



BSI Standards Publication

# Electromagnetic compatibility (EMC) —

Part 5-9: Installation and mitigation guidelines – System-level susceptibility assessments for HEMP and HPEM

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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.

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# TECHNICAL SPECIFICATION

BASIC EMC PUBLICATION

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**Electromagnetic compatibility (EMC) –  
Part 5-9: Installation and mitigation guidelines – System-level susceptibility  
assessments for HEMP and HPEM**

INTERNATIONAL  
ELECTROTECHNICAL  
COMMISSION

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## CONTENTS

|                                                                                           |    |
|-------------------------------------------------------------------------------------------|----|
| FOREWORD.....                                                                             | 5  |
| INTRODUCTION.....                                                                         | 7  |
| 1 Scope.....                                                                              | 8  |
| 2 Normative references .....                                                              | 8  |
| 3 Terms and definitions .....                                                             | 9  |
| 4 General .....                                                                           | 11 |
| 4.1 Introduction .....                                                                    | 11 |
| 4.2 Systems and subsystems .....                                                          | 12 |
| 5 Interaction mechanisms and protection methods .....                                     | 13 |
| 5.1 General.....                                                                          | 13 |
| 5.2 Front-door coupling .....                                                             | 13 |
| 5.3 Back-door coupling.....                                                               | 13 |
| 5.4 Protection methods .....                                                              | 14 |
| 6 Description of overall assessment methodology .....                                     | 14 |
| 6.1 Methodology.....                                                                      | 14 |
| 6.2 Subsystems and equipment characterization phase.....                                  | 16 |
| 6.3 System analysis phase .....                                                           | 17 |
| 6.4 System test phase.....                                                                | 17 |
| 6.4.1 General .....                                                                       | 17 |
| 6.4.2 Low-level tests .....                                                               | 18 |
| 6.4.3 High-level testing.....                                                             | 18 |
| 6.5 Susceptibility assessment phase .....                                                 | 20 |
| 6.6 The use of reverberation chambers to characterise immunity .....                      | 20 |
| Annex A (informative) Classification of effect.....                                       | 24 |
| Annex B (informative) Good measurement practice.....                                      | 27 |
| Annex C (informative) Computational electromagnetics .....                                | 30 |
| Annex D (informative) System level assessment – HEMP .....                                | 33 |
| Annex E (informative) System level assessment – HPEM .....                                | 35 |
| Annex F (informative) Limitations.....                                                    | 39 |
| Annex G (informative) Detailed description of low-level techniques.....                   | 42 |
| Annex H (informative) Detailed description of high-level test techniques.....             | 54 |
| Annex I (informative) Data processing and analysis .....                                  | 61 |
| Bibliography.....                                                                         | 66 |
| Figure 1 – Example system architecture .....                                              | 12 |
| Figure 2 – Example of radiated HPEM at high frequencies [3].....                          | 14 |
| Figure 3 – Methodology flowchart .....                                                    | 15 |
| Figure 4 – Reverberation chamber results: all effects.....                                | 21 |
| Figure 5 – Reverberation chamber results: susceptibilities.....                           | 22 |
| Figure 6 – Frequency spectrum of several HPEM sources .....                               | 23 |
| Figure A.1 – Classification of effect.....                                                | 24 |
| Figure B.1 – Effect of adding ferrites to connecting cable: swept frequency example ..... | 27 |

|                                                                                                                                                                                                    |    |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----|
| Figure B.2 – Effect of adding ferrite to connecting cable: reverberation chamber example .....                                                                                                     | 28 |
| Figure B.3 – Effect of adding ferrite to connecting cable: transient example (time domain) .....                                                                                                   | 28 |
| Figure B.4 – Effect of adding ferrite to connecting cable: transient example (frequency domain) .....                                                                                              | 29 |
| Figure E.1 – Steps taken in the system assessment .....                                                                                                                                            | 36 |
| Figure E.2 – Maximum free-space separation distances.....                                                                                                                                          | 38 |
| Figure E.3 – Critical regions for permanent damage.....                                                                                                                                            | 38 |
| Figure G.1 – Electromagnetic interaction sequence diagram for a facility illuminated by an external antenna .....                                                                                  | 43 |
| Figure G.2 – Illustration of the difference of a directed, narrow-beam antenna exciting the facility with a spot beam, along with a plane wave providing illumination to the entire facility ..... | 45 |
| Figure G.3 – Measurement equipment and configuration for measuring transient responses in a buried facility, as reported by [G-6] .....                                                            | 47 |
| Figure G.4 – Example of a measured transient cable current (a) and the resulting spectral magnitude, as computed by a Fourier transform (b) .....                                                  | 48 |
| Figure G.5 – Plots of the analytical pulser output open circuit voltage waveform (a) and spectral magnitude (b), which are used as reference for computing the transfer function $T_{SC}$ .....    | 48 |
| Figure G.6 – The radiated E-field from the IRA at a distance of 6 meters for the analytical pulser excitation (a) and the resulting spectral magnitude (b).....                                    | 49 |
| Figure G.7 – The spectral magnitude of the computed transfer function $T_{SC}$ (a) and the corresponding transient transfer function (b).....                                                      | 49 |
| Figure G.8 – The spectral magnitude of the computed transfer function $T_{EC}$ (a) and the corresponding transient transfer function (b).....                                                      | 50 |
| Figure G.9 – LLCW reference field measurement.....                                                                                                                                                 | 51 |
| Figure G.10 – LLCW induced current measurement .....                                                                                                                                               | 51 |
| Figure G.11 – Typical magnitude-only transfer function.....                                                                                                                                        | 52 |
| Figure H.1 – Microwave injection testing of a low noise amplifier, LNA [H-2]. LNA at the tip of the arrow.....                                                                                     | 54 |
| Figure H.2 – Aircraft testing at the Swedish Microwave Test Facility, MTF [H-3] .....                                                                                                              | 55 |
| Figure H.3 – Measured shielding effectiveness of an equipment compared to the MTF test frequencies (dashed bars) [3].....                                                                          | 56 |
| Figure H.4 – Reverberation chamber .....                                                                                                                                                           | 58 |
| Figure I.1 – Prediction of induced current using magnitude-only transfer functions [I-1] .....                                                                                                     | 61 |
| Figure I.2 – IEC 61000-2-9 HEMP Waveform .....                                                                                                                                                     | 62 |
| Figure I.3 – Convolution process.....                                                                                                                                                              | 62 |
| Figure I.4 – Predicted induced current .....                                                                                                                                                       | 63 |
| Figure I.5 – Comparison of transfer function predictions with simulator measurements .....                                                                                                         | 64 |
| Figure I.6 – Extrapolation of measured transients .....                                                                                                                                            | 65 |

Table A.1 – Categorisation of effect by criticality.....25

Table A.2 – Categorisation of effect duration .....26

Table A.3 – Combination of criticality level and duration category .....26

Table I.1 – Comparison of transfer function predictions and simulator measured  
currents .....63

## INTERNATIONAL ELECTROTECHNICAL COMMISSION

**ELECTROMAGNETIC COMPATIBILITY (EMC) –****Part 5-9: Installation and mitigation guidelines –  
System-level susceptibility assessments for HEMP and HPEM**

## FOREWORD

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

IEC/TS 61000-5-9, which is a technical specification, has been prepared by subcommittee 77C: High power transient phenomena, of IEC technical committee 77: Electromagnetic compatibility.

This Technical Specification forms Part 5-9 of IEC 61000. It has the status of a basic EMC publication in accordance with IEC Guide 107 [1]<sup>1</sup>.

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

|               |                  |
|---------------|------------------|
| Enquiry draft | Report on voting |
| 77C/190/DTS   | 77C/194/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.

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<sup>1</sup> Figures in square brackets refer to the Bibliography.

## 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 (in so far 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 and published either as International Standards or as 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 a second number identifying the subdivision (example: IEC 61000-6-1).

## ELECTROMAGNETIC COMPATIBILITY (EMC) –

### Part 5-9: Installation and mitigation guidelines – System-level susceptibility assessments for HEMP and HPEM

#### 1 Scope

The aim of this part of IEC 61000 is to present a methodology to assess the impact of High-altitude Electromagnetic Pulse (HEMP) and High Power Electromagnetic (HPEM) environments on electronic systems. In this context a system refers to a collection of sub-systems, equipment and components brought together to perform a function. (A more complete definition is given in 3.20.) The techniques associated with this methodology and their advantages and disadvantages will be presented along with examples of how the techniques can be applied to evaluate the susceptibility of electronic systems such as those found in installations. This work is closely related to the evaluation of EMC system level susceptibility.

The purpose of this Technical Specification is to provide information on available methods for the assessment of system-level susceptibility as a result of HEMP and HPEM environments. The advantages and disadvantages of the methods will be discussed along with examples of how the techniques should be employed.

Typical systems have external connections, wired or wireless, and the assessment of these are included within this specification.

This specification gives general guidance. It does not cover safety issues nor does it conflict with ITU-T efforts concerning the protection of telecommunications equipment [2]<sup>2</sup>.

#### 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 – Chapter 161: Electromagnetic compatibility*

IEC/TR 61000-1-5:2004, *Electromagnetic compatibility (EMC) – Part 1-5: General – High power electromagnetic (HPEM) effects on civil systems*

IEC 61000-2-9:1996, *Electromagnetic compatibility (EMC) – Part 2: Environment – Section 9: Description of HEMP environment – Radiated disturbance. Basic EMC publication*

IEC 61000-2-10:1998, *Electromagnetic compatibility (EMC) – Part 2-10: Environment – Description of HEMP environment – Conducted disturbance*

IEC 61000-2-13:2005, *Electromagnetic compatibility (EMC) – Part 2-13: Environment – High-power electromagnetic (HPEM) environments – Radiated and conducted*

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<sup>2</sup> Figures in square brackets refer to the Bibliography.

IEC/TR 61000-4-32:2002, *Electromagnetic compatibility (EMC) – Part 4-32: Testing and measurement techniques – High-altitude electromagnetic pulse (HEMP) simulator compendium*

IEC 61000-4-33:2005, *Electromagnetic compatibility (EMC) – Part 4-33: Testing and measurement techniques – Measurement methods for high-power transient parameters*

IEC 61000-4-35:2009, *Electromagnetic compatibility (EMC) – Part 4-35: Testing and measurement techniques – HPEM simulator compendium*

IEC/TR 61000-5-3:1999, *Electromagnetic compatibility (EMC) – Part 5-3: Installation and mitigation guidelines – HEMP protection concepts*

IEC/TS 61000-5-4:1996, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 4: Immunity to HEMP – Specifications for protective devices against HEMP radiated disturbance. Basic EMC Publication*

IEC 61000-5-5:1996, *Electromagnetic compatibility (EMC) – Part 5: Installation and mitigation guidelines – Section 5: Specification of protective devices for HEMP conducted disturbance. Basic EMC Publication*

IEC/TR 61000-5-6:2002, *Electromagnetic compatibility (EMC) – Part 5-6: Installation and mitigation guidelines – Mitigation of external EM influences*

IEC 61000-5-7:2001, *Electromagnetic compatibility (EMC) – Part 5-7: Installation and mitigation guidelines – Degrees of protection provided by enclosures against electromagnetic disturbances (EM code)*

### 3 Terms and definitions

For the purposes of this document the terms and definitions of IEC 60050-161 as well as the following apply.

#### 3.1

##### **aperture coupling regime**

frequency range where aperture coupling dominates; this is typically between 200 MHz to 18 GHz

#### 3.2

##### **back-door coupling**

coupling of EM energy to equipment via connecting cables or apertures (not via antennas or sensors)

NOTE Detailed discussion of back-door coupling can be found in Clause 5.

#### 3.3

##### **cable coupling regime**

frequency range where cable coupling dominates; this is typically between 500 kHz and 400 MHz

#### 3.4

##### **coupling**

transfer of electromagnetic energy from source to victim

#### 3.5

##### **E/E/PE equipment**

equipment that employs electrical, electronic or programmable electronic technologies

**3.6****equipment**

general designation which includes modules, devices, apparatuses, subsystems, complete systems and installations

**3.7****equipment under test****EUT**

refers to the equipment being tested

**3.8****front-door coupling**

coupling of EM energy to equipment via antennas and/or sensors

NOTE Detailed discussion of front-door coupling can be found in Clause 5.

**3.9****HEMP**

High-altitude Electromagnetic Pulse

**3.10****high-level illumination****HLI**

use of high-level ( $>100$  V/m) signals to assess the immunity or susceptibility

**3.11****HPEM**

High Power Electromagnetic

**3.12****immunity**

ability of a device equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[IEV 161-01-20]

**3.13****installation**

combination of apparatuses, components and systems assembled and/or erected (individually) in a given area

NOTE For physical reasons (e.g. long distances between individual items) it is in many cases not possible to test an installation as a unit.

**3.14****low-level continuous wave****LLCW**

use of low-level signals (typically  $<1$  V/m) to characterise the coupling of an external electromagnetic environment to an internally induced current, voltage or field (magnetic or electric)

**3.15****margin**

usually expressed in dB, this is the amount added to a result to improve confidence or to allow for uncertainties

**3.16****norm**

mathematical function used to describe a parameter of a waveform; several norms can be used to describe the 'uniqueness' of a waveform

**3.17****pulsed current injection****PCI**

use of current injection methods to assess the immunity or susceptibility with a pulsed waveform as opposed to more traditional continuous wave (CW) signals

**3.18****surface current injection****SCI**

injection of current directly on to the surface of an equipment box or system skin

**3.19****susceptibility**

inability of a device, equipment or system to perform without degradation in the presence of an electromagnetic disturbance

[IEV 161-01-21]

**3.20****system**

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

**4 General****4.1 Introduction**

HEMP occurs as a result of a high-altitude nuclear explosion and can cover several millions of square kilometres with electric field strengths of up to tens of kV/m. Further discussion of HEMP can be found in IEC 61000-2-9 and IEC 61000-2-10.

HPEM is the collective name given to a set of high power radio frequency (RF) sources that are capable of generating high levels of RF at ranges <1 km. The waveforms generated by these types of sources vary and include Ultra Wideband (UWB), Damped Sine (DS) also known as Non-Nuclear EMP (N2EMP) and High power Microwave (HPM). Further discussion of these sources can be found in IEC 61000-2-13.

This specification discusses methods available for the assessment of systems as defined in 4.2 (not distributed civil infrastructure<sup>3</sup>) to the effects of HEMP and HPEM. Typical system examples are vehicles, aircraft and small ships. The techniques can be applied to larger systems such as buildings, however, with careful consideration.

The assessment methodology discussed in this specification is not appropriate for geographically large connected or distributed systems. However, the techniques may be applicable to individual components, equipments, subsystems or systems contained within a large connected or distributed system.

The assessment methodology may be used to determine the status of a particular system with respect to its hardening to HEMP and/or HPEM environments.

<sup>3</sup> Distributed civil infrastructure is discussed in IEC 61000-5-8.

It is important to note that the assessment methodology presented within this specification should help to assist in reducing the risk of detrimental system performance due to exposure to HEMP and HPEM environments. This methodology can be applied during the design and development phases of a system. A full system-level test using the HEMP or HPEM environment of interest is an important part of this methodology. Information on worldwide HEMP and HPEM simulators can be found in IEC 61000-4-32 and IEC 61000-4-35 respectively.

#### 4.2 Systems and subsystems

In the context of this specification, a system may consist of several subsystems which are each comprised of several equipments which, in turn, consist of several components. Figure 1 shows a typical system architecture.

A system can also be considered to be a set of **supplied equipments** located within a **defined physical boundary** that are **interconnected** in order to perform a defined function.

The defined physical boundary may be

- the outer hull (for systems located on military platforms – vehicles, aircraft and ships),
- the outer building wall (for systems located within buildings).

The **interconnection** may be either

- wireline (using either metallic or optical cables),
- or wireless,

and the interconnection is made for the purpose of either

- exchanging information,
- or receiving or supplying electrical power.

Any physical connection (i.e. wireline or wireless) with supplied equipment that does not originate from within the system's defined physical boundary is an **interface**. Interfaces may be permanent (in the case of buildings, where a permanent connection with wireline power and telecommunications infrastructure can be expected) or temporary (in the case of military platforms, where the inherent mobility of the platform prevents permanent wireline interfacing).

Individual **supplied** pieces of **equipment** may themselves be individual systems (i.e. subsystems, or sub-subsystems, and so forth) that should themselves have been subject to the methods contained within this specification.

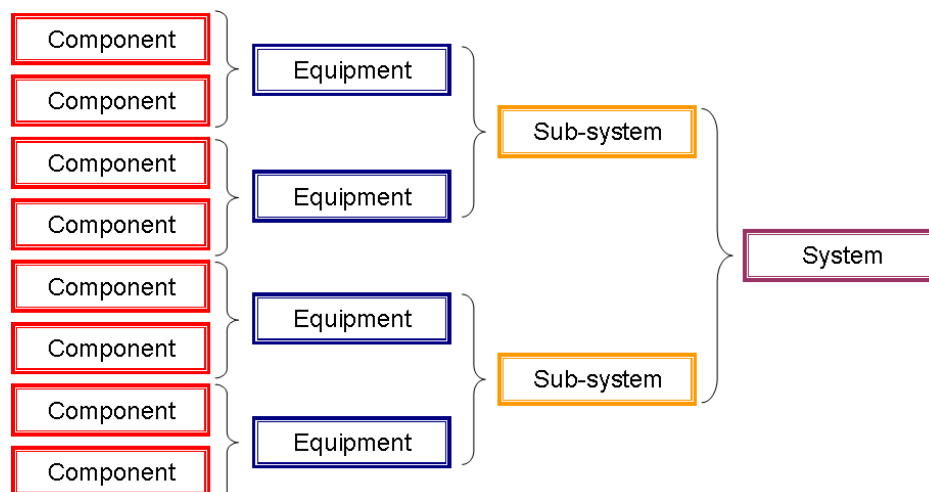


Figure 1 – Example system architecture

For example, a vehicle (system) may consist of an engine management unit (subsystem) which consists of circuit boards (equipment) and integrated circuits (component).

## 5 Interaction mechanisms and protection methods

### 5.1 General

Within IEC 61000-1-5, the terms deliberate penetration and inadvertent penetration are used to describe the penetration of EM energy into a system. This specification uses the terms back-door coupling and front-door coupling (see Figure 2) since they better relate to the fundamental difference that exists regarding the possibility to protect a system without degrading its function. While careful back-door shielding should not degrade the function of a system at all, protection against in-band front-door coupling may degrade the function of the system.

### 5.2 Front-door coupling

The radiation couples to equipment ports intended for wireless communication or other interaction with the external environment. Hence, they cannot easily be fully shielded against electromagnetic radiation without loosing or severely degrading their function. Examples are antennas and sensors.

Front-door coupling can be subdivided into first and second order, as follows.

a) Front-door coupling, first order (in-band)

The frequency of the radiation coincides, at least partly, with the working frequency of the equipment. An example is a telecom base-station irradiated in its pass band.

b) Front-door coupling, second order (out-of-band)

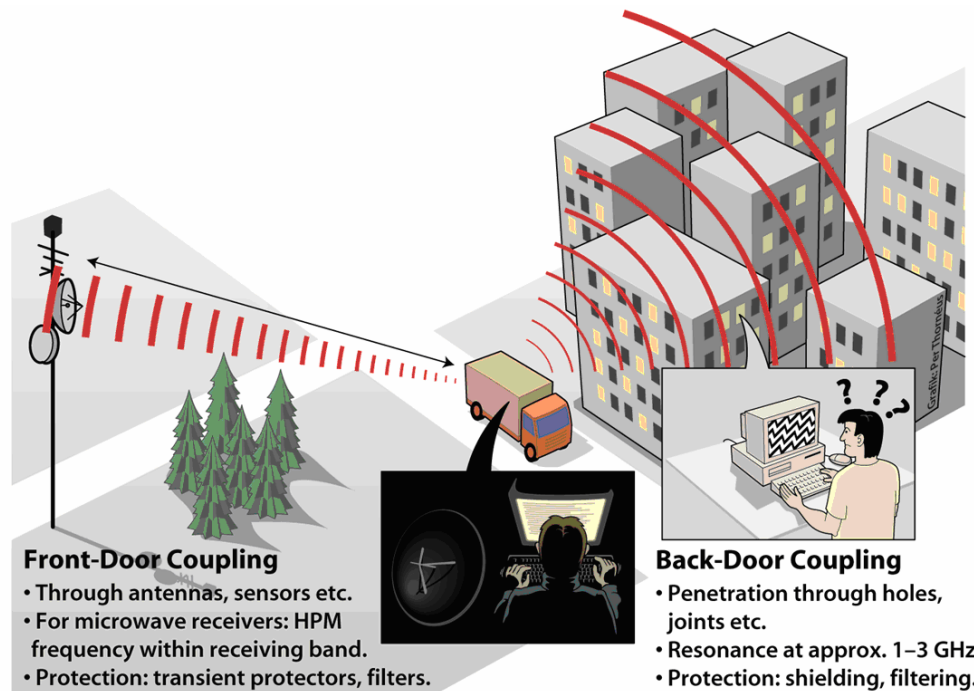
The frequency of the radiation does not coincide with the working frequency of the equipment. An example is a HF radio antenna exposed to high power microwaves.

### 5.3 Back-door coupling

The radiation couples to electronic circuits through imperfections (apertures) in the electromagnetic shield enclosing the electronics, or directly to the electronic circuit boards. In the case of a shielded structure this leakage gives rise to a diffuse and complex field pattern within the structure. The apertures can be unintentional or intentional. An example of the former is a paint, or an oxide, layer in a shielding joint between conductive surfaces. Examples of the latter are holes for drainage or ventilation. The radiation may also couple directly to an external wire connected to a component or a subsystem [3]. The reason to define such a wire as back-door coupling and not as a second-order front-door coupling is motivated by the fact that the wire could be shielded without degrading the function of the equipment.

It is important to note that HEMP or HPEM disturbances can be radiated or conducted in nature. It follows therefore, that the source of the front-door or back-door coupling can be radiated or conducted in nature. It should be noted that conducted disturbances cannot only be out-of-band but also occur under normal operating conditions (in-band and out-of-band). Examples of this include transient overvoltages much higher than the voltage under normal operation or surge currents flowing in a system.

This specification deals mainly with back-door coupling although some attention is given to front-door coupling in Annex H.



The van in the centre of the picture contains the HPEM source.

**Figure 2 – Example of radiated HPEM at high frequencies [3]**

#### 5.4 Protection methods

**Front-door coupling:** While in-band disturbances are difficult to neutralize, permanent damage effects can be mitigated by use of transient protectors. Out-of-band disturbances, that is, second-order front-door coupling, can be handled by use of filtering, for example for radio equipment, or by use of metallic meshes or thin films for optical equipment. Often, protective measures will lead to some degradation of the intended function of the system.

**Back-door coupling:** Use of conventional EMC protection techniques, such as shielding and filtering, should suffice to achieve a 30 dB protection level [4], which should be sufficient for the HPEM threat (although not for the military HPM threat). Transient protection devices may be required to protect filters from high-voltage transients and should be carefully combined with filters to increase the level of protection.

An alternative way of considering protection is based on the type of HEMP or HPEM disturbance to be protected against. Radiated disturbances can be mitigated by the use of shielding and conducted disturbances can be mitigated by the use of transient protection devices and filters.

Detailed information on protection methods can be found in IEC/TR 61000-5-3, IEC/TS 61000-5-4, IEC 61000-5-5, IEC/TR 61000-5-6 and IEC 61000-5-7.

## 6 Description of overall assessment methodology

### 6.1 Methodology

This clause discusses the overall assessment methodology.

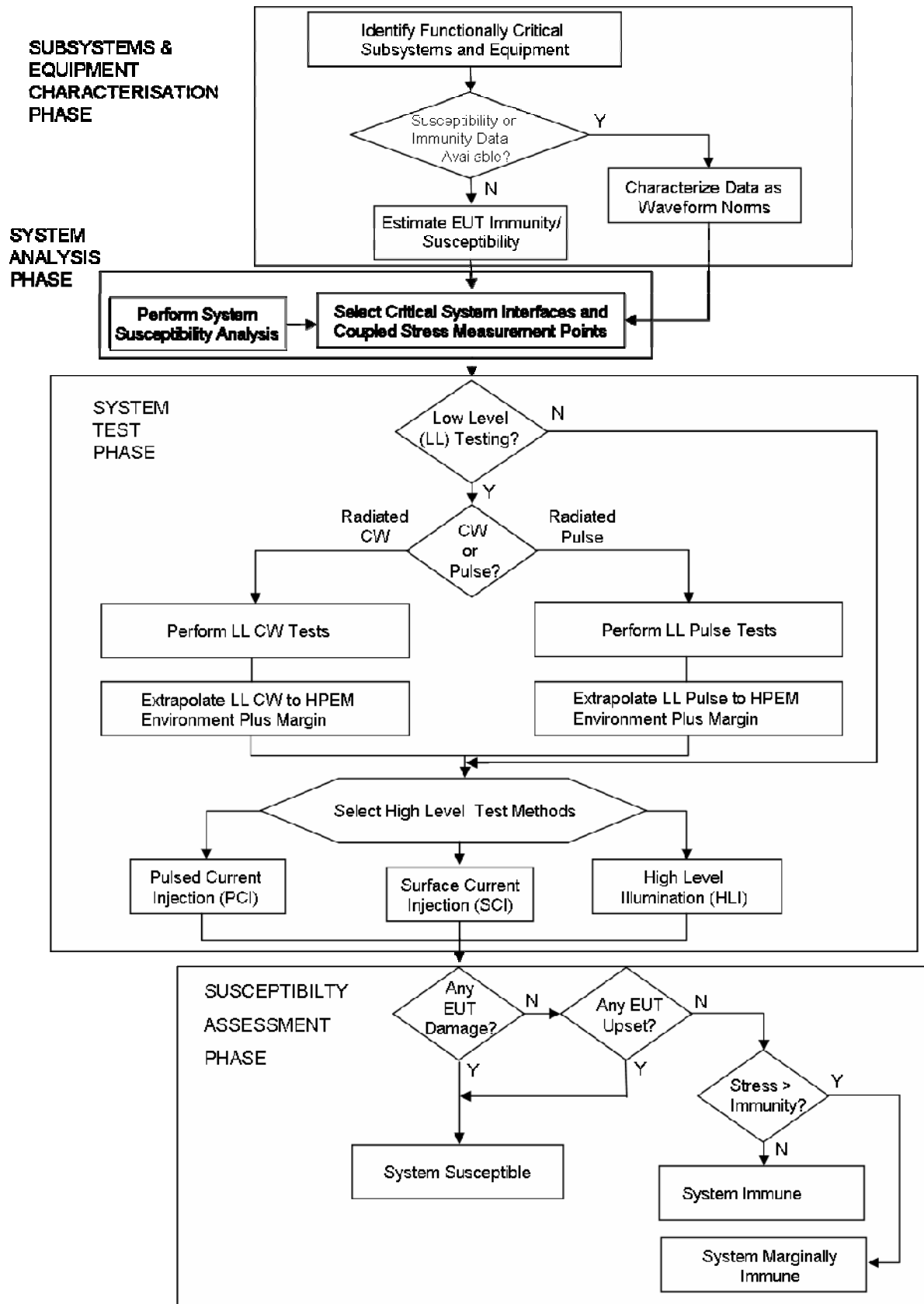


Figure 3 – Methodology flowchart

## 6.2 Subsystems and equipment characterization phase

Characterization of the subsystems and equipment shall be completed prior to any detailed evaluation or assessment. At this stage, it is essential that functional and topological descriptions of the system are generated to allow for critical aspects of the system to be identified.

A functional description deals with the intentional flow of information within the system that is the information flow for decision-making and responses from the intentional external interface throughout the system.

A topological description deals with;

- a) the physical units that correspond to each function within the functional description (i.e. the individual boxes, cards or units),
- b) the intended physical interconnections between the physical electronics (i.e. cabling),
- c) the relative location of each physical unit and intended physical interconnection. This allows an assessment to be made of the relative importance of the three fundamental interactions: box-to-box, cable-to-box and box-to-cable radiation.

Together, functional and topological descriptions allow the propagation of front-door and back-door coupling within the system to be understood and hence hardening strategies to be developed. In addition, these descriptions will enable the impact of any HEMP or HPEM induced effect to be correctly assigned as either immunity or susceptibility during the susceptibility assessment phases. Also, areas of potential weakness should be identified based upon information about similar systems or technology types.

During this phase it is necessary to gather immunity and/or susceptibility information that may be relevant. This should be obtained from electromagnetic compatibility (EMC) test data. If waveforms associated with susceptibilities are available, waveform norms that allow parameters of waveforms to be mathematically quantified should be computed for later use. Further details on the use of waveform norms can be found in IEC 61000-4-33, Annex A [5].

A typical subsystem and equipment characterization will breakdown the system into its component subsystems and equipments. Each of these subsystems and pieces of equipment will then be assessed for coupling paths relevant to the frequency density of the illuminating HEMP or HPEM environment of interest. This is performed by translation of the frequency content of the illuminating environment into wavelengths by using the simple expression given in Equation (1).

$$c = f\lambda \quad (1)$$

where

$c$  is the speed of light in a vacuum ( $3 \times 10^8$  m/s),

$f$  is the frequency (Hz),

$\lambda$  is the wavelength (m).

Depending on the type of coupling path, frequencies corresponding to a wavelength of  $L/2$  or  $L/4$  (where  $L$  is the length of the conductor of interest, for example, a cable) tend to dominate and this provides an indication of the ability of the illuminating HEMP or HPEM environment to couple to the subsystem and equipment being characterised.

Any protection added should be noted during this phase of the assessment and may negate the need for more extensive testing during the later stages. An effective shield at the frequencies of interest may reduce the illuminating HEMP or HPEM environment to a level that is below the immunity requirements for commercial electronics, thus demonstrating that further radiated testing of the commercial electronics is not required. In this case, a conducted

test would still be required, unless adequate filtering can be demonstrated to show that anticipated conducted currents and voltages would be attenuated to a level for which the electronics has been demonstrated to be immune. However, testing at the later stages is recommended to assure that the added protection is adequate.

For example, a shield affording 80 dB (a factor of 10 000 in terms of electric field strength) of attenuation would reduce an external illuminating HEMP field of 50 kV/m to 5 V/m. Immunity test data (driven by EMC requirements) are typically amplitude modulated (AM) continuous wave (CW) but the induced current expected from HEMP illumination will be damped sinusoidal in nature. Evaluation of the energy content of a CW and a damped sinusoidal waveform of the same (centre) frequency shows that the CW waveform has much greater energy. Thus, if an equipment or system is immune to 5 V/m CW, it is possible that it will be immune to larger peak amplitudes of transient (damped sinusoidal) signals. For interference the peak amplitude is likely to be the susceptibility driver, but for permanent damage, energy is a key susceptibility driver.

A further consideration here is that EMC tests are driven by the need to demonstrate continued operation in a particular EM environment that is they are required to demonstrate immunity in that environment. Without the appropriate test information, it is generally not possible to make conclusions about susceptibility based on immunity data only. However, in the context of system level assessments, the immunity data plays an important role as it can be used as a lower bound on equipment strength and provide an indication of the range from HPEM environments where continued functionality (immunity) can be expected. Without susceptibility information, this type of calculation will provide the system user with a range at which the system will continue to operate, but does not provide information on the range at which effects can be expected. Detailed susceptibility data is required in order to generate this information.

Knowledge of the shielding effectiveness of equipment, subsystem and system interfaces also provides important information as subsystem immunity of 5 V/m (CW) with system shielding of 26 dB means that the subsystem will continue to operate in an externally illuminating field of 100 V/m (CW).

Information obtained during this phase will be used in the next phase. Waveform norms can be computed to enable a rigorously mathematical method of comparing data. Norms are discussed in more detail in C.2.2.

### **6.3 System analysis phase**

The purpose of the system analysis phase is to identify critical subsystems and equipment, system configurations and operational modes that will be assessed through a combination of low-level and high-level tests to estimate a system's susceptibility to the HEMP and HPEM environments. A key element in this process is selection of a set of measurement or test points at critical interface locations within the system that will be used later in the susceptibility assessment phase to compare coupled stress waveform data (obtained in the system test phase) to EUT immunity or susceptibility waveform data at corresponding interfaces (obtained in the subsystems and equipment characterization phase). During the test point selection process, emphasis should be placed on choosing test points at EUT interfaces that both;

- a) are predicted to have the highest level stresses and
- b) are functionally critical to proper operation of the system.

### **6.4 System test phase**

#### **6.4.1 General**

This phase describes EUT and/or system level testing that can be used to provide information on the system's overall protection against a HEMP or HPEM environment. In some cases, test facilities cannot manage large systems therefore breaking down the system level test into a

test for subsystems and/or equipments and combining the results may be an acceptable alternative. If this approach is to be adopted, extreme care shall be taken to ensure that the integration of equipments and subsystems does not impact on the effect of the HEMP or HPEM environment at the system level.

To conduct a complete system level test, all subsystems and equipment should be installed in the system, interconnected and functioning in its normal intended operational state.

#### **6.4.2 Low-level tests**

Low-level (LL) tests can be conducted with either continuous wave (CW) or pulsed illuminating fields.

Transfer function and attenuation data should be collected for those cable bundles and areas of interest identified by the system analysis. For HEMP and/or HPEM environments that dominate in the cable coupling regime (500 kHz to 400 MHz, depending on the length of cabling) convolution with cable bundle transfer functions will result in predicted currents as a result of the incident field of the environment of interest. For HEMP and/or HPEM environments that dominate in the aperture coupling regime (400 MHz to 18 GHz) convolution with attenuation data will result in predicted fields within the system enclosure. This data can then be compared with any available electromagnetic compatibility (EMC) test results to provide immunity and possibly, susceptibility thresholds.

As these tests are conducted at low-level, they will not adequately characterise the performance of non-linear phenomenon such as arcing and transient protection devices [6]. The performance of these devices should be carefully considered in the overall assessment.

#### **6.4.3 High-level testing**

##### **6.4.3.1 General**

High-level (HL) susceptibility tests should be conducted by an appropriate technique. This could include free-field (directional) methods, reverberation chamber methods, or via direct injection methods. Reverberation chamber testing can be said to represent a worst case illumination from a polarisation and orientation perspective, due to the statistically isotropic environment of the chamber. However, for the same reason, it essentially represents only an average case in terms of the stress on the EUT, compared with a plane wave having the same field strength [7]. High-level free field testing will identify susceptibility dependencies on polarisation, orientation and HPEM waveform parameters within the constraints of the facility used for the assessment.

Consideration of the parameters of the HPEM and/or HEMP waveform of interest and the likely upset parameters for the technology contained within the subsystem or equipment under test (EUT) is necessary in order to utilise the optimum test parameters during the assessment.

During this part of the assessment, the EUT should be made to operate in a representative configuration. This must include careful location of cables used during the EUTs deployed state. Any RF link between a screened chamber and the outside world requires hard-wired replacement such that the EUT can be monitored for any induced susceptibility. It is important that the addition of any such link is suitably attached to the EUT, such that changes in the electromagnetic properties of the EUT are minimised. This is particularly the case when replacing RF links for hard-wired links as the RF link has inherent physical isolation but a hard-wired link introduces another path for coupling of RF to the system. The impact of this is typically alleviated by the use of ferrite loaded cables to prevent the circulation of skin currents in the screen of the cable (discussed further in Annex B). Bulkhead connectors should also be used to prevent the transfer of any circulating current entering the inside of the system and re-radiating.

The result of this stage of the assessment will be a set of frequencies at which the system has been affected allowing susceptibilities to be identified. A frequency density spectrum can be generated for all HPEM and/or HEMP sources of interest. This can be compared against the frequency bands for susceptibilities to identify sources that could generate the same effect.

Where applicable, an accurate comparison of the effects of different modulation types at this stage is critical.

#### **6.4.3.2 Pulsed current injection (PCI)**

This part of the assessment involves the injection of pulsed waveforms whilst the EUT or system is monitored for susceptibility. This can involve the injection of damped sinusoidal waveforms that are centred on a single frequency or complex transients that consist of many frequencies. For example, it is possible to obtain a predicted induced cable bundle current for an illuminating HEMP or HPEM environment using the transfer functions gathered during 6.4.2.

During this part of the assessment, it is important to consider the impact of single port excitation when the HEMP or HPEM environment may excite many ports simultaneously. In particular, multi-port excitation should be used on EUT where redundancy may be built in during practice. If multi-port excitation is used, the assessment must give due care to ensuring that all ports are excited within the cycle time of the EUT as failure to do this may result in an misleading test result.

The PCI methods described in IEC 61000-4-23 [6], IEC 61000-4-24 [8] and IEC 61000-4-25 [9] may be useful during this phase.

#### **6.4.3.3 Surface current injection (SCI)**

Direct drive techniques may be used to inject currents onto either a return conductor built around the system under assessment or the system itself. The current flow, on the return conductor or on the system exterior, cross-couples to the cabling within the system. This method can be used at low level to measure transfer functions or at high levels to monitor for susceptibilities. One of the advantages of this technique is that it can be applied at lower frequencies than the LLCW methods discussed in 6.4.2 [6].

#### **6.4.3.4 High-level illumination (HLI)**

This part of the assessment involves exposing the system to high power RF sources indicative of the types of technology that could be used as HPEM and/or HEMP. These include Ultra Wideband (UWB), High Power Microwave (HPM), Damped Sinusoid (DS) and hybrid sources although other more general microwave sources can also be considered. It is essential that the set-up used during the radiated susceptibility phase is used to ensure that the coupling paths to the system remain unchanged. Changes in the set-up could either remove or provide additional modes of ingress into the system that could potentially alter the electromagnetic properties of the system.

Selection of HEMP and/or HPEM waveform parameters should be based around the modulations used during the radiated susceptibility. The effect of variation in pulse length, pulse amplitude and pulse repetition frequency (prf) should be investigated during this stage.

At this stage, it is important to increase the level of the incident environment in stages up to the full level [6, 9]. Experience of HEMP qualification testing shows that the system can exhibit no effects at 10 kV/m and 50 kV/m but many effects at 30 kV/m. In these cases the protection devices did not operate at 30 kV/m but the environment contained enough energy to cause effects in some of the system's equipments. At 50 kV/m protective devices operated and protected the system.