. An item of equipment might contain several components (for example power supply, printed circuit board, display) as well as a cabling scheme.
– The interaction between each combination of items of equipment shall be analyzed and assessed in terms of immunity, including the influence of both the external and internal electromagnetic environment. This might result in an analysis and assessment of the immunity of all the combinations of components of both items of equipment, as shown schematically for example in Figure 3.
– The functional performance criteria of the various components when they are interfered with should be analyzed in terms of their overall impact on the particular design of the safety-related system concerned. Some degradations of performance that are acceptable for a component when it is tested stand-alone, or in a different system, may not be acceptable if they occur in a particular safety-related system.

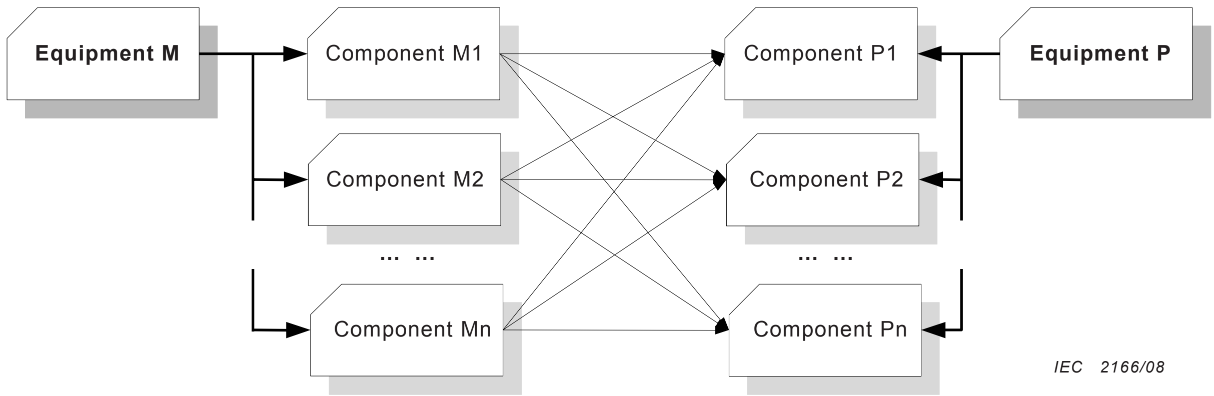


Figure 3 – EMC between equipment M and equipment P

Further guidance on design, design management techniques and other measures is given in Table 4. These techniques are graded in terms of safety integrity level (SIL) according to best expert judgement. Table 4 also refers to technical design measures that are given in Annex B.

Table 4 – Design, design management techniques and other measures

No.	Design, design management technique or other measures	SIL 1	SIL 2	SIL 3	SIL 4
1	EMC safety planning	R	R	HR	HR
2	Provide the end user with information on any restrictions concerning future changes to the electromagnetic environment	R	R	HR	HR
3	Taking into account the technical design measures (see Annex B)	R	HR	HR	HR
4	Take into account the EMC requirements stated in the product safety manual for all purchased products and equipment	M	M	M	M
5	Procedures for maintaining lifetime electromagnetic characteristics in operation, maintenance, repair and refurbishment, modifications and upgrades	HR	HR	M	M
6	Consider the effects of reasonably foreseeable faults and misuse on the electromagnetic characteristics and mitigation measures	M	M	M	M

M The technique or measure is a mandatory requirement and shall be carried out for this safety integrity level (or systematic capability).

HR The technique or measure is highly recommended for this safety integrity level (or 'systematic Capability') and shall be carried out unless there is a technical justification for not doing it. If this technique or measure is not used then the rationale behind not using it shall be fully detailed during the safety planning and agreed upon with the assessor.

R The technique or measure is recommended for this safety integrity level (or systematic capability) and should be carried out as a lower recommendation to a HR recommendation.

NOTE When a technique or measure is recommended it is considered to be more likely to achieve the desired result than alternative techniques or measures. It is not mandatory or highly recommended and an alternate technique or measure may be chosen. However, where an alternate technique or measure is used, the designer should be able to competently justify that choice.

7.3 EMC aspects on equipment level

The immunity of a safety-related system depends on the immunity of its equipment and on the electromagnetic characteristics and mitigation measures employed, and shall be sufficient to meet the safety requirements specification (SRS) over the anticipated lifetime of the system. Any electromagnetic disturbances generated by equipment inside of a safety-related system shall not unduly affect the other items of equipment of the safety-related system.

All the EMC measures shall be designed and implemented in such a way that they are effective over the lifetime of the equipment when taking into account the physical environment (which includes mechanical, climatic, chemical, biological and other stresses and strains). This is because emissions and immunity can be altered over the lifetime of the equipment by exposure to its physical environment. The design of the equipment shall be such that it maintains its required electromagnetic characteristics.

Hence immunity against electromagnetic disturbances shall be considered on the equipment level. Equipment immunity requirements shall be derived by taking into account

– the external electromagnetic environment the equipment is exposed to,
– the local electromagnetic environment the equipment is exposed to due to other equipment in close proximity,
– requirements derived from system/equipment aspects taking into account any system mitigation measures and,
– any requirements as identified during the process of EMC safety planning.

This results in an equipment requirements specification (ERS) which shall contain

– the electromagnetic disturbances against which immunity has to be achieved,
– the immunity levels,
– particular test parameter requirements (such as increased test periods) and,
– the performance criteria specifying a defined behaviour of the equipment under test (for example using a particular performance criterion taking into account aspects of functional safety of the overall system).

NOTE 1 The equipment requirements specification (ERS) considers the situation at a particular installation. It is not necessarily identical to the product specification that a manufacturer fulfils for the products he offers on the market and to which he has to prove evidence by application of appropriate methods. In some cases both the specifications may be identical, but in other cases additional measures might have to be applied to the product in order to be compliant with the equipment requirements specification (ERS). See Annex D and especially Figure D.2 for a description of this process.

The equipment requirements specification (ERS) can be fulfilled by using appropriate design management techniques such as determining natural electromagnetic susceptibilities, designing electromagnetic characteristics to cope with foreseeable faults and misuse, using more than one layer of protection, avoiding components with non-acceptable electromagnetic characteristics and verifying electromagnetic design aspects individually.

Where a number of identical items of equipment are used in multiple channels to provide redundancy, the systematic capability of the individual items shall not be less than the systematic capability that is required for the overall system.

NOTE 2 The effects of electromagnetic disturbances and the physical environment on items of equipment of the same design are usually common-cause or systematic (see Clause 5) – they have the same effect on all the items at the same time.

8 Verification/validation of immunity against electromagnetic disturbances for functional safety

8.1 The verification and validation processes

In most cases there is no simple or practicable way to check and to verify by means of testing or measuring that immunity is achieved for the safety-related system in its entirety with respect to other systems, equipment or the external electromagnetic environment for all operating conditions and operating modes. This is due to the fact that not every combination of operating conditions, of operating modes and of electromagnetic phenomena acting on the system can be achieved in a reasonable way and in a reasonable period. Hence it is recommended that well-defined processes are applied at both the equipment and system levels in order to demonstrate that immunity has been achieved in accordance with the safety requirements specification (SRS).

In order to demonstrate that a safety-related system complies with the safety requirements specification (SRS), verification and validation processes have to be carried out. Appropriate planning of these processes is recommended. This can be done as part of the EMC-planning or separately in validation and verification planning.

The relationship between the processes of verification and validation, as well as their relation to the safety life cycle, can be demonstrated by the diagram shown in Figure 4. For clarity the diagram considers those parts of the life cycle only which are related to EMC specific aspects. The diagram shows these parts in a more detailed structure using a V representation of the life cycle (instead of the purely sequential representation given in Figure 1).

A V representation reflects the lifecycle in combination with an approach when going from the system level via the equipment level to the level of the components of which the system is composed.

NOTE 1 Depending on the complexity of the system, more or fewer levels may be employed.

The top-down branch (left side) can generally be assigned to the design and development, and is a refining process beginning with the entire safety-related system and ending with the system's components. The bottom-up branch (right side) is related to assembly, manufacturing, and installation of the whole system.

The V representation indicates that the activities of acceptance are intrinsically linked to the design and development activities insofar as what is actually designed has to be finally checked in regard to the requirements. The representation is effective in showing verification and validation tasks within the lifecycle. It further indicates the level these tasks are assigned to.

NOTE 2 Example: a required immunity of an entire safety-related system can partly be traced back to immunity requirements for the components or equipment making up the entire system. So during a verification process, the required immunity of the individual components or equipment should be checked, for example by immunity tests with results described in a corresponding test report.

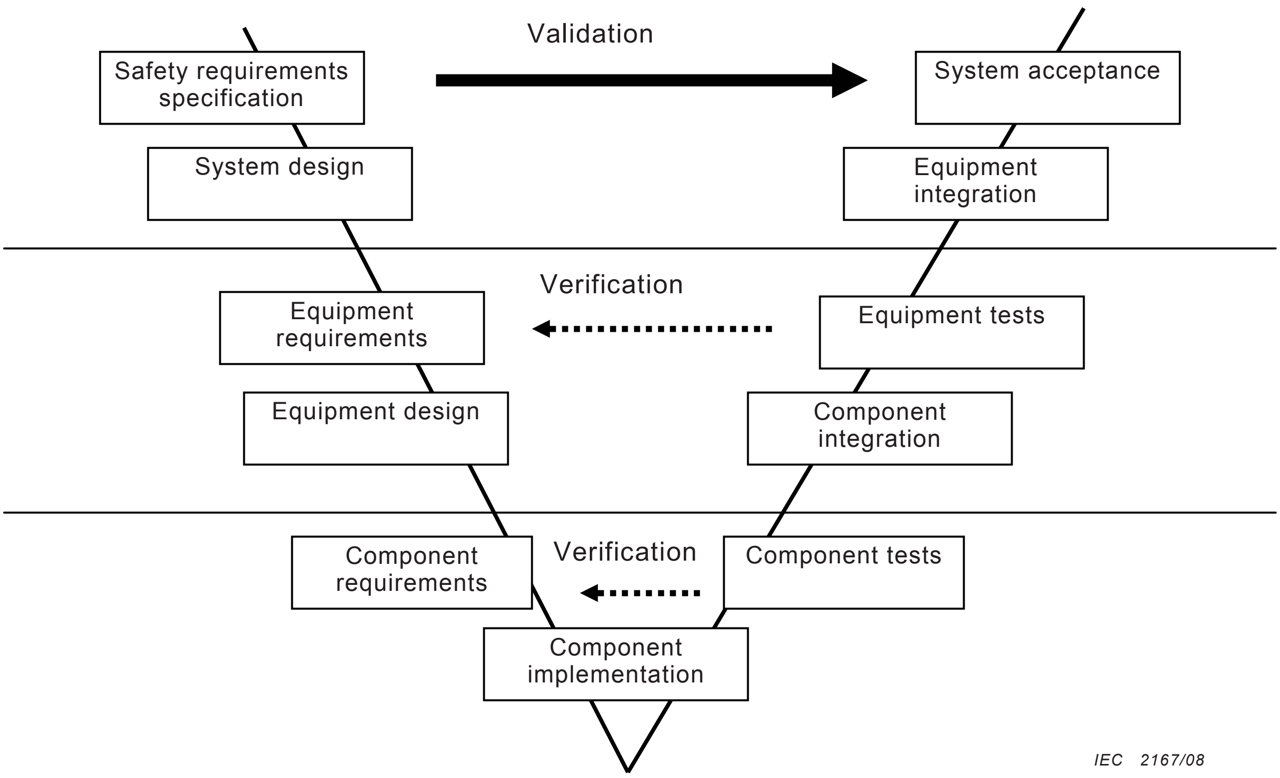


Figure 4 – V representation of the life cycles demonstrating the role of validation and verification

8.2 Verification

The objective of verification is to confirm and to demonstrate that the deliverables of each phase meet in all respects the requirements of that phase. Hence verification is performed within the individual phase and is related to the levels below the overall system level: for example equipment level or component level.

The verification shall take into account all the relevant electromagnetic phenomena against which an immunity is required, as well as the required immunity levels. It shall address specific pass/fail criteria (for example particular performance criteria taking into account functional safety aspects), a positive choice of verification methods and activities as well as the need for particular EMC provisions.

Verification may be performed by only one activity or by combination of several activities. In most cases, however, verification will be done by means of testing (see Clause 9) on the basis of standardized test methods, in combination with appropriate performance criteria taking into account functional safety aspects (see 9.3 and 9.4). The compliance is demonstrated by fulfilling the technical, quantitatively stated requirements of the standards defining these test methods (for example the IEC 61000-4 series) and documented by means of test reports, test certificates or equivalent documents.

Further verification activities can include:

– reviews on completion of each lifecycle phase to ensure compliance with the objectives and requirements of this phase, taking into account the specific inputs to that phase;
– appropriate non-standardized tests performed on the designed products to ensure that they perform according to their specification;
– individual and/or integrated hardware tests performed where different parts of a system are put together in a step-by-step manner and by the performance of environmental tests to ensure that all the parts work together in the specified manner.

The results of verification are described in a verification report (which could be for example a test report) or in a technical construction file.

8.3 Validation

The objective of validation is to get a final confirmation that the entire safety-related system meets all the required objectives. This involves a mixture of several activities such as predictions, reviews or tests. In order to demonstrate that all safety requirements have been fully addressed it is recommended to plan ahead as to how the reviews, tests, etc. will be structured. This is sometimes called a quality plan, but is often called a validation plan, and it may be part of the EMC plan or a separate document.

The validation should take into account all the phases of the lifecycle and may show audit points. It should address specific pass/fail criteria, a positive choice of validation methods and activities and a clear handling of non-conformances.

Validation activities include:

– demonstration that the safety requirements are fully addressed and correctly implemented;
– checklists (e.g. to ensure that EMC measures are adequately observed, applied and implemented);
– inspections (e.g. concerning observance of the installation guidelines);
– reviews and audits (e.g. close-out audit at the completion of the project);
– assessments;
– testing (e.g. factory acceptance test or on-site testing).

The process of validation is described in the validation plan. It contains the structure and schedule of the validation activities, as well as the technical rationale as to how the chosen activities demonstrate that the safety requirements are met.

In cases where there are changes to the system or its use or to the electromagnetic environment, the appropriate phases of the lifecycle shall be revisited and revalidation carried out if necessary.

The results of the validation process are described in a validation report.

8.4 Performance criteria

8.4.1 Performance criterion for safety applications

Performance criteria used for safety applications shall be specified in the safety requirements specification (SRS).

A specific performance criterion designated as FS is defined as follows for functions contributing to or intended for safety applications taking into account functional safety aspects.

The functions of the Equipment under Test (EUT) intended for safety applications are not affected outside their specification or may be affected temporarily or permanently if the EUT reacts to a disturbance in a way that detectable, defined state or states of the EUT are maintained or, achieved within a stated time. Also destruction of components is allowed if a defined state of the EUT is maintained or, achieved within a stated time.

NOTE 1 In consequence it will be possible for the defined state to be outside normal operating limits or otherwise detectable.

The functions not intended for safety applications may be disturbed temporarily or permanently.

NOTE 2 Generalized performance criteria A, B and C as defined in generic EMC standards and also more precise performance criteria as defined in EMC product or product family standards were not specifically created for use in functional safety applications, however, performance criterion A is always acceptable.

8.4.2 Application of the performance criterion FS

This performance criterion, only applicable for functions contributing to or intended for safety applications, shall be considered for all electromagnetic phenomena. There is no differentiation required between continuous and transient electromagnetic phenomena.

Equipment performing or intended to perform safety functions or parts of safety functions shall behave in a specified manner. The specified behaviour of a safety-related system is intended to achieve or maintain safe conditions of the equipment and the related equipment under control. To achieve this, the behaviour of the equipment has to be known under all considered conditions.

In the safety requirements specification (SRS) of a system both the safety function and the required behaviour in case of failure or occurrence of a fault are specified. The required functional behaviour and the related time constraints may differ from the general specification of performance criteria A, B and C as defined in the generic standards or product standards.

Where a device or system performs both safety and non-safety functions the requirements for functional safety apply in context with the safety functions only.

8.4.3 Test philosophy for equipment intended for use in safety-related systems

Even though functional safety requires the correct functioning of the complete system, for example comprising sensors, logic solver and actuators, it is possible to test its devices individually. To allow this the individual devices intended to be used to construct a safety-related system shall be sufficiently specified. This specification comprises the intended function and the allowed behaviour in case of failure. The objective of the immunity tests is to prove that the specification is fulfilled for the considered electromagnetic phenomena.

Equipment intended for use in safety-related systems has a specification of its intended functions. If a disturbed function will become dangerous or not is unknown because it depends on the future application in a safety-related system. Therefore the test shall show the behaviour of the equipment under test. Deviations from the undisturbed functions shall be detectable and shall be documented in the test report.

The performance criteria for functional safety define specific requirements on the equipment that is intended for use in safety-related applications. In this case both the normal requirements and the specific requirements for functional safety apply. The performance criteria for normal immunity tests within their associated limits and the performance criteria for EMC safety tests are considered separately which could result in different tests.

NOTE Normal immunity tests/requirements are those tests/requirements which are carried out according to specifications given in generic or product standards where those specifications do not consider functional safety aspects.

The general approach is shown in Table 5.

Table C.1 in Annex C illustrates the application of the relevant performance criteria for equipment in more detail by showing which effects due to specific electromagnetic disturbances are allowed.

Table 5 – Applicable performance criteria and observed behaviour during test of equipment intended for use in safety-related systems

Normal EMC tests	EMC safety tests
- A - B + observed deviation + recovery time to be documented - C + observed behaviour, detectable and documented	**FS**
NOTE 1 The description of the performance criteria A, B and C is given in generic standards such as IEC 61000-6-1 and adapted accordingly in product standards. NOTE 2 For more detailed information about allowed effects during immunity testing, see Tables C.1 and C.2. NOTE 3 The potential of performance criteria B and C to result in misuse of the safety function (for example disablement of the safety function) should be assessed.	

8.4.4 Test philosophy for safety-related systems

The intended functions and possible safe states are specified for a safety-related system. The aim of the immunity tests is to show whether the system as a whole behaves as specified and required by the safety requirements specification (SRS).

The performance criteria for functional safety define additional requirements for safety-related systems. The performance criteria for normal EMC tests within their associated limits and the performance criteria for EMC safety tests are considered separately.

Table C.2 in Annex C illustrates the application of the relevant performance criteria for systems in more detail by showing which effects due to specific electromagnetic disturbances are allowed.

System testing should be performed at the highest practicable level of assembly, if necessary using appropriate on-site or in-situ test methods.

9 EMC testing with regard to functional safety

9.1 Electromagnetic test types and electromagnetic test levels with regard to functional safety

9.1.1 Considerations on testing

In most cases there is no simple or practicable way to verify by means of testing alone that adequate immunity has been achieved (see Clause 7). EMC testing for functional safety requires some special considerations.

9.1.2 Types of immunity tests

Usually, the functional immunity tests in a product or generic standard do not consider all of the possible electromagnetic phenomena (as listed in Table A.1). It is also conceivable that a high level electromagnetic disturbance that has not been taken into account could have a safety implication.

With regard to safety, it is therefore necessary to evaluate whether disturbances that may not have been considered in the product or generic standards, can occur. If their relevance has been demonstrated, their impact shall be analysed and the corresponding tests shall be carried out.

9.1.3 Testing levels

Immunity testing levels specified in the EMC product or generic standards are related to normal environmental disturbance levels.

For safety purposes, system designers shall specify test levels that are based on the maximum levels of the electromagnetic disturbances where the safety-related systems are intended to be employed. Product committees or manufacturers shall specify tests and levels that are based on the maximum levels likely to occur in the most probable environments where the equipment is intended to be installed. System designers should ensure that disturbances and levels specified by product committees or manufacturers are consistent with the safety requirements specification (SRS).

When possible, that is when the experience or the knowledge of the environment is sufficient, it is also necessary to take the statistical distribution of the disturbance levels into consideration.

It might therefore be necessary to enhance the functional immunity test levels by a value derived from the assessment of the electromagnetic environment. It is not always possible to give general advice on this value, which depends on numerous conditions including uncertainty (see 9.4). It shall be specified case by case and may be different for each type of electromagnetic phenomenon based on the fact of its occurrence. In certain circumstances, it will be necessary that this value is specified so that it leads to a greater test level than for performance reasons.

In equipment or systems with specific safety-related parts two series of tests may be considered:

– a series of tests for system parts not relevant for safety;
– a series of tests for system parts relevant for safety with different requirements.

9.2 Determination of test methods with regard to functional safety

With regard to the variety of equipment, of environmental conditions, and of conditions specific to the installation under consideration, it is difficult to provide exact rules for how to select the tests. Basically the selection of tests shall take into account all the electromagnetic phenomena that have been identified as occurring in the electromagnetic environment. This environment comprises both the electromagnetic phenomena due to external conditions and electromagnetic phenomena resulting from processes inside the installation. The tests shall be selected and determined in such a way that they reflect and simulate the influence of the electromagnetic phenomena upon the safety-related system and its components.

NOTE 1 In some cases it is impractical to apply tests on a safety-related system as a whole and tests will be applied to the individual equipment separately. In these cases the tests should be selected in such a way that their application on individual equipment represents the effect which the electromagnetic phenomena have on the whole safety-related system.

When determining a test method for an immunity test, the test uncertainty shall be assessed and be taken into account, both with respect to the test performance as well as with respect to the applicable immunity test parameters.

There are several possibilities for determining the appropriate test methods:

a) Use of standardized test methods, for example the basic immunity test standards of the IEC 61000-4 series

In most cases electromagnetic phenomena such as electrical fast transients (bursts) or electrostatic discharges (ESD) have to be considered as they are to be expected in typical installations. But in addition some other electromagnetic phenomena will have to be considered due to the situation at the particular installation; for example, the occurrence of relatively strong power frequency magnetic fields or the presence of a bad power supply showing significant voltage unbalances or frequent voltage interruptions. These phenomena have been well understood for several decades, and test methods have been worked out to represent the effect of the disturbances on the equipment under test. Corresponding test methods are described in the IEC 61000-4 series. Valuable experience has been obtained regarding the test performance and test parameters in order to represent the effect of disturbances as realistically as possible.

b) Use of variants of standardized test methods

Although standardized test methods, for example described in the basic immunity test standards of the IEC 61000-4 series, and the test parameters described therein cover a wide range of electromagnetic phenomena there may be situations where an electromagnetic phenomenon actually expected in the installation differs to some extent from that one as covered by a standardized test. In these cases it is useful to assess the deviation of the actual phenomenon from that treated in a standardized test method and to check the applicability of the standardized test method when tailored accordingly.

NOTE 2 An example may demonstrate this approach. When looking at the immunity against power frequency magnetic fields the test methods and parameters as described in IEC 61000-4-8 can be applied. This standard mainly focuses on the effects of 50 Hz/60 Hz magnetic fields. If, however, the assessment of the electromagnetic environment shows that there are significant harmonics to be considered, the basic test method of this standard can also be used for testing the immunity against magnetic fields at harmonic frequencies.

c) An electromagnetic phenomenon is not covered by existing standards or variants of it

In some particular installations electromagnetic phenomena occur which are neither covered by standardized test methods, such as the basic immunity test standards of the IEC 61000-4 series, nor could they be modelled by accordingly tailored standardized test methods. This may be the situation when for example new technologies have emerged showing electromagnetic phenomena that are not yet considered by the standardized test methods. In these cases particular test methods, whose performance and parameters shall reflect the effect of the electromagnetic phenomenon under consideration as realistically as possible, have to be developed.

NOTE 3 Developing a new test method generally raises the concerns for its correct application. Therefore it is recommended to validate and to verify the new method in order to demonstrate that it produces accurate and reliable test results.

9.3 Considerations on test methods and test performance with regard to systematic capability

9.3.1 General

It is recommended that the immunity tests and immunity test levels be selected for the various electromagnetic phenomena by taking into account:

– the characteristics of the electromagnetic environment where the installation under consideration is intended to be operated;
– the maximum amplitude of the actual electromagnetic disturbance to be expected at the various locations of the installation;
– the maximum uncertainty due to test method and test equipment.

All activities should give an indication of test methods and test levels to be used for immunity tests. The second and third considerations given above are based on the fact that for electromagnetic phenomena it is normally not possible to establish a simple, evident and provable correlation between applicable immunity test requirements and safety integrity level (SIL) due to probabilistic aspects of a safety integrity level (SIL) determination. Since these maximum amplitudes are not correlated with the safety integrity level (SIL), they should be used to determine the test levels.

Beside the immunity test levels there are further parameters that may determine the suitability of immunity tests. Such parameters are for example:

– testing period;
– number of tests with different test set-ups or test samples;
– variation of test settings (e.g. direction of incident electromagnetic field, phase relationship between test impulse, type of modulation of RF field);
– environmental factors (e.g. temperature, humidity or the appearance of different electromagnetic phenomena at the same time);
– performance criteria.

For standardized immunity tests, for example the basic immunity test standards of the IEC 61000-4 series, these parameters are determined in such a way as to reflect typical interference situations or typical conditions. The parameters are derived on a technical/economical basis. For example, the test period is limited to one that represents a compromise between the amount for testing time and the confidence that the testing time is considered as long enough for typical stress conditions.

Hence these parameters may be modified in order to increase the level of confidence that an accordingly modified immunity test reflects the effect of an electromagnetic disturbance with a higher probability than using the parameters given for example in the basic immunity test standards of the IEC 61000-4 series. In this regard the parameters may be modified according to the required safety integrity level (SIL). Some examples of modification of parameters are given in Table 6.

NOTE As in case of the immunity levels, it will not be possible to establish a simple, evident and provable correlation between the accordingly modified immunity test and the required safety integrity level (SIL). Hence the modification or variation of immunity tests will mainly rely on technical judgement.

Table 6 – Examples for methods to increase level of confidence

Type of electromagnetic phenomena	Example of standards	Method to increase test severity compared to the requirements in the basic standard
Continuous Audio Frequency (AF)/Radio Frequency (RF)	IEC 61000-4-3 IEC 61000-4-6 IEC 61000-4-16 IEC 61000-4-8 IEC 61000-4-13	Frequency of modulation (e.g. 2 Hz, 400 Hz, 1 kHz, 1 Hz to 10 kHz) Different test set-ups (testing of different combination of equipment / versions / cabling) Type of modulation (for example amplitude-modulated AM, frequency-modulated FM, pulse-modulated PM) Different carrier frequencies at the same time
Transient phenomena	IEC 61000-4-4	Increasing test time (no change in normative parameters) Changing repetition frequency of pulses Changing packet length / repetition time of pulses Different test set-ups (testing of different combination of equipment / versions)
	IEC 61000-4-12 IEC 61000-4-18	Different test set-ups (testing of different combination of equipment / versions) Different carrier frequencies at the same time
	IEC 61000-4-2 IEC 61000-4-5	Number of pulses Changing repetition rate / time between pulses / phase angle Different test set-ups (testing of different combination of equipment / versions)
NOTE 1 Some methods may not be applicable to some of the test methods given in the basic standards. NOTE 2 The parameters mentioned under the methods should only be applied if these parameters of electromagnetic phenomena could really occur in the electromagnetic environment under consideration.		

9.3.2 Testing period

Some of the electromagnetic phenomena to be considered may be related to an operating state of equipment in a statistical way only, for example the simultaneous occurrence of an impulse peak with respect to the momentary state of a digital circuit or a digital signal transmission.

In order to increase the level of confidence regarding immunity against electromagnetic disturbances for a higher safety integrity level (SIL), it may be required, to perform immunity tests against such electromagnetic phenomena with a greater number of pulses compared to the requirements of the corresponding basic standards. This can be done by using a longer test time or by applying more test impulses, and these modifications may depend on the safety integrity level (SIL).

NOTE Example of a modification of the electrical fast transients immunity test (IEC 61000-4-4): the coupling of pulses is normally applied for a period of 1 minute for each polarity. This period may be increased by a factor depending on the safety integrity level (SIL).

9.3.3 Number of tests with different test set-ups or test samples

There may be a variation in the immunity behaviour of equipment, for example due to tolerances in the devices used in the equipment or due to tolerances in manufacturing the equipment. Further uncertainties may result from various possibilities concerning a test set-up. Hence it may be reasonable to expand the immunity tests by

– testing more samples of the product under consideration or,
– testing a sample several times with variations in the test set-up.

These may be done alternatively and/or in combination.

9.3.4 Variation of test settings

Standardized immunity tests, for example the basic immunity test standards of the IEC 61000-4 series, describe a detailed test set-up as well as settings to be applied during the immunity test. These settings as well as further ones may be used to increase the level of confidence. By doing this rather than by using the settings of the basic immunity standards, a broader range of possible effects of the electromagnetic phenomenon upon the equipment is considered. Examples of such modifications include

– modifications concerning the coupling of an electromagnetic phenomenon on the equipment under test,
– modifications concerning the physical placement of the equipment under test.

NOTE 1 Example of a modification of the surge immunity test (IEC 61000-4-5): coupling of pulses on a.c. lines at phase angles in addition to those given in the basic standard.

NOTE 2 Example of modifications of the radiated, radio-frequency, electromagnetic field immunity test (IEC 61000-4-3): incident field faces not only to the main sides but also to tilted orientations of the equipment under test; the equipment is tested with different types of modulation frequencies (for example 2 Hz to 10 kHz) or different carrier frequencies at the same time.

9.3.5 Environmental factors

Beside the variation in the immunity behaviour of equipment due to tolerances in the devices used, or in its assembly, there might be the possibility that the immunity is affected by environmental parameters. Such factors are, for example, the temperature or humidity which may vary in a broad range at the final location of the installation. The possible impact of these factors on the immunity should be considered.

Another aspect of the testing is to quantify the impact of stresses, ageing, foreseeable misuse, etc., on the electromagnetic characteristics of the equipment or system. There are many kinds of possible stresses, including physical (e.g. bending, twisting, etc.) and climatic (e.g. air pressure, temperature, humidity, etc.). After the initial electromagnetic functional testing has been performed as described above, and the equipment passes those tests, ageing testing should be performed, if it can be reasonably and foreseeably expected that the electromagnetic characteristics will change during life time of equipment. This testing should include, for example, the evaluation of the reduction in effectiveness of electromagnetic mitigation measures associated with the equipment or product due to corrosion or mechanical movement during the anticipated lifetime of the system. As appropriate during or after these stress/ageing tests, the electromagnetic characteristics shall be measured to determine whether the equipment’s electromagnetic characteristics has been excessively degraded. All physical stresses and ageing aspects within the specification of the equipment/system shall be evaluated and documented. The results of such testing and its impact on the electromagnetic characteristics during the anticipated lifetime of the equipment or system shall also be documented for each electromagnetic phenomenon considered.

Alternatively, where the equipment is protected from its electromagnetic and physical environment by an external enclosure, it is permissible to test the finished enclosure for its reduction in electromagnetic characteristics due to physical stresses, ageing, foreseeable misuse, etc. over its anticipated lifetime. The tested enclosure should include the same types of cable entries, door and panel fixings, etc., as the one that is supplied with or specified for the equipment. There is no requirement to test the products and other equipment that are to be housed within the enclosure at the same time.

Some manufacturers of such enclosures may provide appropriate test results for their enclosures to assist designers in the choice of enclosure. Where aspects of physical stresses, ageing and foreseeable misuse are included in the enclosure specification, the products or equipment within the enclosure need not be tested for those in the normal way as described above.

9.4 Testing uncertainty

The required immunity of products or items of equipment to electromagnetic phenomena is in most cases demonstrated by means of immunity testing based on basic EMC standards. The results of the tests are used to conclude whether the equipment under test fulfils the requirements and consequently whether it can be used in a safety-related system.

Hence it is important to have some indications of the quality of the results, that is, the extent to which they can be relied on for the purpose in hand. One of the means to demonstrate the quality of the immunity test performance and of the test results is the evaluation and the assessment of the associated uncertainty.

Whether an immunity test is a standardized or a modified one, it shall be developed so that reproducible results are obtained if different parties perform the same test with the same EUT. Beside this fact of repeatability, an immunity test set-up and the adjusted immunity test level shall reflect the specified levels as closely as possible. Hence special attention has to be given to any factors that can cause a deviation from the specified levels and the impact of which can quantitatively be described by means of the uncertainty. Substantial information about all the aspects related to uncertainty and its determination are given in the CISPR 16-4 series of standards.

As a consequence, the uncertainty associated with an immunity test shall be determined and assessed with respect to its impact on the test results.

The uncertainty of test instrumentation can be compensated by increasing immunity test levels

– if the applicable uncertainty exceeded the specific value by following a similar approach to that used in CISPR 16-4-2 and/or;
– if the expanded uncertainty method is used for ensuring increasing confidence that the test was carried out at the specific level. The method is described in IEC 61000-4-6.

NOTE 1 The type of uncertainty to be considered and the value of uncertainty not to be exceeded depend on the particular immunity test.

NOTE 2 There might be other factors of testing uncertainty to be considered in addition to the instrumentation uncertainty.

10 Documentation

The documentation shall be done according to the requirements given in IEC 61508-1.

Annex A
(informative)

Examples of electromagnetic disturbance levels

This annex is provided to support the methodology for determining safety-related system electromagnetic environment specifications. It is based initially on the classification of electromagnetic environments described in IEC 61000-2-5, which classifies electromagnetic environments and gives basic guidance for the selection of immunity levels. The levels described in IEC 61000-2-5 are compatibility levels, and the electromagnetic compatibility level is defined as the specified electromagnetic disturbance level used as a reference level for co-ordination in the setting of emission and immunity levels (see Figure A.1).

NOTE 1 By convention, the compatibility level is chosen so that there is only a small probability that it will be exceeded by the actual disturbance level. However, electromagnetic compatibility is achieved only if emission and immunity levels are controlled such that, at each location, the disturbance level resulting from the cumulative emissions is lower than the immunity level for each device, equipment and system situated at this same location.

NOTE 2 The compatibility level may be phenomenon, time or location dependent.

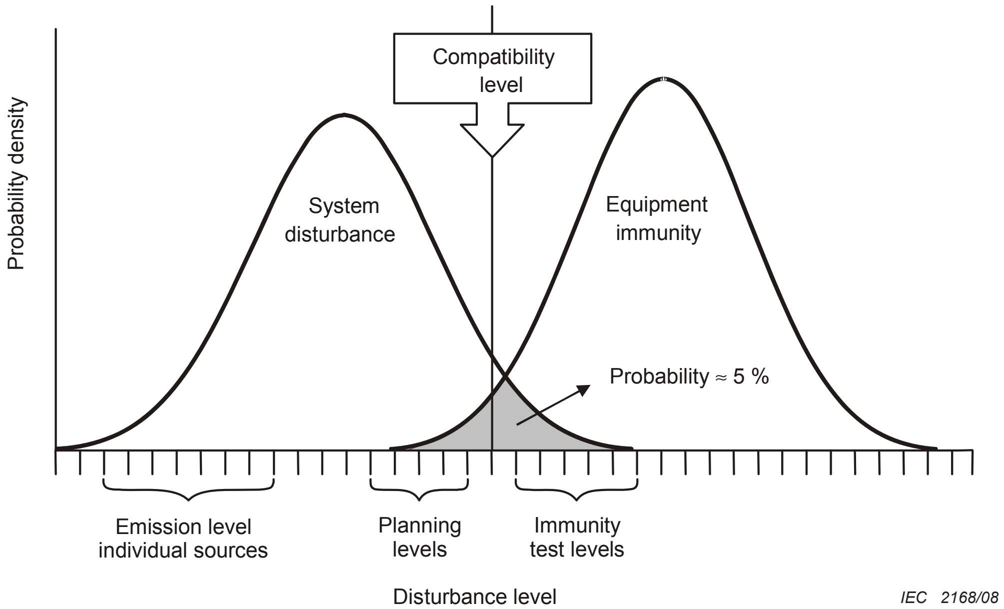


Figure A.1 – Emission/immunity levels and compatibility level, with an example of emission/immunity levels for a single emitter and susceptor, as a function of some independent variable (e.g. the frequency)

Examples of compatibility levels for different phenomena are described in Annex A of IEC 61000-2-5 for typical location classes. The description covers 8 different environments (locations) in Tables A.1 to A.8 of IEC 61000-2-5. Typical compatibility levels are defined for each electromagnetic phenomenon in each environment. It is stated that different immunity characteristics might be appropriate for the different functions of a multifunction item. For instance, a function for a safety application should have a higher immunity level than a function having no impact on safety, although this should be accomplished by determining the electromagnetic environments appropriate for safety purposes as opposed to arbitrarily increasing immunity test levels.

Levels given in IEC 61000-2-5 are compatibility levels. Immunity levels shall exceed the compatibility levels, but some of the immunity levels specified, for example, in the generic EMC standard for industrial applications, IEC 61000-6-2, are below the corresponding compatibility levels described in IEC 61000-2-5 (for example the level of HF-conducted disturbances on control and signal lines for location class type 5). This has to be taken into account for the development of the immunity levels required for functional safety.

Electromagnetic phenomena mentioned in IEC 61000-2-5 are analysed and compared with the levels specified in the Generic EMC Standard IEC 61000-6-2 (industrial applications) and an example is shown in Table A.1.

Table A.1 – Example of selection of electromagnetic phenomena for functional safety in industrial applications

No.	Phenomena according to IEC 61000-2-5 Test level according to IEC 61000-6-2	Basic standard	Phenomenon relevant for functional safety	Immunity level for functional safety to be specified	Comments
1	ESD 4 kV (contact) 8 kV (air)	IEC 61000-4-2	yes	yes	Levels shall be applied in accordance with the environmental conditions described in IEC 61000-4-2. Levels specified in the Generic Standard may only be chosen if the appropriate environmental conditions exist.
2	HF field 10 V/m (80-1000 MHz) 3 V/m (1,4-2,0 GHz) 1 V/m (2,0 GHz to 2,7 GHz)	IEC 61000-4-3	yes	yes	An increased level shall be applied in frequency ranges used for mobile transmitters in general, except when reliable measures are realised to avoid the use of such equipment near by. ISM frequencies have to be taken into account on an individual basis.
3	Burst 1 kV (I/O) 2 kV (a.c./ d.c.)	IEC 61000-4-4	yes	yes	Higher levels can be expected in industrial applications compared with the levels specified in applicable standards for functional reasons.
4	Surge a.c.: 2 kV (L-L) 1 kV (L-G) d.c. 0,5 (L-L) 0,5 (L-G) I/O: 1,0 (L-G)	IEC 61000-4-5	yes	yes	Increased requirements may be adequate, but additional external EMC measures have to be considered.
5	HF conducted 10 V (0,15 MHz – 80 MHz)	IEC 61000-4-6	yes	yes	An increased level shall be applied in frequency ranges used for mobile transmitters in general, except when reliable measures are realised to avoid the use of such equipment near by. ISM frequencies have to be taken in to account on an individual basis.
6	50/60 Hz magnetic field 30 A/m	IEC 61000-4-8	yes	no	Applicable in accordance with the common exceptions given in the generic standard. No increased level in general. An increased level may be adequate in an environment as

No.	Phenomena according to IEC 61000-2-5 Test level according to IEC 61000-6-2	Basic standard	Phenomenon relevant for functional safety	Immunity level for functional safety to be specified	Comments
					defined in IEC 61000-6-5 or similar like an industrial switchyard.
7	Pulse magnetic field	IEC 61000-4-9	no	n.a.	No increased level in general. An increased level may be adequate in an environment as defined in IEC 61000-6-5 or similar like an industrial switchyard.
8	Oscillatory magnetic field	IEC 61000-4-10	no	n.a.	No increased level in general. An increased level may be adequate in an environment as defined in IEC 61000-6-5 or similar like an industrial switchyard.
9	Voltage dips 0 % for 1 period 40 % for 10/12 periods 70% for 25/30 period	IEC 61000-4-11	yes	no	To be decided case by case
10	Voltage interruptions 0 % for 250/300 period	IEC 61000-4-11	yes	no	To be decided case by case
11	Voltage variations	IEC 61000-4-11	no	n.a.	Voltage variations are considered as functional aspects and not EMC related
12	Ring wave	IEC 61000-4-12	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
13	Harmonics	IEC 61000-4-13	yes	no	To be decided case by case
14	Interharmonics	IEC 61000-4-13	yes	no.	To be decided case by case
15	Mains signalling	IEC 61000-4-13	no	n.a.	To be decided case by case
16	Conducted, common mode, 0 Hz to 150 kHz	IEC 61000-4-16	yes	yes	Increased level for short time power frequency phenomena only. Limited to the rated voltage of the power supply.
17	Oscillatory wave	IEC 61000-4-18	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
18	HEMP radiated	IEC 61000-4-23	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
19	HEMP conducted	IEC 61000-4-24	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
20	HEMP immunity tests	IEC 61000-4-25	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
21	Unbalance three-phase mains	IEC 61000-4-27	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
22	Variation of power frequency	IEC 61000-4-28	no	n.a.	Not applicable in general, but may be considered for special

No.	Phenomena according to IEC 61000-2-5 Test level according to IEC 61000-6-2	Basic standard	Phenomenon relevant for functional safety	Immunity level for functional safety to be specified	Comments
					applications like UPS, emergency power supply systems and so on.
23	Voltage dips d.c. power port	IEC 61000-4-29	yes	no	To be decided case by case
24	Interruption d.c. power port	IEC 61000-4-29	yes	no	To be decided case by case
25	Voltage variations d.c.	IEC 61000-4-29	no	n.a.	Not applicable in general, but may be considered for functional safety purposes
26	d.c. in a.c. networks		yes	no	To be decided case by case
27	d.c. magnetic field		no	n.a.	Not applicable in general, but may be considered for special applications (e.g. traction systems, aluminium process).
28	16 2/3 Hz magnetic field		no	n.a.	Not applicable in general, but may be considered for special applications like traction systems.
29	Non-power system related magnetic field		no	n.a.	To be decided case by case
30	Power system harmonics magnetic field		no	n.a.	To be decided case by case
31	d.c. electric field		no	n.a.	
32	16 2/3 Hz electric field		no	n.a.	
33	50/60 Hz electric field		no	n.a.	
34	Transient electric field		no	n.a.	
35	ESD field		no	n.a.	
36	Transients milliseconds		no	n.a.	
NOTE Product committees can use this table as a basis for their work to make a case by case decision for every phenomenon / test level.					

As the information developed in Table A.1 is based on the disturbances documented in IEC 61000-2-5 for EMC purposes, the results presented may not cover the higher disturbance levels that can occur with low probability. These low probability electromagnetic environments should be considered for functional safety purposes. Table A.2 provides an example of the maximum electromagnetic disturbance levels appropriate for two classical environment locations – residential and heavy industrial. These were derived by examining the available literature and considering the possibility that cellular phones could be located very close to safety-related equipment. These high-level radiated disturbances from cellular phones have not been considered in IEC 61000-2-5 and therefore shall be evaluated separately at this time. It should be noted that for some specific applications the levels of the electromagnetic disturbances could be higher.

In the two left columns Table A.2 shows a list of the immunity test standards related to the various electromagnetic disturbances, which have been considered. It should be noted that not all phenomena are listed. For safety purposes additional electromagnetic phenomena should be considered by all parties involved.

Table A.2 – Estimates of maximum electromagnetic disturbance levels

		Maximum electromagnetic levels	
Phenomena and ports	**Units**	**Residential**	**Heavy Industrial**
ESD air contact	kV	15 8	15 8
RF fields [a] ≤80 MHz to 1 000 MHz	V/m mod	50	50
RF fields digital telephone 0,9 (1,8) GHz	V/m mod	50	50
Fast transients – AC power – DC power – control/signal – functional earth	kV	 4 4 2 2	 8 8 4 2
Surges 1,2/50 μs (8/20 μs) – AC power L→G – AC power L→L – DC power L→G – DC power L→L – control/signal L→G – control/signal L→L	kV	4 2 2 2 2 1	8 4 2 2 4 2
Conducted HF disturbances 0,15 MHz to 80 MHz [a] – AC power CM – DC power CM – control/signal CM – functional earth	V mod	vary 50 50 50 10	vary 50 50 50 10
Power frequency magnetic fields	A/m	10	60
AC voltage dips	Δ % U_n periods	10 to 95 0,5 to 150	10 to 95 0,5 to 300
AC voltage interruptions > 95 %	periods	2 500	2 500
Ring Wave – 0,1 MHz (a.c. power) – 0,1 MHz (control)	kV	 4 2	 4 2
Harmonics: THD 5th	% U_n % U_n	8 6	10 8
AC voltage fluctuations	ΔU_n%	+10, –10	+10, –15
Oscillatory waves – slow (0,1 and 1 MHz) – fast (3, 10, 30 MHz)	kV	4 4	4 4

THD = Total harmonic distortion; RF = Radio frequency
CM = Common mode; L→G = Line to Ground
5th = Example 5th harmonic; ESD = Electrostatic discharge
DM = Differential mode; L→L = Line to Line

[a] Maximum levels are not necessarily observed in the entire frequency ranges.

Annex B
(informative)

Measures and techniques for the achievement of functional safety with regard to electromagnetic disturbances

B.1 General principles

It is important to ensure that safety-related systems do not become unsafe as a result of their electromagnetic environment (including electromagnetic disturbances created by their own equipment).

It is also important to ensure that the emission of electromagnetic disturbances by a system (or a part of it) does not cause safety risks by interfering with safety-related systems.

Accordingly, appropriate electromagnetic measures should be applied throughout the lifecycle of a safety-related system, including the products and equipment it is assembled from.

In most cases mass-produced E/E/PE products and other devices that are often used to assemble safety-related systems cannot be expected to have electromagnetic emissions and/or immunity characteristics that are adequate for all of the possible electromagnetic environments that safety-related systems might experience. Therefore, it is important to recognise that electromagnetic measures applied at the level of the equipment, system and/or installation are often an effective way to achieve the required electromagnetic characteristics and hence safety.

The aim of this annex is to give an informative overview of the measures and techniques that are available for the achievement of functional safety with regard to electromagnetic disturbances. The table below summarizes these measures and techniques. Further information is given in the clause referenced in the third column of this table.

Table B.1 – Overview of measures and techniques for the achievement of functional safety with regard to electromagnetic disturbances

Practice	Overview	Reference for further information
EMC safety planning	A competent person is given authority to ensure that all the following measures and techniques are correctly applied where appropriate to help ensure that adequate safety is achieved over the lifecycle despite electromagnetic disturbances.	B.2
Estimating the unwanted safety events to be avoided	Consider: a) Non-operation when operation is required b) Operation when no operation is required c) Wrong or inaccurate operations	-
Obtaining the necessary background information for the design	Estimating the reasonably foreseeable lifecycle	B.3.1
	Estimating the maximum electromagnetic environment over the reasonably foreseeable lifecycle	B.3.2
	Estimating the worst-case physical environment over the reasonably foreseeable lifecycle	B.3.3
	Estimating the functional characteristics to be achieved over the reasonably foreseeable lifecycle	B.3.4

Practice	Overview	Reference for further information
Design and development measures and techniques to be considered	Designing system architecture to adequately reduce the probability of dangerous failures due to electromagnetic interference	B.4.1
	Avoiding the use of components, products, circuits, mechanical and software techniques that increase susceptibility to electromagnetic disturbances	B.4.2
	Choosing components and products; and designing circuits, mechanics and software, to reduce the probability of dangerous failures due to electromagnetic interference	B.4.3
	Employing testing to determine the electromagnetic and physical characteristics of components, products, circuits, mechanics and software when exposed to electromagnetic disturbances and physical stresses representative of the system's reasonably foreseeable environment	B.4.4
	Designing earthing (grounding), bonding, wiring, cabling and printed circuit boards to maximize electromagnetic characteristics	B.4.5
	Using fibre-optic links instead of metallic conductors	
	Using computer-aided design tools to minimize electromagnetic coupling paths	B.4.6
	Using electromagnetic mitigation techniques including shielding; filtering; overvoltage protection; overcurrent protection; suppression of electrostatic discharge; power conditioning, galvanic isolation, etc.	B.4.7
	Using techniques that mitigate the severity of the physical environment, to help the components, devices, products, equipment and mitigation measures maintain adequate electromagnetic characteristics over their reasonably foreseeable lifecycle, for example anti-vibration mounting, water proofing, etc.	B.4.8
	Design so that safety is maintained despite the degradation of electromagnetic characteristics caused by reasonably foreseeable faults and misuse, for example interlocking a shield door and initiating safe reaction.	B.4.9
	Using two or more layers of mitigation rather than relying solely on a single layer. Using checklists based upon case studies and experience obtained in similar applications. Taking into account the power distribution earthing system (for example. TNS, TNC, IT, etc., see IEC 60364-1)	B.4.10 B.4.11
Implementation and integration measures and techniques to be considered	Procure materials, components and products according to their electromagnetic specification.	B.5.1
	Assemble according to the design, using the correct materials, components and products according to their electromagnetic specification.	B.5.2
	Install according to the electromagnetic design.	B.5.3

Practice	Overview	Reference for further information
Installation and commissioning measures and techniques to be considered	Any constraints on physical positioning of the items of equipment that comprise the system.	B.6.3
	Any constraints on types, lengths and routing of power, control and signal interconnecting cables.	B.6.4
	The methods of terminating any cable screens (shields).	B.6.5
	The types of connectors to be used and any special assembly requirements.	B.6.6
	The electrical power supply requirements (power quality).	B.6.7
	Any additional screening (shielding) required.	B.6.8
	Any additional filtering required.	B.6.9
	Any additional overvoltage and/or overcurrent protection required.	B.6.10
	Any additional power conditioning required.	B.6.11
	Any additional electrostatic discharge protection requirements.	B.6.12
	Any additional physical protection required.	B.6.13
	The earthing (grounding) and bonding requirements.	B.6.14
	The procedures and materials to be used. Protection against corrosion. NOTE The proper installation requirements of the different protections shall be checked.	
Operation and maintenance measures and techniques to be considered	Comprehensive user instructions including operating procedures necessary to maintain adequate electromagnetic characteristics of the mitigation measures	B.7.1
	Maintenance procedures and planning related to electromagnetic characteristics of the mitigation measures.	B.7.2
	Changes in the external electromagnetic environment to deal with new electromagnetic threats arising that were not included in the original design.	B.7.3
	Disassembly/reassembly techniques to preserve electromagnetic characteristics.	B.7.4
	Periodic testing (proof testing) of critical components for electromagnetic characteristics (for example transient suppressors, shielding, earthing and bonding connections, etc.).	B.7.5
	Periodic replacement of critical components susceptible to degradation or wear-out over time (for example transient suppressors). Verification of the absence of corrosion.	B.7.6
Modifications and upgrades (hardware and software)	Assessing the effect of proposed modifications and upgrades on electromagnetic characteristics of the safety-related system concerned, and on any other safety-related system that might be affected.	B.8.1
	Ensuring that modifications and upgrades do not reduce the electromagnetic characteristics below acceptable levels, for the system concerned, and for any other safety-related system that might be affected.	B.8.2

B.2 EMC safety planning

Good electromagnetic safety design for the lifetime of a safety-related system needs appropriate management, using an EMC safety plan. This plan shall be created by (or for) a senior person, who has the necessary authority and budget to ensure it is carried out, and who is held responsible for its correct execution.

The plan will identify

a) what is being managed (the boundaries of the equipment or system),
b) the specification of the equipment or system concerned,
c) the purpose and functions of the equipment or system,
d) the location(s) where the equipment or system is intended to be installed,
e) the specification of the electromagnetic and physical environment(s) over the anticipated lifetime,
f) for a system: its safety requirements specification (SRS),
g) the name of the person who has overall responsibility for the electromagnetic plan, and responsibility for ensuring that the final electromagnetic characteristics are good enough for the required functional safety over the lifetime,
h) the names of any other people who also take some part of the responsibility for the final electromagnetic characteristics being good enough for the lifetime,
i) identification of all standards, specifications, design guides, quality assurance (QA) procedures, and in-company design guides and checklists that are to be used to guide the design, testing and QA to its eventual outcome,
j) any training, third party expert assistance, or third-party testing services when required by the above personnel to be able to discharge their responsibilities correctly,
k) any publications, computer-aided tools or test equipment required by the above personnel to be able to discharge their responsibilities correctly,
l) a list of the documentation that will be produced by the above personnel

   Firstly: for in-company use to demonstrate that they have discharged their responsibilities correctly;

   Secondly: (for items of equipment) to provide to customers to ensure they are correctly advised on all of the electromagnetic and physical issues and on the resulting functional behaviour when exposed to all of the electromagnetic disturbances that could occur in its environment over its lifecycle;
m) fixed points in the project programme where progress is reviewed by senior personnel and/or independent experts and changes to the programme of the project made as a result – if necessary,
n) the timescale for the EMC activities carried out by the above personnel.

B.3 Obtaining the necessary background information for the design

B.3.1 Estimate the reasonably foreseeable lifetime

This is required so that the system or equipment can be designed to maintain adequate EMC characteristics for safety purposes over its anticipated lifetime.

A lifetime includes everything that follows after the final manufacture of the system or equipment, including periods of storage, transport, non-operation or maintenance, as well as operation. Some types of systems or equipment might be required to be mothballed for several years, maybe after several years of use, and expected to function safely again when put back into service. Some systems might need to have very long lifetimes.

The lifetime includes second-hand use, and use following refurbishments, modifications or upgrades.

For some safety systems (for example in nuclear power plants), a lifetime might also need to include the time taken to dismantle the installation they are a part of.

B.3.2 Estimate the maximum electromagnetic environment over the reasonably foreseeable lifetime

Make an assessment of the reasonably foreseeable maximum electromagnetic environment of the system or equipment over its expected lifetime, over the site (or vehicle, etc.) where the final safety system is to be installed, allowing for reasonably foreseeable future developments in both the site (or vehicle) and the ambient.

For continuous disturbances, consider their reasonably foreseeable

– frequency ranges,
– types of modulation,
– range of modulation frequencies,
– maximum levels
– and rates of occurrence, that might have an impact on the design.

For transient disturbances, consider their reasonably foreseeable

– voltage and current waveshapes,
– maximum levels
– and rates of occurrence (include the foreseeable effects of lighting, LV and HV earth faults, etc.).

The effects of reasonably foreseeable faults should also be taken into account in all of the above. For example, insulation faults in mains power supplies are common enough for safety standards to require fuses or circuit-breakers for protection. So the electromagnetic effects of insulation faults should be taken into account when assessing an electromagnetic environment for a safety system. These faults can cause high levels of broadband noise for hours or days (or longer) as the insulation breaks down; high levels of pulsed magnetic fields due to the fault currents when the insulation finally breaks down completely (can easily exceed 1 kA in a 13 A rated mains circuit); high levels of surge voltage as the energy stored in the magnetic field of the cable collapses when the fuse or circuit-breaker opens; plus high levels of broadband noise due to the arcing in the fuse or circuit-breaker as it opens.

The assessment should also consider the likelihood of two or more electromagnetic disturbances occurring at the same time, for example a continuous RF field (or cable common mode current) at one frequency – plus a fast transient burst, surge, or ESD event. Multiple continuous RF fields or cable common mode currents are also possible and their likelihood should also be assessed. If these can occur (and they usually can) appropriate design analysis techniques can be employed to deal successfully with them without requiring tests to be carried out with simultaneous disturbances.

The effects of reasonably foreseeable use and misuse should be taken into account in all of the issues identified in this subclause. For example, people might ignore warning signs or forget their training, and might operate cellular phones or walkie-talkies closer than was assumed by the electromagnetic environment specification.

See Clause 6 and Annex A for guidance on assessing an electromagnetic environment.

B.3.3 Estimate the worst-case physical environment over the reasonably foreseeable lifetime

The physical environment includes influences due to

– mechanical,
– climatic,
– chemical,
– biological; etc.,

stresses that the safety-related system or its constituent equipment has to endure over its lifetime.

These stresses can affect its electromagnetic characteristics, for example: the effectiveness of shielding can be degraded by mounting or other applied forces that cause joints to open up; and/or by the wear-out or corrosion of metal fixings and conductive gaskets. The effectiveness of filtering can be degraded by high supply voltages, and/or by high temperatures or broken or corroded ground bonds. Feedback circuits can become unstable at radio frequencies due to component ageing, and/or temperature extremes or conductive dusts or liquids.

Therefore, it is necessary to make an assessment of the physical environment, over the site (or vehicle, etc.) where the final safety system is to be installed, allowing for reasonably foreseeable future developments in the site (or vehicle, etc.). This is done so that the electromagnetic measures can be designed and tested so that the system will still achieve sufficient electromagnetic characteristics to ensure adequate safety up to the end of its life.

A lifecycle includes

– design and development,
– manufacture and test,
– storage,
– transport and shipping,
– installation,
– commissioning,
– operation,
– cleaning,
– replacement of consumables,
– maintenance,
– repair,
– modification,
– refurbishment,
– upgrade,
– dismantling and disposal.

The physical stresses that should be considered include, but are not limited to, reasonably foreseeable

– supply voltage extremes and cycling,
– temperature extremes and cycling,
– air pressure extremes and cycling,
– humidity extremes and cycling,

– static mechanical stresses (e.g. non-flat mounting surfaces, surface loading from objects placed on top, etc.),
– repetitive mechanical stresses such as shock and vibration,
– wear and ageing (whether caused by repetitive user activities or not),
– exposure to condensation, water, spray, cleaning fluids and materials, beverages, fuels, bodily fluids, other liquids, gases and dusts, sand, etc.,
– mould growth,
– activities of animals (e.g. gnawing by rodents),
– cleaning and maintenance regimes (including the materials, tools and methods that could be employed),
– modification, repair, refurbishment and upgrade activities,
– abuse and misuse, such as stacking equipment that was not designed to be stacked, or operation in indoor environments with leaky roofs or failed heating/cooling/humidity control systems.

Reasonably foreseeable use, misuse and faults, should also be fully taken into account in all of the above. For instance, overloading, leaky roofs, failed air-conditioning.

B.3.4 Estimating the functional performances to be achieved over the reasonably foreseeable lifecycle

Determine the performance requirements for each system safety function, or equipment function, when the system or equipment is subjected to the electromagnetic disturbances that could occur in their environment over their lifetime.

There will be two types of performance requirement:

a) Performance remains within some specified limits and functional safety is maintained.

Safe shutdown is not acceptable. Examples of systems where this criterion should be applied include life-support systems, where shutdown cannot be to a safe state and continuous operation is required for safety.

b) As a) above – except that safe shutdown is acceptable in specified circumstances.

It generally helps to specify the unwanted safety events that could occur. Unwanted safety events should take into account the following:

– no operation when operation is required (e.g. a warning lamp that does not light up when it should);
– operation when no operation is required (e.g. start-up of a motor when it is required to be stationary for maintenance purposes);
– incorrect operation (e.g. an error in measuring a parameter that has implications for safety) resulting in incorrect data or control.

B.4 Design and development measures and techniques to be considered

B.4.1 Designing system architecture to adequately reduce the probability of dangerous failures due to electromagnetic interference

Appropriate design measures and techniques may include

– fail-safe design,
– the use of parallel redundant channels; etc.

Important elements or circuits with regard to safety may be duplicated and connected in parallel in order to ensure the equipment behaviour in case of failure. It is recommended that each parallel system element should be designed in a different technology (for both hardware and software) to prevent more than one of them failing at the same time due to any given electromagnetic disturbance.

B.4.2 Avoiding the use of components, circuit designs, and mechanical and software techniques that can increase susceptibility to electromagnetic disturbances

Some components, circuit designs, mechanical and software design techniques are generally known to be especially susceptible to certain electromagnetic disturbances, or can be shown by analysis to be especially susceptible. Some may have been found by experience to be especially susceptible in particular applications.

Steps should be taken to prevent the use of counterfeit components, sub-assemblies, modules or equipment. Avoiding the use of these components, circuit designs, mechanical and software techniques ease the electromagnetic safety design of the system.

B.4.3 Choosing components and products, and designing circuits, mechanics and software, to reduce the probability of dangerous failures due to electromagnetic interference

Some components and products, circuit designs, mechanical and software design techniques, are generally known to be especially resistant (more immune) to certain electromagnetic disturbances or physical effects, or can be shown by analysis to be especially resistant. Some may have been found by experience to be especially resistant in particular applications.

Using components, circuit designs, mechanical and software techniques that are appropriately resistant, given the electromagnetic and physical specifications for the system and the planned use of any electromagnetic and/or physical mitigation measures (see B.5.7 and B.5.8), ease the electromagnetic safety design of the system.

Electromagnetic test standards for integrated circuits (ICs) are being published, so it may soon be possible to select ICs on the basis of their manufacturers' published electromagnetic characteristics data. Where the electromagnetic characteristics of an IC or other semiconductor is not known, it is usually possible to choose between competing parts by operating them in an evaluation mode and applying simple electromagnetic tests (for example using close-field or other types of probes to measure relative emissions or inject RF fields or transients).

As far as digital circuits are concerned, software techniques can be used to help ensure safe operation, for example:

- digital information coding;
- error detection algorithms;
- correction algorithms.

Error correction works in such a way that, in the presence of a transient perturbation, the system can resume normal operation as signal errors are detected and corrected. This should be done without posing any risk to the system users.

The safety of a system can also be improved through judicious software design and the design of its structure. In particular, it should be able to account for the occurrence of errors caused by the action of electromagnetic disturbances (unexpected program jump, or change in operating instructions, address codes, etc.).

The same approach should be taken for components, circuits, mechanics, software and products that are custom-designed for use in the safety system, even if made by the same company that is responsible for the final safety system.

B.4.4 Employing analysis and/or testing to determine the electromagnetic and physical characteristics of components, products, circuits, mechanics and software when exposed to electromagnetic disturbances and physical stresses representative of the system's intended environment

It helps achieve system safety if their safety functions are constructed using components, circuits, products, mechanics and software that have been proven by testing to function as intended in the maximum foreseeable electromagnetic environment as specified by the safety requirements specification (SRS).

Where the system employs electromagnetic mitigation (see B.4.7) some or all of the EMC tests applied to the components or circuits that are protected by the mitigation might not need to be as severe as the system electromagnetic specification.

– Identifying the electromagnetic characteristics of items of equipment and/or their circuits or devices is an important technique that helps understand how electromagnetic mitigation measures (e.g. shielding, filtering, surge and ESD suppression, etc.) should be applied most easily and cost-effectively to achieve the required safety integrity in real life. An item of equipment (or a circuit or device) can be susceptible to its electromagnetic disturbances, such as demodulation, intermodulation between two or more signals, overvoltage, overcurrent or overdissipation.

There are a number of ways of performing the required analysis. Two methods are outlined below.

a) Prior experience of identical items (or circuits) that use identical devices.

   Note that a semiconductor that has had a mask-shrink or die-shrink, or is packaged differently, is not an identical device as far as its electromagnetic characteristics are concerned. The experience shall be based on measurements and documentation.

b) Subjecting unprotected items (or circuits or devices) to EMC tests designed to fully determine their natural emissions and susceptibilities.

   These emission and immunity tests can use any appropriate method and need not follow IEC standards, as long as the results can be meaningfully interpreted from the point of view of the electromagnetic characteristics of the finished equipment.

   During these tests, the equipment (and/or circuits) should be free from all electromagnetic mitigation measures. That is, they should not use any shielding, filtering, surge or ESD protection, automatic shutdown, etc.

Note that b) is generally preferred to be used whenever there is existing hardware that can be tested, since it is very rare that two designs are truly identical in both hardware and software.

Similar techniques can be applied to determine the natural susceptibilities to physical stresses, to aid the physical design and mitigation of the system so that adequate electromagnetic characteristics are maintained over the anticipated lifecycle.

Electromagnetic measures required for the achievement of adequate system safety should be evaluated using electromagnetic testing and highly accelerated life testing (HALT), to demonstrate that individual electromagnetic design aspects (e.g. circuit design, shielded enclosure design, filter design, design of surge transient or ESD protection, etc.) should reliably achieve the necessary electromagnetic characteristics over their reasonably foreseeable lifecycle.

Such tests should be carried out as early in a project as possible, to reduce technical risks and save time and cost. Some of them will not need to have a functioning unit available, for example the shielding effectiveness of a PCB-mounted shield, enclosure, cable or connector can be tested in isolation.

The EM / HALT testing should be based upon the system electromagnetic and physical requirements specifications, and can use any appropriate technique so need not be limited to IEC standard methods, as long as the results can be meaningfully interpreted from the point of view of the electromagnetic characteristics of the finished equipment over its reasonably foreseeable lifecycle.

Comparison (relative) measurements of electromagnetic measurands, often based on un-calibrated close-field probes and similar measuring devices, during or else before-and-after HALT, might be all that is required in some instances.

NOTE 1 HALT testing on individual elements of a design are recommended where an item of equipment is required to perform safety functions with a high level of integrity (high reliability). Adding electromagnetic tests to these HALT tests need not add a lot of extra cost or time if they are designed appropriately.

NOTE 2 The HALT Test Plan should be designed by HALT experts, based on the system's physical environment specification.

NOTE 3 Other methods of assessing physical degradation could be used instead of HALT.

Where suitable data exists or can be calculated for a particular electromagnetic design aspect – and when it is fully documented in the project's records (not referenced, because references may become unavailable) – the above combined electromagnetic and physical testing may not be necessary. Alternatives to the above testing include

- manufacturer's data:
  - for example, good gasket manufacturers perform a variety of tests on their products simulating a variety of lifetime physical exposures;
  - manufacturer's data can only be used where their parts are applied fully in accordance with the manufacturer's application instructions.
- data from previous projects:
  - this could be from design tests, or from documented experience of identical designs in identical physical environments.

B.4.5 Designing earthing (grounding), bonding, wiring, cabling and printed circuit boards to maximise electromagnetic characteristics

The purpose of earthing (grounding) is to maintain the potential of metallic structures (shields, enclosures, chassis) at a constant value. This can be done at one or several points. Clause 5 of IEC 61000-5-2, recommends a meshed earthing network with several interconnected earth electrodes, which is common to an entire building or other structure.

Bonding helps provide an electrical homogeneity in metallic structures to reduce potential differences between items of equipment, and also to provide a path for common mode currents. The impedance of bond straps should be low over a wide frequency range, and they should thus be as short as possible (but note that direct metal-to-metal bonding is preferred to straps). If they are susceptible to corrosion, they should be easy to remove and replace (see Clause 6 of IEC 61000-5-2). IEC 61000-5-2 recommends the creation of a Meshed Common Bonding Network or MESH-CBN. Earthing and bonding connections shall be protected against corrosion effects.

A proper wiring/cabling technique should avoid the induction of disturbing voltages or currents by external fields, and crosstalk between conductors, and should control the paths taken by common-mode currents. The wiring/cabling scheme should be designed carefully. The interaction between wiring/cabling and electromagnetic disturbances should be minimised, for instance by using the following techniques:

- cable screening (shielding);
- the use of double screening (shielding);
- peripheral (360°) termination of cable screens (shields) to enclosure shields at both ends of a cable (inside equipotential zones only or with the addition of a parallel earthing conductor);
- the use of twisted wire pairs (with or without cable shielding);
- the separation of cables carrying signals of different levels and/or types (IEC 61000-5-2 recommends the use of five cable classes and the minimum spacings between them);
- the shielding that may be able to be achieved by the use of metallic structures;
- providing a low-impedance path for a cable's common-mode current in close proximity to the cable, for example by using bonded metal conduit or ducting;
- the use of fibre-optic, infra-red or radio links instead of conductive cables (fibre-optic links are now available that can transfer electrical power up to several Watts).

Printed circuit board, PCB (printed wiring board, PWB) layout plays an important role in the mastery of EMC problems, in the areas of emission as well as immunity. There are many electromagnetic design techniques that may be applied in their design, including these principal ones:

- the provision of a ground or 0V reference that has a low impedance over the frequency range to be controlled;
- the provision of power distribution systems that have low impedance and low-Q resonances over the frequency range to be controlled;
- separation (segregation) between switch-mode power converter, analogue and digital circuits. Inside each area thereby created the circuits should be further separated to provide areas for sensitive and/or low-level circuits, and digital circuits be separated according to their working speed. In this manner, internal crosstalk is reduced;
- localised shielding and/or filtering of components or areas of the PCB;
- suppression of conducted disturbances at the interfaces between a PCB/PWB assembly and other boards or cables, using shielding, filtering, overvoltage suppression and/or galvanic isolation techniques.

Interactions between the PCB/PWB assembly and conducted and radiated electromagnetic disturbances are thus controlled to reduce intra-system interference.

B.4.6 Using computer-aided design tools to minimise electromagnetic coupling paths

Computer-aided design tools can help speed up the design/development process by allowing virtual design iterations to improve electromagnetic characteristics before any hardware is made or tested. They are not (yet) an alternative to testing actual hardware, but make it possible to deal with any major electromagnetic problems quickly and at low cost before the first hardware prototype.

B.4.7 Using mitigation techniques including shielding; filtering; overvoltage protection; overcurrent protection; suppression of electro-static discharge; power quality improvement, galvanic isolation, etc.

There is a great deal of information publicly available on the correct use of electromagnetic mitigation techniques, on the internet and in numerous publications and textbooks.

Shielding is done with metallic barriers that are used to reduce the propagation of electromagnetic fields from one region to another. It can be used to substantially contain an electromagnetic field from a given source within a shielded volume, to reduce emissions. It can also be used to improve immunity by reducing the amount of external electromagnetic fields entering a volume and affecting its circuits. Shielding can be applied to cables, and/or to enclosures.

Shielding of cables and enclosures can be rendered partially or totally ineffective due to the presence of apertures, gaps, joints and other openings in the shield, or if the electrical continuity between the parts making up the shield is insufficient.

Enclosure shielding can be rendered partially, or even totally ineffective if any/all of the wires or cables entering or exiting the enclosure are not shielded and/or filtered to the appropriate degree. In either case the shields or filters shall be correctly bonded to the enclosure shield at the point of penetration of the enclosure shield.

Filtering uses specially designed circuits to reduce the propagation of conducted disturbances on wires and cables from one region to another. It can be used to substantially contain conducted electromagnetic disturbances from a given source to reduce emissions, and can also be used to improve immunity by reducing the amount of external conducted electromagnetic disturbances entering a circuit.

Filters can be used in power supply conductors (d.c. and a.c.) and also on signal conductors. They are designed as a function of the current or the type of signal to be passed through the filter, and of the types and levels of electromagnetic disturbances that are to be suppressed.

Overvoltage protection is used to prevent conducted transient or surge disturbances from causing interference or actual damage to circuits and devices. For protection from electrostatic discharge transients overvoltage protection devices shall operate in under 1 ns but need only be rated for low total energies, whereas for protection from surges on the electrical power supply they may be able to operate as slowly as 100 ns to 1 ms but be rated for very large energies. In all cases, overvoltage protection devices require a ground reference that has a low impedance, sufficient to absorb the required current without creating an appreciable rise in potential, over an appropriate frequency range.

Overcurrent protection is used to protect overvoltage protection devices (and hence the circuits and devices they protect) from damage due to electrical faults (e.g. in the electrical supply distribution network) that would cause them to exceed their power ratings.

Electrostatic discharge can be mitigated by using air or solid insulation that has a sufficient level of voltage withstand capability (dielectric strength) to prevent the electrostatic charge that is the cause of the disturbance from discharging to the equipment. Alternately, the electrostatic discharge can be permitted to occur if mitigation techniques such as shielding, filtering, overvoltage suppression, software techniques, etc., are used to prevent the discharge from causing unacceptable effects on any safety functions.

There are a large number of electromagnetic disturbances that affect power distribution systems, reducing their power quality, and for each type of disturbance there are mitigation techniques that can improve the power quality – from simple measures up to complete regeneration of the supply using a motor-generator set or charging a battery or super capacitor and using the stored energy to power a local inverter.

Galvanic isolation breaks the path of ground loop and CM currents, and helps resist CM voltages. A number of techniques are available for use with power and/or signals, including: isolating transformers, optical isolators, fibre-optics, wireless and infra-red.

Several IEC standards or technical reports (e.g. the IEC 61000-5 series) give detailed guidance on how to apply certain mitigation measures. They might also be recommended in the relevant product standards.

Mitigation methods are generally used to create electromagnetic zones, which are volumes within a structure that provide different levels of electromagnetic protection from the external ambient for the equipment and/or products located within them.

Electromagnetic zones are created by the use of earthing/grounding structures, filtering, shielding and surge suppression at the boundary between one zone and another (IEC 61000-5-2 and IEC 61000-5-6 are the relevant IEC documents).

The levels of protection required for a zone depends upon the original assessment of the electromagnetic environment plus the electromagnetic characteristics (emissions and immunity) of the equipment intended to be located within it.

Items of equipment and their cables are then located within these zones according to the degree of protection they need from each other; the degree to which the electromagnetic environment needs to be protected from them; or the degree to which they need to be protected from the electromagnetic environment over their lifetime.

For instance, in a hospital the best location for the operating theatre and life-support wards is on the ground floor of a multi-storey building, in the middle of the building’s area, because of the protection that this zone generally affords from lightning and lightning electromagnetic pulse.

B.4.8 Using techniques that mitigate the severity of the physical environment, to help the components, devices, products, equipment and mitigation measures maintain adequate electromagnetic characteristics over their reasonably foreseeable lifecycle

Physical mitigation measures for equipment design include measures for the reduction of stresses due to mechanical; climatic; chemical; biological; etc. effects. They include (but are not limited to) the following techniques:

- shock and vibration mountings (active or passive);
- vibration-proof fixings for electrical contacts and other fixings;
- protective enclosures (e.g. splash-proofing, waterproofing);
- conformal coatings and/or encapsulation;
- grease (conductive or not, as appropriate);
- paint (conductive or not, as appropriate);
- cable ties;
- anti-condensation techniques (e.g. heaters, humidity control);
- forced ventilation, air-conditioning, etc.;
- maintaining at least minimum levels of humidity to limit electrostatic discharge potentials.

Physical mitigation methods are generally used to create ‘physical protection zones’, which are volumes within a structure that provide different levels of physical protection from the external ambient for the equipment and/or products located within them.

They are created by controlling the presence or variations in physical, climatic, chemical, biological, etc., parameters, based on the original assessment of the physical environment (see B.3.3).

Items of equipment and their cables are then located within these zones according to the degree of protection they need from the system’s physical environment, to help ensure that their electromagnetic characteristics do not become excessively degraded at any point during their lifecycle.

For instance, in a motor vehicle mounting an electronic subassembly in the passenger cabin makes its electromagnetic design much easier, than if it is located in the engine bay where it is exposed to water and salt sprays from the roads, oil, brake fluid, etc., and more extreme temperatures and temperature cycling.

B.4.9 Design so that safety is maintained despite the degradation of electromagnetic characteristics caused by reasonably foreseeable faults and misuse, for example interlocking a shield door and initiating safe reaction

Faults can significantly affect immunity to the normal electromagnetic environment, for example

- short-circuits, dry joints, out-of-tolerance components (e.g. can seriously compromise EMI filtering);
- loose, damaged or missing fixings or conductive gaskets (e.g. can seriously compromise EMI shielding);
- failure of a transient/surge protection device (seriously compromising immunity to overvoltage transients).

So the design should take into account what faults could foreseeably occur, and either reduce the incidence of the faults or use methods that limit their safety impact (for instance, a fault that could lead to an unacceptable degradation of electromagnetic characteristics could be detected and used to initiate a safe reaction), to the extent appropriate for the safety integrity level (or systematic capability) required.

Electromagnetic disturbances and physical stresses can cause common faults (not random faults) in identical elements – making many of IEC 61508 techniques ineffective (e.g. redundancy using identical elements operating in parallel).

Misuse can also significantly affect immunity to the normal electromagnetic environment, for example:

- failure to follow the installation requirements could result in an unshielded cable being used where shielded was required, or shielded cable being used with incorrect shield termination, or incorrect cable routing leading to unanticipated levels of electromagnetic coupling;
- operating with shielded doors open (or not closed correctly), or with shielding panels removed (or not fixed correctly);
- operating a mobile or portable radio transmitter too close to a cable or item of equipment.

The above has described electromagnetic design to cope with reasonably foreseeable faults and use/misuse to help achieve the required safety. A similar approach should be followed for the physical design of the electromagnetic elements that help maintain electromagnetic safety.

B.4.10 Using two or more layers of mitigation rather than relying solely on a single layer

More confidence in safety integrity can be achieved by using a number of layers of electromagnetic or physical protection or mitigation, rather than relying on one layer (such as shielding and filtering of one overall enclosure). It is often less costly and easier to design using multiple layers, because the characteristics of each electromagnetic or physical protection layer might not need to be as high.

It is recommended to design so that if one layer should fail (for some unforeseen reason), the system or equipment will still maintain adequate electromagnetic and physical characteristics. This helps avoid problems caused by unforeseen use, misuse or faults.

For example: suppose that a minimum of 40 dB suppression was required from 850 MHz to 950 MHz (e.g. for protection from nearby mobile phones). An expensive shielded/filtered enclosure could easily achieve suppression of 80 dB at 900 MHz, and is easy to purchase from numerous suppliers. But if someone cut a hole 15 mm in diameter in the enclosure (e.g. to add an indicator lamp) it would reduce its shielding effectiveness from 80 dB to just 20 dB at 900 MHz, below the 40 dB requirement. And, of course, if the enclosure door was opened the shielding effectiveness would drop to almost zero.

Instead, using a three-layers-of-protection design where each layer achieved only 20 dB from 850 MHz to 950 MHz would achieve 60 dB for the overall system or equipment, and even completely destroying the outermost layer of protection would still leave 40 dB of shielding effectiveness. It is easier to design protection that achieves 20 dB around 900 MHz than it is to achieve 40 dB, and it may cost less too.

When using layers it is important to understand the possible interactions between the layers so that the overall result is the sum of its parts. For example, cascading certain types of mains filters can result in filtering effectiveness that is less than that of just one filter, although this can be avoided by the use of appropriate design techniques that are well-known to filter experts.

Electromagnetic mitigation measures (e.g. shielding; filtering; surge, transient, and ESD protection, etc.) – and physical mitigation measures – can be applied to the following layers:

– individual semiconductor devices;
– printed circuit assemblies;
– modules and sub-assemblies;
– complete stand-alone items of equipment;
– the overall enclosure level for the equipment (e.g. a rack cabinet);
– rooms or small vehicles;
– collections of rooms in a large building or large vehicle or vessel;
– buildings, or large vehicles;
– entire sites comprising numbers of buildings or other structures, or the sites where vehicles operate.

B.4.11 Using checklists that are based upon case studies and experience obtained in similar applications

Experienced personnel in organisations learn many things about the electromagnetic characteristics and their possible effects on the safety of the systems they are associated with. They also learn about similar systems manufactured or operated by other organisations through publications, conferences and similar events.

Technical guidance in international standards shall be general, within the scope of the standard, but the knowledge gained by experienced personnel can modify the guidance in the relevant standards, or be additional to it.

It is important for the responsible people in organisations to actively seek out specialised safety information on their own and other systems, and then to ‘capture’ this knowledge in checklists, so that when experienced personnel leave an organisation, their knowledge is not lost to that organisation. Using checklists in this way, the electromagnetic safety knowledge of the organisation is maintained and new or less experienced personnel can quickly be come acquainted with what has found to be necessary to achieve adequate safety in new designs.

It is also important for such checklists to be kept up-to-date, and to be applied along with the relevant standards to the manufacture of all new systems.

B.5 Implementation and integration

B.5.1 Procure materials, components and products according to their electromagnetic specification

A QA procedure shall ensure that the designer specifies all the necessary parameters for purchasing the materials, components and products that are required to construct the system, plus the methods that are to be used in its assembly and production test. The QA procedures shall ensure that the other departments in the company comply with these specifications and that the end result is what was originally designed.

Design or component changes that suppliers make to their products can be important for electromagnetic characteristics and/or resistance to the lifetime physical environment. This is especially true for the suppliers of electronic units or sub-assemblies, but can also be true for suppliers of items such as pieces of metalwork that are often assumed to be insignificant. Semiconductor suppliers might substitute die-shrunk versions of their product in the same packaging with the same part numbers, and since these can have very different emissions and immunity characteristics from the original units this possibility should be actively controlled by the QA procedures.

Ideally, a QA system should control all relevant issues of the build-states of the components and products supplied by others, but this is often very hard to do, so instead most manufacturers rely on sample-based electromagnetic and physical inspections and tests. These inspections and tests are best applied upon delivery, before accepting a new batch of goods (before any value has been added). The electromagnetic and physical checks or tests do not need to follow IEC or ISO test standards, and relative comparison tests are preferred because they can be quick and easy to design, construct, and apply. They should check or test all of the significant parameters.

In serial manufacture, full electromagnetic and physical tests could be required whenever a supplier or subcontractor introduces a significant design change to their components or products.

B.5.2 Assemble according to the design, using the correct materials, components and products according to their electromagnetic specification

The QA system should control every aspect of the build state that helps achieve the electromagnetic characteristics and maintain it over the reasonably foreseeable lifecycle. All of the following issues (and more) can be very important.

– A single ‘form, fit and function’ replacement device or component.
– A wire or cable routed differently.
– IC and semiconductor mask-shrinks (die-shrinks).
– Changes in painting method or supplier; example: A new painting method or painter creates overspray onto areas where metal-to-metal or metal-to-conductive-gasket electrical contact is required.
– Metal parts supplied with non-conductive finishes; example: Non-conductive passivation coatings can sometimes be applied despite not being required by the drawing, resulting in electromagnetic problems for chassis-bonding, shielding and filtering. This often occurs when changing metalwork suppliers, but has even occurred despite using the same metal supplier.
– Metal fixings supplied with non-conductive finishes; example: Metal screws that always used to be conductively-coated, are instead supplied with a non-conductive finish resulting in electromagnetic problems due to higher impedances in chassis-bonding, shielding and filter grounding.
– Changes in a plating method; example: Over time can result in poor chassis bonding or EMC gasket characteristics due to oxidation and/or galvanic corrosion.

– Use of a different kind of shake proof washer; example: Where the shake proof washer was providing useful protection against the effects of vibration, changing to a different type can compromise that aspect of resistance to the lifetime physical environment.

The QA system should ensure that no changes in any aspect of build-state can occur, however insignificant they may seem, unless they have been checked and approved by the person responsible for the electromagnetic safety performance of the system.

The person responsible might want to do some quick EMC checks, or even full retesting, before he/she feels confident in authorising the proposed change or deviation.

In serial manufacture, full electromagnetic and physical tests should be applied on a sampled basis, every few months or every few thousand items manufactured, or whenever a significant design change is introduced. More frequent sample-based checks of electromagnetic and physical characteristics can be used to reduce the frequency of full tests.

B.5.3 Install according to the electromagnetic design

Inspections, checks and testing should be carried out to ensure that the design features relating to achieving functional safety with regard to electromagnetic disturbances are correctly implemented in the installed system.

Inspections check the assembly against the design documents. For example, checking whether the correct types of EMC gaskets have been fitted properly; the screens of screened cables terminated correctly in connectors; the correct types of cables used and routed correctly.

Checks of electromagnetic characteristics can be performed using simple tests using close-field probes and similar low-cost RF transducers, using ad-hoc methods as appropriate. Such checks are quick and low-cost techniques for discovering a range of assembly errors especially with regard to mitigation techniques such as shielding and filtering.

Electromagnetic testing is required to prove that the electromagnetic characteristics of the final system are what was specified.

B.6 Installation and commissioning

B.6.1 General

To ensure the correct installation and commissioning of the system on its operational site, to achieve the desired electromagnetic safety performance, the system designer should consider the following.

B.6.2 Procedures and materials to be used

The procedures and materials to be used should be chosen to help ensure that the required electromagnetic characteristics, which could affect a safety function, are achieved, despite the effects of the physical environment over the reasonably foreseeable lifecycle.

B.6.3 Any constraints on the physical positioning of the items of equipment that comprise the system

The initial system planning should have identified areas within and outside the site that could cause interference with elements of the safety system, or that elements of the safety system could interfere with (inter-system interference). It should also have identified elements of the safety system that could cause interference with other elements of the same system, or that might suffer interference from them (intra-system interference).

Information on the electromagnetic protection measures resulting from the above analysis should be carried forward into the installation phase of the work, to ensure that the necessary minimum distances to prevent interference are achieved.

Similar issues apply to the physical environment (e.g. not placing electronics in areas of very high temperature, prone to flooding, or other significant physical effects).

B.6.4 Any constraints on types, lengths and routing of power, control and signal interconnecting cables

The electromagnetic characteristics of different cable types vary very widely, so it is important to specify the types of cables to be used during installation in every case. A manufacturer's part number for a cable type can help, and is often taken as a guide to the cable characteristics required. In some cases it may be that only a specified manufacturer's cable type is permitted to be used for certain purposes in the installation of the system, and where this is so, it should be made very clear in the installation instructions.

Similar to B.7.2, cables may need to be separated to prevent intra and inter-system interference. IEC 61000-5-2 provides the essential guidance on good electromagnetic engineering practices for this issue, based upon at least 5 classes of cable depending upon the types of signals they carry and their propensity for creating electromagnetic emissions or suffering from electromagnetic interference.

CM currents are the main cause of problems with conducted and radiated electromagnetic emissions and immunity, and crosstalk between cables. Designing the installation to provide appropriate paths for CM currents, so that they are well controlled, is a good technique for improving emissions and immunity. For example, the IEC 61000-5-2 publication provides guidance on this, and other guides exist.

B.6.5 Methods of terminating any cable screens (shields)

Where cables are screened, correct termination techniques should be used at both ends of the cable to ensure the electromagnetic shielding characteristics of the cable is achieved. IEC 61000-5-2 is the relevant IEC publication providing guidance on this, and other guides exist.

B.6.6 Types of connectors and glands to be used, and any special assembly requirements for them

The electromagnetic characteristics of different types of cable connectors and glands vary very widely, so it is important to specify the types to be used in every case. A manufacturer's part number for the connector or gland can also help, and is often taken to be a guide to the characteristics required. In some cases it may be that only a specified manufacturer's part number should be used for certain purposes in the installation of the system, and where this is the case, it should be made very clear in the installation instructions.

B.6.7 Electrical power supply requirements (the quality of the electrical power supply)

Electrical power distribution or generation suffers from a large number of possible conducted electromagnetic disturbances (RF currents and voltages, surge overvoltages and overcurrents, fast transient bursts, etc.) often at the highest levels of any of the cables associated with a system.

There are also a number of power quality electromagnetic issues such as waveform distortion (harmonics and interharmonics), dips, dropouts, short and long interruptions, voltage sags, swells, flicker, etc., that afflict power distribution networks and generated supplies. These are also classified as electromagnetic disturbances, even though they may occur over timescales of seconds.

The electromagnetic characteristics of the electrical power supply can be very important indeed for the achievement of electromagnetic safety, so it is important that they are assessed very early in a project (see B.3.2) to help create the system's electromagnetic specification. For the same reason it is very important that the specifications for the electrical power supply are applied to the installation, so that the installer can ensure that they are achieved (for instance, by taking the power from a suitable point of common connection in the distribution network, or providing an appropriate generator or UPS).

It is also important to specify the electromagnetic requirements for the electrical power supply so that the owner of the installation can ensure they are maintained despite future changes to the site over the anticipated lifecycle of the system (see B.8.1).

B.6.8 Any additional screening (shielding) required

The electromagnetic mitigation measures required by the system might require shielding to be applied during its installation (for example, the provision of a screened room). Where such requirements exist, they should be clearly specified in the installation instructions.

Such additional shielding can be specified either by a description of the exact build state to be achieved (requires detailed assembly drawings) or by specification of the electromagnetic characteristics (attenuation versus frequency range, for each type of radiated disturbance) that it is to achieve, plus the test methods that should be used to verify it.

B.6.9 Any additional filtering required

The electromagnetic mitigation measures required by the system might require filtering to be applied during its installation. Where such requirements exist, they should be clearly specified in the installation instructions.

Such additional filtering is generally specified in terms of the electromagnetic characteristics (attenuation versus frequency range) that it is to achieve, and the test methods that should be used to verify it. It is also possible to specify it by a description of the exact build state to be achieved (requires detailed schematics and assembly drawings).

B.6.10 Any additional overvoltage and/or overcurrent protection required

The electromagnetic mitigation measures required by the system might require overvoltage and/or overcurrent protection to be applied during its installation (for example, the provision of a lightning protection system meeting certain performance specifications). Where such requirements exist, they should be clearly specified in the Installation Instructions.

Such additional protection is generally specified in terms of the electromagnetic characteristics (the attenuations achieved for various waveshapes of surges) that it is to achieve, and the test methods that should be used to verify it. It is also possible to specify it by a description of the exact build state to be achieved (requires detailed schematics and assembly drawings).

B.6.11 Any additional power conditioning required

As discussed in B.7.6, part of the initial design process is to assess the foreseeable electromagnetic characteristics of the electrical power supply provided at the site, and design the safety system accordingly. As a result of this process, the safety system might require additional power conditioning to be installed during installation.

There are many kinds of power conditioning available, depending on the power supply characteristics to be controlled. Where such additional power conditioning requirements exist for the installation, they should be clearly specified in the Installation Instructions along with the methods to be used for verifying that the requirements have been successfully implemented.

For example, it is not uncommon for some sort of emergency power back-up to be required for a few seconds or tens of seconds to permit the system to shutdown safely in the event of an interruption in the power supply, or in the event of a serious degradation in power quality that could affect system safety (e.g. a voltage sag of more than 10 % below nominal).

In the case of life-support equipment, or where shutdown would cause significant disruption or financial losses, power back-up could be required for minutes, hours, maybe even for days or weeks. Such requirements are commonly satisfied by the installation of appropriately-rated uninterruptible power supplies (UPSs). These typically use super capacitors, batteries, or fuel cells for their energy storage, with the super capacitor and battery types relying on switching to local power generation for long-term back-up.

B.6.12 Any additional electrostatic discharge protection requirements

The levels of electrostatic discharge (ESD) that a system shall be protected from can be reduced by a variety of techniques, including the use of electrically dissipative materials for floorings, furnishings and clothing to reduce furniture and personnel ESD. Appropriate electrical bonding and charge dissipation measures can reduce the levels of discharges from ESD caused by machinery. Other techniques for ESD control include maintaining the air to be above a specified minimum level of humidity (typically >25 %); and blowing air that has been ionised by an a.c. source so that it is neutral overall but more conductive than normal air at that humidity.

Where such additional ESD reduction requirements exist for the installation, they should be clearly specified in the Installation Instructions, either in terms of their detailed construction requirements, or the performance to be achieved, and the test methods to be used to verify their effectiveness.

B.6.13 Any additional physical protection required

As discussed in B.3.3, the reasonably foreseeable physical environment that the safety system has to endure over its reasonably foreseeable lifecycle should be assessed early in a project, so the designer knows how to realise the electromagnetic characteristics so that they remain adequate over the lifecycle.

It may be that during the installation of the system, additional physical mitigation measures might need to be applied so that the system remains safe enough over its lifecycle. These might include roofs or enclosures to protect from rain and snow, air-conditioning or heaters to protect from condensation, anti-vibration floors or mountings, etc.

Where such additional physical protection requirements exist for the installation, they should be clearly specified in the Installation Instructions, either in terms of their detailed construction requirements, or the characteristics to be achieved, and the test methods to be used to verify that they are providing the required characteristics.

B.6.14 Any earthing (grounding) and bonding requirements

The earthing or grounding structure should provide an equipotential network over a specified range of frequencies (for example: to handle surges, transients, and RF noise currents, etc.).

The frequency range should be identified and the earthing/grounding structure designed and constructed so that it provides a low-enough impedance, given the frequencies and currents concerned, to achieve the degree of equipotentiality required.

See IEC 61000-5-2.

B.7 Operation and maintenance

B.7.1 Comprehensive user instructions including operating procedures necessary to maintain adequate electromagnetic characteristics

These should clearly describe the electromagnetic and physical environment specifications of the safety system, plus everything that the user should do, for all lifecycle stages, to ensure that the system maintains its electromagnetic and physical characteristics to help ensure adequate safety over its reasonably foreseeable lifecycle.

This should include the operating procedures necessary to preserve EMC characteristics and electromagnetic safety. It should also include the specifications for any planned maintenance necessary to preserve adequate electromagnetic characteristics over the reasonably foreseeable lifecycle, for example checking/replacement of transient suppressors, batteries, etc., before their characteristics degrades too much.

It may also be necessary to include specifications for cleaning materials, techniques and procedures that should be used to preserve electromagnetic characteristics over the anticipated lifecycle (e.g. do not paint specified bonding areas, do not use wire brushes on plated areas, etc.).

Product manufacturers should also provide similar comprehensive user instructions to prospective purchasers. This information helps the safety system designer decide which products to purchase, which electromagnetic and/or physical zones to locate the products within, and whether new zones need to be created to protect them using electromagnetic and/or physical mitigation techniques (see B.4.7 and B.4.8).

B.7.2 Maintaining procedures related to electromagnetic characteristics

The designer should provide instructions for the proper maintenance of the EMC (emission and immunity) of a system in a General Maintenance Manual, to help ensure that maintenance work can be performed safely.

NOTE Maintenance repair and refurbishment should not alter any aspects of the build-state that help achieve the electromagnetic, physical and functional characteristics required over the reasonably foreseeable lifecycle.

The general rule is – “Do not design it if it cannot be repaired” – and this is good advice for equipment that is large, has a high-value, is expected to have a long life, or is permanently installed.

But some household appliances, consumer goods, high-volume or low-cost products are intended never to be maintained or repaired over their lifetime – so their functional safety design can be more challenging, especially because these products are often sold in large numbers, so a great many people could be exposed to their safety risks at any one time.

Partial or full electromagnetic and physical inspection or testing may be required after the repair or refurbishment, to ensure that the electromagnetic characteristics over what remains of the lifetime have not been compromised.

Each maintenance, repair or refurbishment activity may be specified as being carried out by the user, by the original manufacturer, or by a specified third party. It is very important to make quite clear to all involved what is required to be done, who is required to do it, and when.

Maintenance sometimes requires that certain installed components serving to ensure electromagnetic characteristics be removed or disassembled (e.g. doors, access panels, etc.). Those people performing the maintenance work should thus be warned of the risks linked to any malfunctions that may result from the lowering of the level of immunity. Although this can be done in the manual, warning signs or panels should be posted on or near the equipment in question.

Resumption of normal operation of the system, either manually or automatically, shall be done only in the absence of any foreseeable risk.

B.7.3 Changes in the external electromagnetic environment to deal with new electromagnetic threats arising that were not included in the original design

Restrictions should be applied on the operation of other equipment that might not achieve an adequate level of electromagnetic compatibility with respect to the equipment in the safety system. This can include constraints on proximity to other equipment, including mobile transmitting equipment (especially mobile phones, walkie-talkies, but possibly including other mobile radio transmitters including Wi-Fi, Bluetooth and the like).

NOTE In some applications it is practical or necessary to control the external electromagnetic environment. For example, an airliner only travels in designated routes avoiding known areas of high field strength, and the captain has the authority to control the use of personal electronic devices used by staff and passengers.

B.7.4 Disassembly/reassembly techniques to preserve EMC characteristics

The designer should provide the user with appropriate instructions to help ensure that disassembly and reassembly, for example for maintenance or repair, does not degrade the electromagnetic characteristics of the safety-related system below what is necessary for the maintenance of acceptable safety risks.

In some cases, especially where safety integrity levels (SIL) are high, the instructions might need to include requirements for verification or validation of the system's electromagnetic characteristics after reassembly, using techniques similar to those mentioned in B.7.5 (periodic testing), or as described in Clauses 8 and 9.

B.7.5 Periodic testing (proof testing) of critical components for electromagnetic characteristics (e.g. transient suppressors, shielding, etc.)

Some components can wear out or suffer from corrosion or ageing over their life. For example: transient suppressors are only rated for a given number of transients of given energies, and so should be considered to have a specified operational lifetime in a given electromagnetic environment. Joints and gaskets in shielding can suffer degraded electromagnetic characteristics due to friction and corrosion.

Where the electromagnetic characteristics of such components are important for maintaining the desired electromagnetic characteristics of the safety-related system, the designer should provide the user with appropriate instructions on their periodic testing (proof testing) to help ensure that the necessary electromagnetic characteristics of the safety-related system are maintained over its anticipated lifetime.

An alternative to proof testing might be to employ a planned maintenance regime, as briefly described in B.7.6.

There are many types of proof testing that could be effective, for example: visual inspections (e.g. for gasket damage, broken wires, etc.); electrical checks/tests (e.g. contact resistance, clamping voltage, leakage current, etc.); tests of electromagnetic characteristics (e.g. shielding effectiveness, filter attenuation, etc.), etc.

The interval between the proof tests should be specified based upon the anticipated rate of degradation of the components, and should be much less than the time over which the degradation is expected to become unacceptable. The higher the safety integrity level (SIL) of the safety-related system, the shorter should be the proof test interval, and the more searching and stringent should be the proof tests themselves.

Where a component is becoming too degraded, given the safety integrity level (SIL), instructions should be provided for its correct repair/replacement (also see B.7.4) so as to preserve the necessary electromagnetic characteristics of the safety-related system over its anticipated lifetime.

Periodic proof testing can be made less costly if the components are designed so they can easily be tested and replaced where necessary.

B.7.6 Periodic replacement of critical components susceptible to degradation or wear-out over time (e.g. transient suppressors)

Some electromagnetic-characteristics related components have a limited life expectancy. Some will 'wear out' due to repetitive overvoltage/overcurrent transients or physical overstresses. Such components may require planned maintenance regimes, which can be made less costly if the components are designed so they can easily be checked and replaced where necessary.

Examples: surge protection devices; filters connected to a.c. supply or long cables; gaskets around doors; batteries for program memories, etc.

B.8 Modifications and upgrades (hardware and software)

B.8.1 Assessing the effect of proposed modifications and upgrades on electromagnetic characteristics of the safety-related system concerned, and on any other safety-related system that might be affected

The electromagnetic characteristics of the safety-related system shall be maintained over its anticipated lifetime, despite modifications, upgrades, etc.

Before any modifications or upgrades are carried out, their effects on the electromagnetic characteristics of the safety-related system should be assessed. The electromagnetic immunity of the modified/upgraded system should be maintained at acceptable levels given its electromagnetic environment and safety integrity level (SIL). Also its emissions may need to be limited to avoid upsetting other systems, especially if they are safety-related.

The purpose of this assessment is to foresee any areas where the modifications/upgrades might unacceptably degrade the required electromagnetic characteristics of the safety-related system.

Where this assessment shows that unacceptable degradation could occur, it is necessary to determine appropriate actions. These actions should ensure that when the modification/upgrade is carried out on the actual system, the resulting electromagnetic characteristics are adequate for the achievement of acceptable safety risks (according to the safety integrity level).

The result of this assessment will be instructions that describe any necessary detailed changes to the design of the modification/upgrade, and any necessary instructions for the detailed implementation of the modification/upgrade. A modification or upgrade might require the modification, upgrade or addition of electromagnetic mitigation measures such as shielding, filtering, transient suppression, etc.

These instructions should be provided to the appropriate personnel, and might need to include requirements for verification or validation of the system's electromagnetic characteristics after the modification or upgrade has been carried out. Depending on the safety integrity level (SIL), these might use techniques similar to those mentioned in B.7.5 (Periodic testing), or as described in Clauses 8 and 9.

B.8.2 Ensuring that modifications and upgrades do not reduce the electromagnetic characteristics below acceptable levels, for the system concerned, and any for other safety-related system that might be affected

Modifications and upgrades (to mechanical structures, hardware or software) to the design and construction of equipment or systems can affect the achievement of the necessary electromagnetic and physical characteristics over the reasonably foreseeable lifecycle. So the procedures and techniques that are necessary here are the ones relating to design, see B.5.

Each modification or upgrade activity may be specified as being carried out by the user, by the original manufacturer, or by a specified third party. It is very important to make quite clear to all involved what is required to be done, who is required to do it, and when.

Annex C
(informative)

Information concerning performance criteria

The following Tables C.1 and C.2 give an overview of the allowed effects during immunity tests on the different functions, that is non-safety-related and safety-related functions. The occurrence of eight possible effects is considered. Table C.1 refers to the situation when equipment is concerned and Table C.2 refers to the situation when looking at the entire safety-related system.

These tables present the approach that can be applied for determining allowed effects during tests. These effects depend on the following considerations:

- type of function (safety-related functions or non-safety-related functions) and
- type of test (normal EMC test or EMC safety test).

Table C.1 – Allowed effects during immunity tests on functions of equipment

		Safety-related function				Non-safety-related function		
		Normal EMC test		EMC safety test		Normal EMC test		
	Effect during test	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short time transient electromagnetic phenomena	long time transient electromagnetic phenomena
1	function undisturbed	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**
2	reproducible degradation of performance, degradation information is provided (degradation is not necessarily detectable by automatic diagnostic)	**allowed within specified limits only**	**allowed**	**allowed**	**allowed**	**allowed within specified limits only**	**allowed but no need to provide information**	**allowed but no need to provide information**
3	temporary loss of function, operates as intended after test (self recovering) + failure is detectable by automatic diagnostic (failure information is provided)	**not allowed** (function must not fail, normal undisturbed operation is required due to normal EMC behaviour)	**allowed**	**allowed**	**allowed**	**not allowed**	**allowed**	**allowed**
4	temporary loss of function, operates as intended after test (self recovering) + failure is not detectable by automatic diagnostic (internal or external of the EUT)	**not allowed**	**not allowed** (FS specific aspect dominates)	**not allowed**	**not allowed**	**not allowed**	**allowed**	**allowed**
5	temporary loss of function which requires operator intervention or reset for recovery + failure is detectable e.g. by diagnostic (failure information is provided)	**not allowed** (normal EMC requirement dominates i.e. the function must not fail)	**allowed**	**allowed**	**allowed**	**not allowed**	**not allowed**	**allowed**

		Safety-related function				Non-safety-related function		
		Normal EMC test		EMC safety test		Normal EMC test		
	Effect during test	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short time transient electromagnetic phenomena	long time transient electromagnetic phenomena
6	temporary loss of function which requires operator intervention or reset for recovery **+** failure is not detectable by automatic diagnostic (internal or external of the EUT)	**not allowed**	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed**	**not allowed**	**allowed**
7	as 5, however, no recovery (damage included)	**not allowed** (normal EMC requirement dominates)	**not allowed** (normal EMC requirement dominates)	**allowed**	**allowed**	**not allowed**	**not allowed**	**not allowed**
8	as 6, however no recovery (damage included)	**not allowed**	**not allowed**	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed**	**not allowed**	**not allowed**

NOTE As short time transient electromagnetic phenomena are considered: ESD, burst, surge; and as long time transient electromagnetic phenomena are considered: voltage dips and voltage interruptions.

Table C.2 – Allowed effects during immunity tests on functions of a system

		Safety-related function				**Non-safety-related function**		
		Normal EMC test		**EMC safety test**		**Normal EMC test**		
No	**Effect during test**	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short time transient electromagnetic phenomena	long time transient electromagnetic phenomena
1	function undisturbed	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**	**always allowed**
2	loss of function, operates as intended after test (self recovering) **+** fault reaction as specified is performed	**not allowed** (function must not fail, normal undisturbed operation is required due to normal EMC behaviour)	**allowed**	**allowed**	**allowed**	**not allowed**	**allowed**	**allowed**
3	temporary loss of function, operates as intended after test (self recovering) **+** specified fault reaction is not performed	**not allowed**	**not allowed** (FS specific aspect dominates)	**not allowed**	**not allowed**	**not allowed**	**allowed**	**allowed**
4	temporary loss of function which requires operator intervention or reset for recovery **+** specified fault reaction is performed	**not allowed** (normal EMC requirement dominates i.e. the function must not fail)	**allowed**	**allowed**	**allowed**	**not allowed**	**not allowed**	**allowed**
5	temporary loss of function which requires operator intervention or reset for recovery **+** specified fault reaction is not performed	**not allowed**	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed**	**not allowed**	**allowed**

		Safety-related function				Non-safety-related function		
		Normal EMC test		EMC safety test		Normal EMC test		
No	**Effect during test**	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short and long time transient electromagnetic phenomena	continuous electromagnetic phenomena	short time transient electromagnetic phenomena	long time transient electromagnetic phenomena
6	as 4, however, no recovery (damage included)	**not allowed** (normal EMC requirement dominates)	**not allowed** (normal EMC requirement dominates)	**allowed**	**allowed**	**not allowed**	**not allowed**	**not allowed**
7	as 5, however, no recovery (damage included)	**not allowed**	**not allowed**	**not allowed** (except safe failure)	**not allowed** (except safe failure)	**not allowed**	**not allowed**	**not allowed**

NOTE As short time transient electromagnetic phenomena are considered: ESD, burst, surge; and as long time transient electromagnetic phenomena are considered: voltage dips and voltage interruptions.

Annex D
(informative)

Considerations on the relationship between safety-related system, equipment and product, and their specifications

D.1 The relationships between the terms: safety-related system, equipment and product

D.1.1 General

This annex is intended to explain the different relationships between the terms safety-related system, equipment and product as used in this document.

For the purposes of this document, a safety-related system should be understood to be composed of one or more items of equipment. In turn, each item of equipment should be understood to comprise one or more products. This concept is shown in Figure D.1 below.

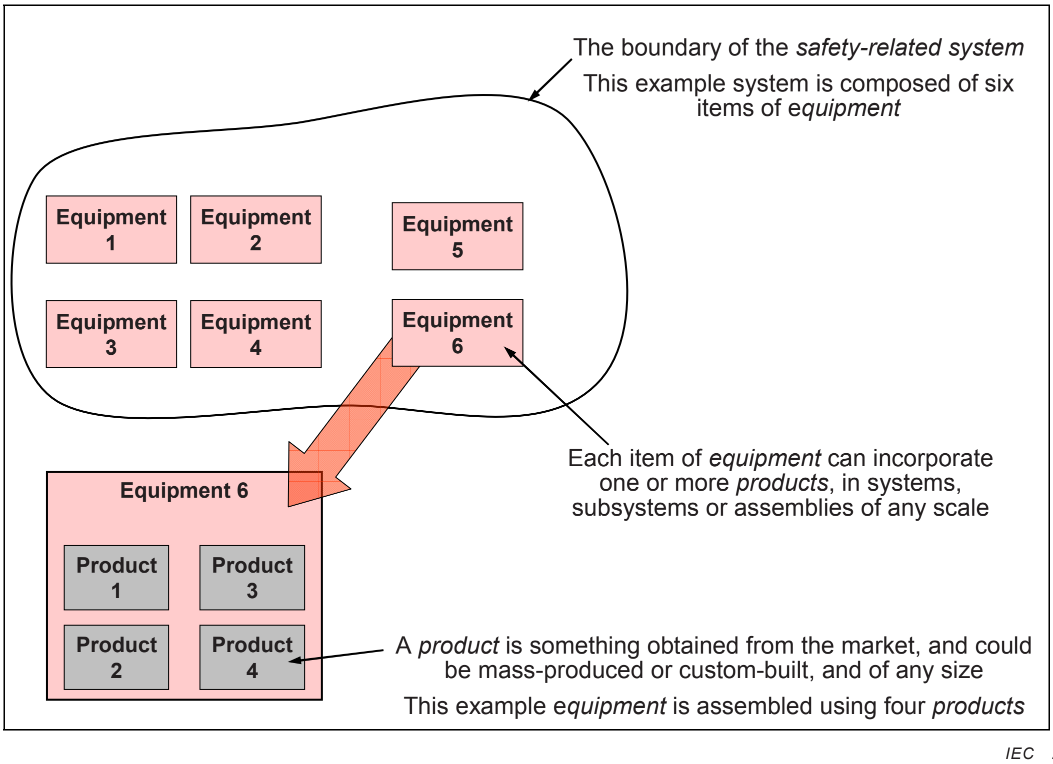


Figure D.1 – The relationships between the safety-related system, equipment and products

D.1.2 The safety-related system

This comprises all of the items of equipment in the safety-related system that is to be designed.

D.1.3 Product

A product is an item that is commercially available on the market, from manufacturers or their agents, for example an industrial computer, motor drive, thermocouple amplifier, etc.

Products could be mass-produced standard items, or items made to special order, or items that have been custom-designed specifically for a particular purpose or system.

D.1.4 Equipment

The terms safety-related system and product are used very precisely in this document – as described above. But the term equipment as used in this document is extremely general and is applied to a wide variety of possible sub-systems, appliances and other assemblies of products, including new or re-used items.

D.2 The relationship between electromagnetic mitigation and electromagnetic Specifications

D.2.1 The safety requirements specification (SRS)

The maximum electromagnetic environment that the safety-related system is exposed to over the lifetime is the basis for the electromagnetic performance specifications in the safety requirements specification (see Figure 1).

D.2.2 The equipment requirements specification (ERS)

An equipment requirements specification (ERS) is created for each item of equipment within the safety-related system. Included in each equipment requirements specification (ERS) is an electromagnetic performance specification based upon the maximum electromagnetic environment expected over the lifetime for that particular item of equipment.

It is the job of the designer of the safety-related system to create the equipment requirements specification (ERS) for each item of equipment, including its electromagnetic specifications.

The electromagnetic specification in an equipment requirements specification (ERS) depends upon the safety requirements specification (SRS) and should further take into account the situation provided by mitigation measures applied on the system level. It should be noted that the equipment requirements specification (ERS) might also need to protect certain equipment from the electromagnetic emissions from other parts of the safety-related system, i.e. to take into consideration aspects of the intra-system EMC. The application of electromagnetic zoning concepts is useful in the design of mitigation measures (see IEC 61000-5-6).

This document generally assumes that the designer of the safety-related system creates the equipment requirements specifications (ERS), and that the various equipment designers (working for the same or supplier organisations) choose the products to use within their items of equipment so as to comply with the relevant equipment requirements specification. This situation is typical of large industrial or commercial installations. But where the safety-related system is small enough, equipment requirements specifications (ERS) might not be required.

D.2.3 Product specifications

These are created by the product manufacturers for their own products, and contain electromagnetic performance specifications that will often be related to IEC EMC standards. But it is important to understand that product specifications may be based on general knowledge of the electromagnetic requirements rather than specific knowledge of the safety requirements specification (SRS) or equipment requirements specifications (ERS) for a particular safety-related system.

This means that product specifications may not satisfy the electromagnetic performance required by an equipment requirements specification (ERS) for a given safety-related system.

It is the job of the designer of an item of equipment to achieve the electromagnetic specification in its equipment requirements specification (ERS), using the product

Specifications and electromagnetic mitigation measures, as described in D.2.4 below. This should also take into account the possibility of interference between the various products comprising the equipment.

D.2.4 An overview of the relationships between the SRS, the various ERSs, and product specifications

Figure D.2 shows an overview of an example of the process by which commercially available products are made suitable for the maximum electromagnetic environment they might encounter when used in the safety-related system.

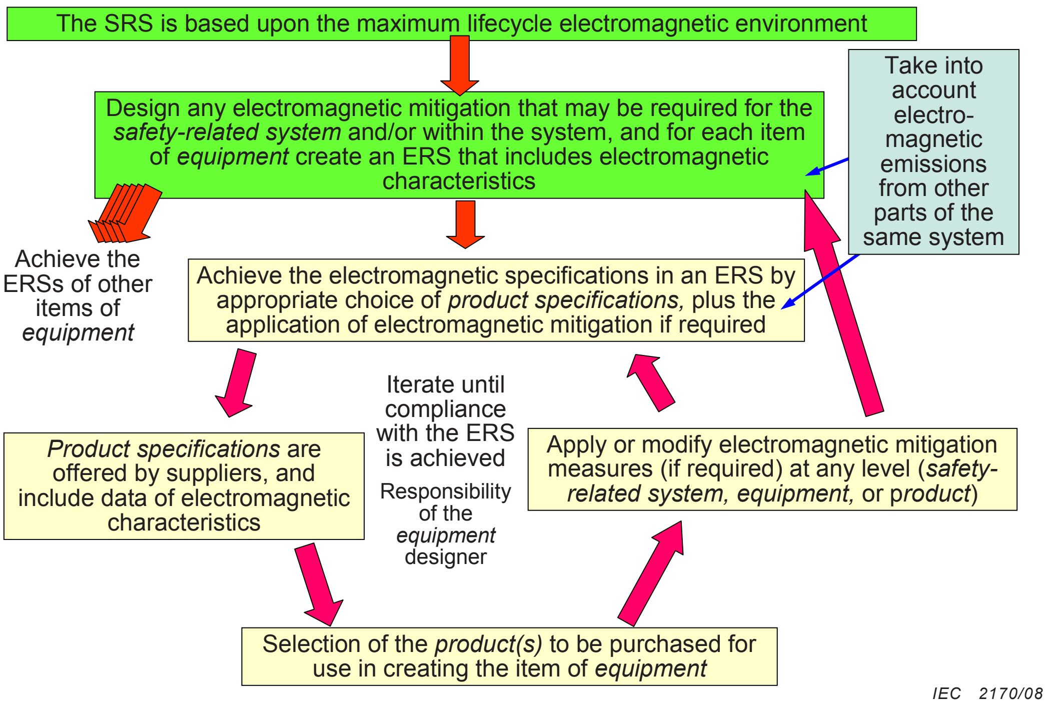


Figure D.2 – The process of achieving the electromagnetic specification in the SRS, using commercially available products

A typical industrial safety-related system uses products purchased from manufacturers' or distributors' catalogues. In such cases, the equipment designer when faced with an equipment requirements specification (ERS) that includes an electromagnetic specification that is more stringent than that of the product specifications that are available commercially, may need to employ electromagnetic mitigation measures, creating electromagnetic zones as required, to be able to use the available products in their equipment whilst complying with its equipment requirements specification (ERS).

Where a particular item is not available commercially, the equipment designer might choose to commission one to be made specially.

Annex E
(informative)

Considerations on electromagnetic phenomena and safety integrity level

This annex is provided to explain some considerations on the topics of electromagnetic phenomena and safety integrity level (SIL).

The quantitative description of the required immunity against electromagnetic phenomena is established in practice by the introduction of appropriate immunity tests, immunity test levels and particular performance criteria. This is a difficult and crucial task because different approaches and strategies for the EMC and functional safety areas have to be considered and have to be brought together.

The classical approach for deriving electromagnetic immunity levels for EMC can be demonstrated by means of Figure E.1 (for further details see IEC 61000-2-5). The left curve of this figure shows the probability density of the occurrence of electromagnetic disturbances resulting from the emissions from individual sources (that is, the system disturbance level).

The curve on the right represents the probability density of the immunity behaviour of equipment against electromagnetic disturbances. In spite of the fact that immunity levels are normally given as discrete quantitative values, a probabilistic curve exists. This curve reflects the fact that often equipment may have a higher immunity than the required one (the immunity is normally tested with respect to the required level only). This curve also shows that there is a variation in the actual immunity, due to tolerances in the equipment itself and uncertainties with the test equipment and the test performance.

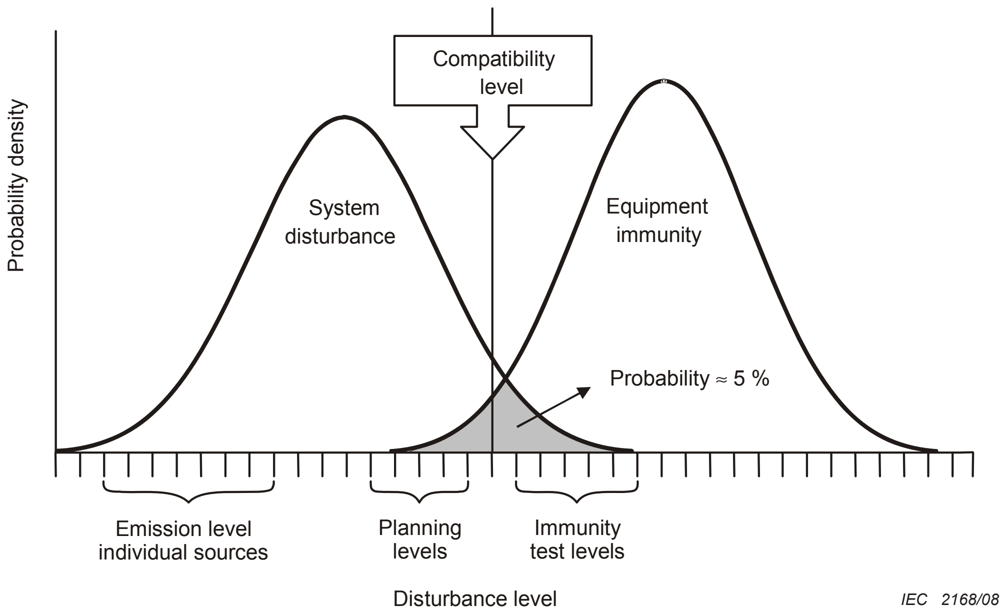


Figure E.1 – Emission/immunity levels and compatibility level, with an example of emission/immunity levels for a single emitter and susceptor, as a function of some independent variables (e.g. burst amplitudes or field strength levels)

For a quantitative description of this situation a compatibility level is introduced and chosen as a kind of reference level for the description of disturbances. Such compatibility levels for the various electromagnetic phenomena are given for example in IEC 61000-2-5. They can be used as a starting point for deriving immunity levels which usually have to be higher levels than the compatibility levels. As a consequence of this situation, electromagnetic compatibility can be achieved only if the emission and immunity levels are controlled such that, at each location, the disturbance level resulting from the cumulative emissions is sufficiently lower than the immunity level for each device, equipment and system situated at the same location. It should, however, be noted that compatibility levels may be phenomenon, time or location dependent.

From the shape of the curves in Figure E.1 it can be concluded that an increasing margin between the compatibility level and the applied immunity level leads to a reduced occurrence of interference situations and therefore to a "better" EMC.

In practice the immunity levels are derived so that the potential overlap between the curve indicating the disturbance levels and the curve indicating the immunity levels is in the range of few percent (typically up to 5 % as shown in Figure E.1). This approach represents a technical/economic compromise which allows specified immunity levels which are not high enough to avoid interference in some cases. The overlap of 5 % does not necessarily mean that there are interferences in 5 % of the installations where these components are used. The resulting probability of interference is normally much lower as explained in Annex A.6 of IEC 61000-1-1.

Theoretically it should be possible to derive immunity levels in such a way that the remaining probability of interference remains below a certain probability. In practice, however, this task cannot be solved in a reasonable way, because:

a) The curves in Figure E.1 show the principal behaviour of the probability of emissions and immunity and the positions of compatibility and immunity levels. These curves are phenomenon, time and/or location dependent. Hence a potential knowledge of such probabilistic density curves for a particular phenomenon at a particular installation cannot be transferred to any other arbitrary electromagnetic phenomenon and installation.

b) The actual knowledge of such probabilistic curves is relatively poor for most electromagnetic phenomena. Indeed, detailed information is available only for few phenomena (as for example for the topic of lightning protection and the area of surge pulses). But also in these cases the knowledge exists more or less regarding the phenomenon itself (in the case of lightning strokes by means of isokeraunic curves), and not so much in the electromagnetic stresses consequently acting upon an equipment.

Even for the case of relatively well known probabilistic curves it can be expected that they are relatively well known in those ranges where their amplitudes are some percent or several tens of percent. This, however, cannot be considered as sufficient when looking at probabilistic requirements as they are defined by the safety integrity levels (SIL). Here the engineers of a safety-related system have to take into account probabilities of 10^{-5} to 10^{-9} failures per hour (see Table 2) for a safety function. This mathematical approach is impossible regarding electromagnetic phenomena as the knowledge of the electromagnetic environment is and will always be insufficient in this respect. For hardware failures data are available, which is not the case for failures due to electromagnetic phenomena.

From these boundary conditions it can be concluded that in most cases there will be no evident and provable way to find a reasonable correlation between the compatibility level of disturbances within an installation, the immunity level for an item of equipment to be installed as a part of a safety-related system in such an installation and the safety integrity level (SIL) to be achieved for the system. Without such a correlation, however, no grading can be established for the immunity levels of equipment in terms of safety integrity level (SIL).

The only practical way to derive appropriate immunity levels is to take into account the particular electromagnetic environment in which the safety-related system is intended to be used and to determine immunity levels for functional safety by means of technical arguments. The compatibility levels can be used only as a kind of basis for deriving the required immunity. Since no probabilistic data can be taken into account, the derived immunity levels are basically applicable for all the safety-related systems in this particular environment, independent of the required safety integrity level (SIL).

An example may illustrate this situation. When considering the phenomenon of immunity against radiated electromagnetic field strengths, two cases result for a particular situation:

a) If the corresponding assessment shows strong RF fields cannot be present during the anticipated lifetime of the safety-related system (for example excluded by means of organisational measures), even considering foreseeable use and misuse, the test levels could be based upon a standard immunity level. This immunity level could be derived for example from a generic standard applicable to the electromagnetic environment under consideration. This only applies to the frequency range covered by the standard used to derive the immunity level. Outside that frequency range, other guidance should be sought (e.g. from other standards). The derived immunity level can be used independent of the particular safety integrity level (SIL) to be established for that installation.

b) If hand held radio transmitters could be used in the close vicinity of relevant equipment, it is the task of the EMC/safety engineer to derive the maximum field strength level produced by such transmitters and to determine the corresponding immunity level to be applied. Normally there will be no reasonable determination of the probability of the occurrence of such field strength levels (they may occur during maintenance, repair or supervision activities, which by their nature cannot be predicted); at least not in such a way to have an evident relation concerning the very low probabilities as allowed for the various safety integrity levels (SIL). Hence the immunity for the equipment has to be derived in such a way that, it is immune against the field strength levels independent of the number of occurrences of these levels and therefore also independent of the required safety integrity level (SIL).

The introduction of such immunity levels, derived by means of technical arguments, can be considered as the simplest possibility to overcome the problems of the unknown statistical and probabilistic parameters. It provides at the same time the maximum confidence that the maximum levels are taken into account. As a further benefit this concept of determining increased immunity levels results in the fact that no safety integrity level (SIL) dependent test levels are required.

Annex F
(informative)

EMC safety planning

F.1 Basic structure

EMC safety planning is a structured process with several steps and activities. The basic structure as well as its relation to the safety assurance process can be demonstrated by the diagram in Figure F.1.

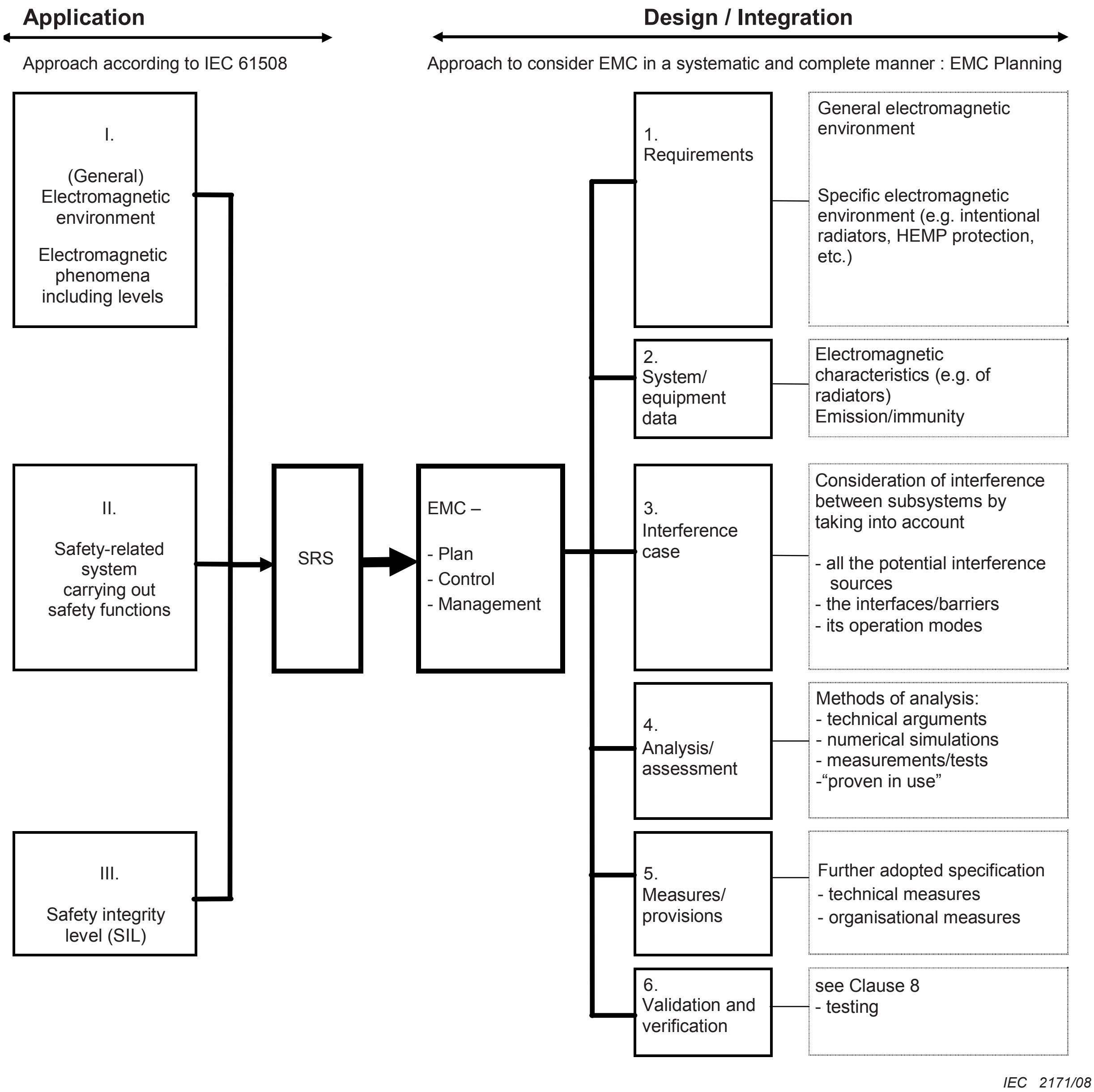


Figure F.1 – EMC safety planning for safety-related systems

F.2 Requirements

The type/character of the electromagnetic environment in which the safety-related system is intended to be operated represents one of the basic inputs into the safety requirements specification (SRS), which then continues into the technical requirement specifications for the system and for all of the equipment within it.

Depending on the electromagnetic phenomena and their levels which are identified to be relevant for this environment, corresponding immunity tests and immunity levels can be derived and associated with appropriate performance criteria for the equipment. This results in one or more equipment requirement specifications for equipment intended to be used in the safety-related system. Fulfilment of the equipment requirement specification represents a precondition for the achievement of functional safety for the integration of the equipment into the safety-related system.

NOTE It may be necessary to apply additional electromagnetic mitigation measures to products to comply with the equipment requirements specification (ERS) identified during the process of EMC safety planning.

In many cases a general description of the electromagnetic environment is all that is required to derive the immunity requirements for the equipment requirements specifications (ERS). However, in some cases this general description may have to be modified due to the presence of particular equipment (e.g. ISM group 2 equipment) or due to equipment planned to be installed in the future. Either of these could result in a modified electromagnetic environment.

Therefore it has to be determined whether the actual electromagnetic environment differs from the general one with respect to some particular electromagnetic phenomena. This consideration may lead to particular immunity requirements on system as well as on equipment level, and/or to mitigation measures to reduce emissions or to improve immunity.

F.3 System/equipment data

In order to assess and to ensure that the resultant configuration will be electromagnetically immune against potential disturbances produced by the system and all its equipment (internal EMC) as well as by systems and equipment in the external electromagnetic environment: all items of equipment shall be identified and described in terms of EMC aspects. This description may partly be based on site surveys, technical specifications, experience, etc. Potential interference sources, coupling mechanisms, and interfaces shall be identified and described as well.

F.4 EMC matrix

On the basis of the identified equipment, a matrix shall be created that reflects all potential interference situations between all of the items of equipment and/or products, both within the system and external to the system. Within this matrix all operational modes and all types of coupling shall be considered.

F.5 Analysis/assessment

All cases of potential interference revealed by the EMC matrix shall be analysed and assessed in a systematic manner. Furthermore, criteria may be defined which indicate to what extent and depth each individual analysis has to be performed.

F.6 Measures/provisions

Beside the fact that the equipment shall be specified to be in compliance with immunity requirements, measures might need to be applied in order to ensure immunity on the system level. In the event that the analysis and assessment show that harmful interference is expected to take place, additional mitigation measures shall be applied to prevent this.

It shall be noted that corresponding measures should not be restricted to increase the immunity only. In particular cases it might be more convenient to apply measures to an interference source.

F.7 Validation/verification

For the safety-related system, compliance with the safety requirements specification (SRS) has to be demonstrated (see Clause 8). This can be done by means of an EMC test plan for the system.

Bibliography

General documents concerning functional safety

IEC Guide 107:1998, *Electromagnetic compatibility – Guide to the drafting of electromagnetic compatibility publications*

Technical information on functional safety

LIMNIOS, N. *Arbres de défaillances.* Paris: Editions Hermès, 1991. 183 p. (Handbook)

Guidance document on EMC and Functional Safety, The IET, http://www.theiet.org/factfiles/EMC/index.cfm,

BROWN SJ. EMC and Safety related Systems. *Proceedings of the IEE International Conference on EMC,* Coventry 1997

JAEKEL, Bernd. Considerations on immunity test levels and methods with regard to functional safety. In LEWANDOWSKI, G. and JANISZEWSKI, JM (ed.). Electromagnetic Compatibility 2006. Wroclaw: Oficyna Wydawnicza Politechniki Wroclawskiej, 2006, p. 187-192, ISBN 83-7085-947-X

ARMSTRONG, Keith. *Why EMC Immunity Testing is Inadequate for Functional Safety*, 2004 IEEE International EMC Symposium, Santa Clara, California, USA, August 9-13 2004, ISBN 0-7803-8443-1, pp 145-149. Also published in Conformity, March 2005, pp 15-23, http://www.conformity.com

ARMSTRONG, Keith. *Design and Mitigation Techniques for EMC for Functional Safety*, 2006 IEEE International EMC Symposium, 14-18 August 2006, Portland, Oregon, USA, ISBN: 1-4244-0294-8.

Parker, W H, Tustin, W and Masone, T. *The Case for Combining EMC and Environmental Testing*, ITEM 2002 pp 54-60, http://www.interferencetechnology.com

BROWN, Simon and RADASKY, William. *Functional Safety and EMC*, IEC Advisory Committee on Safety (ACOS) Workshop VII, Frankfurt am Main, Germany March 9/10 2004.

WILLIAMS, Tim and ARMSTRONG, Keith. *EMC for Systems and Installations*, Newnes, 2000, ISBN: 0-7506-4167-3

Other publications

IEC 60050(191), *International Electrotechnical Vocabulary (IEV) – Chapter 191: Dependability and quality of service*

IEC 60364-1, *Low-voltage electrical installations – Part 1: Fundamental principles, assessment of general characteristics, definitions*

IEC 61000-1-1, *Electromagnetic compatibility (EMC) – Part 1: General – Section 1: Application and interpretation of fundamental definitions and terms*

IEC 61000-1-5, *Electromagnetic compatibility (EMC) – Part 1-5: General – High power electromagnetic (HPEM) effects on civil systems*

IEC 61000-2 (all parts), *Electromagnetic compatibility (EMC) – Part 2: Environment*

IEC 61000-2-3, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 3: Description of the environment – Radiated and non-network-frequency-related conducted phenomena*

IEC 61000-2-4, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 4: Compatibility levels in industrial plants for low-frequency conducted disturbances*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electrical fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-8, *Electromagnetic compatibility (EMC) – Part 4-8: Testing and measurement techniques – Power frequency magnetic field immunity test*

IEC 61000-4-9, *Electromagnetic compatibility (EMC) – Part 4-9: Testing and measurement techniques – Pulse magnetic field immunity test*

IEC 61000-4-10, *Electromagnetic compatibility (EMC) – Part 4-10: Testing and measurement techniques – Damped oscillatory magnetic field immunity test*

IEC 61000-4-11, *Electromagnetic compatibility (EMC) – Part 4-11: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations immunity tests*

IEC 61000-4-12, *Electromagnetic compatibility (EMC) – Part 4-12: Testing and measurement techniques – Ring wave immunity test*

IEC 61000-4-13, *Electromagnetic compatibility (EMC) – Part 4-13: Testing and measurement techniques – Harmonics and interharmonics including mains signalling at a.c. power port, low frequency immunity tests*

IEC 61000-4-16, *Electromagnetic compatibility (EMC) – Part 4-16: Testing and measurement techniques – Test for immunity to conducted, common mode disturbances in the frequency range 0 Hz to 150 kHz*

IEC 61000-4-18, *Electromagnetic compatibility (EMC) – Part 4-18: Testing and measurement techniques – Damped oscillatory wave immunity test*

IEC 61000-4-23, *Electromagnetic compatibility (EMC) – Part 4-23: Testing and measurement techniques – Test methods for protective devices for HEMP and other radiated disturbances*

IEC 61000-4-24, *Electromagnetic compatibility (EMC) – Part 4-24: Testing and measurement techniques – Test methods for protective devices for HEMP conducted disturbance*

IEC 61000-4-25, *Electromagnetic compatibility (EMC) – Part 4-25: Testing and measurement techniques – HEMP immunity test methods for equipment and systems*

IEC 61000-4-27, *Electromagnetic compatibility (EMC) – Part 4-27: Testing and measurement techniques – Unbalance, immunity test*

IEC 61000-4-28, *Electromagnetic compatibility (EMC) – Part 4-28: Testing and measurement techniques – Variation of power frequency, immunity test*

IEC 61000-4-29, *Electromagnetic compatibility (EMC) – Part 4-29: Testing and measurement techniques – Voltage dips, short interruptions and voltage variations on d.c. input power port immunity tests*

IEC/TR 61000-5-1, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 1: General considerations – Basic EMC publication*

IEC/TR 61000-5-2, *Electromagnetic Compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 2: Earthing and cabling*

IEC 61000-5-6: *Electromagnetic Compatibility (EMC) – Part 5-6: Installation and mitigation guidelines – Mitigation of external electromagnetic influences*

IEC 61000-6-1, *Electromagnetic compatibility (EMC) – Part 6-1: Generic standards – Immunity for residential, commercial and light-industrial environments*

IEC 61000-6-2, *Electromagnetic compatibility (EMC) – Part 6-2: Generic standards – Immunity for Industrial environments*

IEC 61000-6-3, *Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments*

IEC 61000-6-4, *Electromagnetic compatibility (EMC) – Part 6-4: Generic standards – Emission standard for industrial environments*

IEC 61000-6-5: *Electromagnetic compatibility (EMC) – Part 6-5: Generic standards – Immunity for power station and substation environments*

IEC 61508-3, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 3: Software requirements*

IEC 61508-5, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 5: Examples of methods for the determination of safety integrity levels*

IEC 61508-6, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 6: Guidelines on the application of IEC 61508-2 and IEC 61508-3*

IEC 61508-7, *Functional safety of electrical/electronic/programmable electronic safety-related systems – Part 7: Overview of techniques and measures*

ISO/IEC Guide 51:1999, *Safety aspects – Guidelines for their inclusion in standards*

ISO/IEC 2382-14, *Information technology – Vocabulary – Part 14: Reliability, maintainability and availability*

ISO 7137:1995, *Aircraft – Environmental conditions and test procedures for airborne equipment*

ISO 7637 (all parts), *Road vehicles – Electrical disturbances from conduction and coupling*

ISO 10605, *Road vehicles – Test methods for electrical disturbances from electrostatic discharges*

ISO 11451 (all parts), *Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy*

ISO 11452 (all parts), *Road vehicles – Component test method for electrical disturbances from narrowband radiated electromagnetic energy*

ISO 14302:2002, *Space systems – Electromagnetic compatibility requirements*

EN 50174-2: *Information technology – Cabling installation – Part 2: Installation planning and practices inside buildings*

EN 50174-3: *Information technology – Cabling installation – Part 3: Installation planning and practices outside buildings*

This page deliberately left blank

British Standards Institution (BSI)

BSI is the independent national body responsible for preparing British Standards. It presents the UK view on standards in Europe and at the international level.

It is incorporated by Royal Charter.

Revisions

British Standards are updated by amendment or revision. Users of British Standards should make sure that they possess the latest amendments or editions.

It is the constant aim of BSI to improve the quality of our products and services. We would be grateful if anyone finding an inaccuracy or ambiguity while using this British Standard would inform the Secretary of the technical committee responsible, the identity of which can be found on the inside front cover.

Tel: +44 (0)20 8996 9000 Fax: +44 (0)20 8996 7400

BSI offers members an individual updating service called PLUS which ensures that subscribers automatically receive the latest editions of standards.

Buying standards

Orders for all BSI, international and foreign standards publications should be addressed to BSI Customer Services.

Tel: +44 (0)20 8996 9001 Fax: +44 (0)20 8996 7001
Email: orders@bsigroup.com

You may also buy directly using a debit/credit card from the BSI Shop on the website **www.bsigroup.com/shop**

In response to orders for international standards, it is BSI policy to supply the BSI implementation of those that have been published as British Standards, unless otherwise requested.

Information on standards

BSI provides a wide range of information on national, European and international standards through its Library.

Various BSI electronic information services are also available which give details on all its products and services. Contact the Information Centre.

Tel: +44 (0)20 8996 7111
Fax: +44 (0)20 8996 7048 Email: info@bsigroup.com

Subscribing members of BSI are kept up to date with standards developments and receive substantial discounts on the purchase price of standards. For details of these and other benefits contact Membership Administration.

Tel: +44 (0)20 8996 7002 Fax: +44 (0)20 8996 7001
Email: membership@bsigroup.com

Information regarding online access to British Standards via British Standards Online can be found at **www.bsigroup.com/BSOL**

Further information about BSI is available on the BSI website at **www.bsigroup.com**

Copyright

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

Tel +44 (0)20 8996 9001
Fax +44 (0)20 8996 7001
www.bsigroup.com/standards

raising standards worldwide™

British Standards