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Space systems — Electromagnetic compatibility requirements

Systèmes spatiaux — Exigences relatives à la compatibilité électromagnétique

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Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

This second edition cancels and replaces the first edition (ISO 14302:2002), which has been technically revised.

The main changes are as follows:

— updating related standard documents such as AIAA, ECSS, MIL-STD and etc., considering with new work has been accomplished over the past 10 years in this field within the US AIAA and ECSS. Particularly in space - there are many more orbiting transmitters and receivers exploiting the EM spectrum for earth observation, communications etc.;

— the inclusion of EMC flow chart to clarify timeline for EMC plan, design, analysis and test/evaluation phase of project;

— the inclusion of technical requirements for multipaction, intermodulation and electrostatic discharge with consideration of changes of electronic equipment with higher speed digital devices, data bus & clock frequencies, and switch mode Power supplies by PWM signalling;

— updating of technical requirements, taking into account that equipment is still being qualified or qualified by similarity to heritage specifications from the 80's.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

This document addresses the equipment-level requirements, verification and rationale of system-level compatibility concerns used in the development and procurement of complete space systems.

This document includes requirements at all the following levels:

— general system requirements;

— specific system requirements;

— equipment-level electromagnetic interference requirements.

The equipment-level requirements are summarized in Tables 1 and 2.

This document does not include detailed design requirements. Instead, engineering issues to be addressed during execution of the electromagnetic compatibility (EMC) control programme are presented. Requirements in this document may be tailored based on contractual agreements.

This document references civilian equipment-level electromagnetic interference (EMI) test methods to minimize cost and allow the use of standard test methods. This document does not contain EMI test limits. Test limits should be developed based on the environment, power quality definition and operational requirements.

Annex A presents the rationale behind each requirement/test technique, guidance for meeting requirements and test procedures where an acceptable reference is not available. Use of Annex A is advised in order to allow for optimal tailoring of this document for individual programmes.

Space systems — Electromagnetic compatibility requirements

1 Scope

This document contains a process to establish performance requirements for the purpose of ensuring space systems electromagnetic compatibility (EMC). The engineering issues to be addressed in order to achieve system-level EMC are identified herein, with guidance and rationale towards achieving specification conformance. The method for the derivation of typical equipment-level requirements from a space-system-level requirement is illustrated. This document also aids in the selection of tailored requirements for a specific mission (see Annex A).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

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

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

ISO 24637, *Space systems — Electromagnetic interference (EMI) test reporting requirements*

ECSS-E-20-01A, *Multipaction Design and Test*

Aerospace Report No. TOR-2014-02198, *Standard/Handbook for Multipactor Breakdown Prevention in Spacecraft Components*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1.1
break-out box
non-flight piece of test support equipment that is connected in-line with a cable that accommodates external connection (usually binding posts) of instrumentation or series/parallel test networks to the wiring in that cable

3.1.2
complete space system
suite of equipment, subsystems, skills, and techniques capable of performing or supporting an operational role

Note 1 to entry: A complete space system includes related facilities, equipment, subsystems, materials, services, and personnel required for its operation to the degree that it can be considered self-sufficient within its operational or support environment.

Note 2 to entry: The complete space system normally refers to the spacecraft or launch vehicle itself.

3.1.3
dead-facing
removal of power from a circuit prior to mating/de-mating of the circuit interface (usually to prevent arcing or inadvertent short circuits)

3.1.4
electromagnetic compatibility
EMC
ability of a space equipment or system to function satisfactorily in its intended electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

3.1.5
electromagnetic interference
EMI
degradation of the performance of a space *equipment* (3.1.6), transmission, channel, or system caused by an electromagnetic disturbance

3.1.6
equipment
integrated set of parts, and components

Note 1 to entry: An equipment accomplishes a specific function.

Note 2 to entry: An equipment is self-contained and classified as such for the purposes of separate manufacture, procurement, drawings, specification, storage, issue, maintenance, or use.

SOURCE: ISO 10795 3.93

3.1.7
faying surface
prepared conductive surface of sufficient area and conductivity that, when joined under pressure contact, ensures a low electrical bond impedance for the required life of the connection

3.1.8
floating
status of a circuit isolated from another one, which is characterized by a resistance of strong value in parallel with a capacity.

Note 1 to entry: In low frequency, the circuit is actually high impedance; it is not the case in HF considering the parasitic capacitor. “Floating” is therefore to use for a frequency domain that it is then necessary to specify.

3.1.9
immunity
ability of a device, *equipment* (3.1.6), or system to perform without degradation in the presence of an electromagnetic disturbance

3.1.10
internal charging
phenomenon caused by penetration of high-energy electrons through spacecraft structures and/or component walls so that these particles are incident on ungrounded metallic or dielectric internal surfaces

3.1.11
line impedance stabilization network
LISN
network inserted in the supply mains lead of an apparatus to be tested which provides, in a given frequency range, specified source or load impedance for the measurement of disturbance currents and voltages and which may isolate the apparatus from the supply mains in that frequency range

3.1.12
power quality requirement
requirement developed for the space system that defines the conducted voltage and current noise (from load regulation, spikes, sags, etc.) the power user can expect

3.1.13
procuring authority
agency or organization funding or administering a contract for the development of the space system

3.1.14
radio frequency interference
RFI
degradation of the reception of a wanted signal caused by a radio frequency disturbance

3.1.15
safety margin
ratio of circuit threshold of *susceptibility* (3.1.18) to induced circuit noise under worse-case expected environmental conditions (intrasystem and intersystem)

3.1.16
subsystem
set of interdependent elements constituted to achieve a given objective by performing a specified function, but that does not, on its own, satisfy the customer's requirement

Note 1 to entry: Generally, a piece of equipment is housed within a single enclosure, while a subsystem may consist of several interconnected units.

Note 2 to entry: ISO 10795 3.231, modified — Note 1 to entry added.

3.1.17
susceptibility
correct operation of electrical *equipment* (3.1.6), referred to as the victim, in the presence of unplanned electromagnetic disturbances

Note 1 to entry: A victim is a component/subsystem that is susceptible to interference.

3.1.18
suppression
act of eliminating electromagnetic noise through the process of filtering, shielding, or other methods that reduce the impact of noise on a system

3.2 Abbreviated terms

ACS	attitude control system
BCI	bulk current injection

CDR	critical design review
CE	conducted emissions
CISPR	International Special Committee on Radio Interference
COTS	commercial off-the-shelf
CS	conducted susceptibility
DSO	digital storage oscilloscope
EED	electro-explosive device
EGSE	electrical ground support equipment
EMCAB	electromagnetic compatibility advisory board
EME	electromagnetic environment
EMEVP	electromagnetic effects verification plan
EMEVR	electromagnetic effects verification report
EMISM	electromagnetic interference safety margin
ESD	electrostatic discharge
EUT	equipment under test
FMEA	failure mode effects analysis
GEO	geosynchronous Earth orbit
HF	high frequency
ICD	interface control document
LEO	low Earth orbit
Mil-Std	military standard
NASA	National Aeronautics and Space Administration
PDR	preliminary design review
RDR	requirements definition review
RE	radiated emissions
RF	radio frequency
RFP	request for proposal
r.m.s.	root-mean-square
RS	radiated susceptibility
r.s.s.	root-sum-square
SAE	Society of Automotive Engineers

SMPS switched mode power supply

TTL transistor-to-transistor logic

UHF ultrahigh frequency

VHF very high frequency

VLF very low frequency

4 Requirements

4.1 General system requirements

4.1.1 General

The space system shall be electromagnetically compatible among all equipment/subsystems within the space system and with the self-induced and defined external electromagnetic environment during all phases of its mission.

4.1.2 System-level EMC programme

4.1.2.1 General

The procuring authority and prime contractor shall establish an overall EMC programme based on requirements of this document, the statement of work, space system specification, and other applicable contractual documents. The purpose of the EMC programme is to ensure space-system-level compatibility with minimum impact to programme, cost, schedule, and operational capabilities. An EMC programme shall include EMC control documentation and an EMC advisory board (EMCAB). The EMC staff responsible for these functions should be appropriate to the size and complexity of the programme. Typical programme milestones and their corresponding EMC data/deliverables are provided in Annex A (see Table A.1). Commercial space programmes having historically successful EMC control and management programmes in place may submit documentation to the procuring authority for an alternate means of equipment-level conformance, providing that the system-level interface requirements of this document are met.

When viewed from the perspective of a specific program or project context, the requirements defined in this document may be tailored to match the actual requirements of the particular program or project. Tailoring of requirements shall be undertaken in consultation with the procuring agency where applicable.

NOTE Tailoring is a process by which individual requirements or specifications, standards, and related documents are evaluated and made applicable to a specific program or project by selection, and in some exceptional cases, modification and addition of requirements in the standards.

4.1.2.2 Electromagnetic compatibility advisory board

The EMCAB shall be responsible for timely and effective execution of the EMC programme under the general project manager. The prime contractor or developer shall chair the EMCAB, with procuring authority oversight. Other EMCAB members may invite associate contractors or developers and an independent expert of a space engineering certification body. Procuring activities may waive this requirement for systems that do not involve sufficient levels of integration to justify such a board; then the prime contractor shall execute EMCAB functions. The EMCAB shall accomplish its duties and document its activities mainly through the use of the system-level EMC documentation. It is also the responsibility of the EMCAB to solve problems related to EMC as they arise.

4.1.2.3 EMC programme

Details of the EMC programme shall be documented in the EMC control plan or other EMC contract documentation. Initial releases shall document the mechanics of the EMC programme, including basic design guidelines, while subsequent routine updates shall document programme progress. The requirements and approach established by the prime contractor shall be in a contractual document. An overall programmatic EMC program is shown in Figure 1. The contents of the EMC control plan or other EMC contract documentation shall include, but not be limited to, the following:

a) EMC programme management is defined by:

   1) responsibilities of procuring authority, prime and associate contractors, lines and protocols of communication, and control of design changes;

   2) planning the EMC programme, consisting of:

      i) facilities and personnel required for successful implementation of the EMC programme;

      ii) methods and procedures of accomplishing EMC design reviews and coordination (within the EMCAB, if applicable);

      iii) proposed charter;

      iv) details of the operation of the EMCAB, if needed;

   3) programme schedules, including integration of the EMC programme schedule and milestones within th e programme development master schedule;

b) system-level performance and design requirements, consisting of:

   1) definition of electromagnetic and related environments; including considerations related to hazards of electromagnetic radiation to fuels, humans, and explosive systems, such as electro-explosive devices (EED's) (see 4.2.9), launch vehicles, interfacing vehicles, and launch site environment, including electronic equipment at the launch site area;

   2) definition of critical circuits;

c) electro-explosive devices, consisting of:

   1) appropriate EED EMC requirements;

   2) design techniques;

   3) verification techniques;

d) subsystem/equipment EMI performance requirements and verification, consisting of:

   1) allocation of design responses at system and subsystem/equipment levels as defined in this document;

   2) allocated EMI performance at the equipment level, including tailored equipment-level requirement of which the control plan is the vehicle for tailoring limits and test methods;

   3) test results from subsystem/equipment level EMI tests shall be summarized:

      i) any specification non-conformances judged to be acceptable shall be described in detail; and analysis of the non-compliant conditions on overall EMC performance shall be provided as a part of the justifying rationale;

ii) cost, mass, schedule, reliability, system operability, and other factors should also be addressed;

e) EMC analysis:

1) by making predictions of intrasystem EMI/EMC based on expected or actual equipment/subsystem EMI characteristics;

2) by designing solutions for predicted or actual interference situations using equipment-level data as input, impedance coupling (conducted emissions), wire-to-wire, field-to-wire:

i) all coupling modes should be considered to determine or predict EMI safety margin (EMISM) of intra-system EMI/EMC based on specified interface control document (ICD) values or actual (waiver/deviation request) values of equipment/subsystem EMI characteristics;

ii) design solutions should address what filtering, shielding, and grounding need to be applied to achieve these predicted EMISM's;

f) spacecraft charging/discharging analysis;

g) space-system-level EMC verification consisting of an outline of system-level EMC verification plan, including rationale for selection of critical circuits for safety margin demonstration, and instrumentation techniques for both critical and EED circuit and sensitization;

h) method of disposing waivers initial release and subsequent updates of the EMC control plan shall be prepared and submitted in accordance with contractual terms.

i)

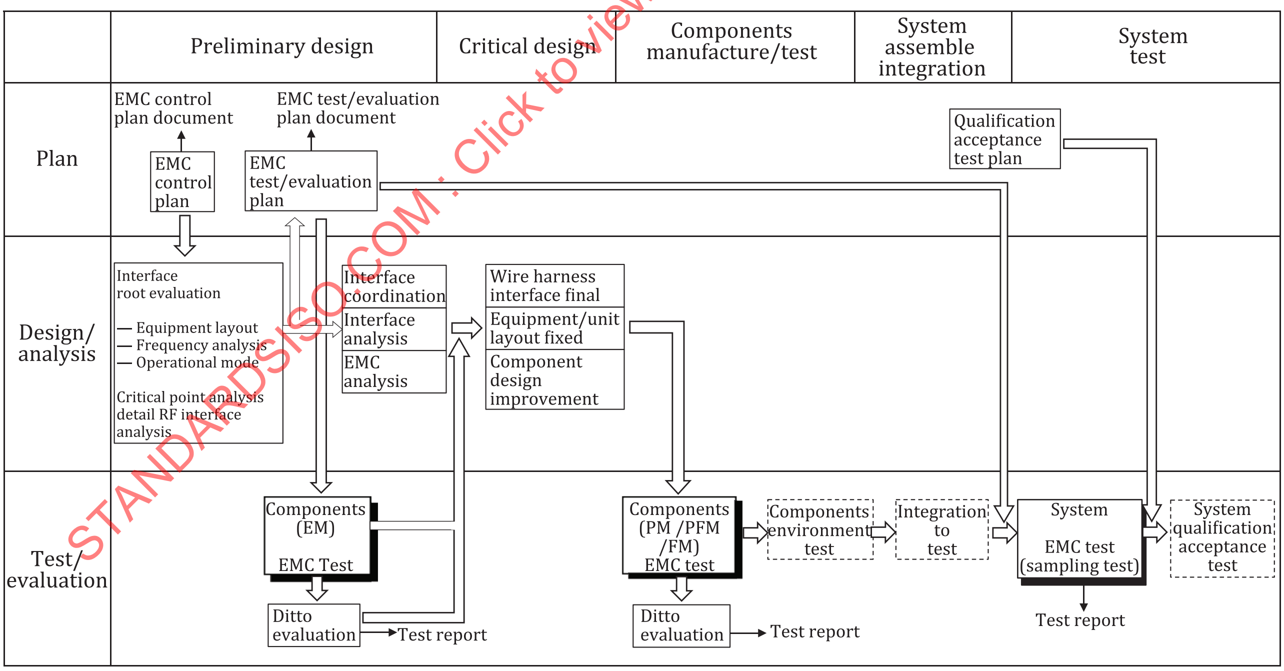


Figure 1 — Overall programmatic EMC program

4.1.3 Equipment/subsystem criticality categories

The EMCAB shall identify functional criticality for all equipment/subsystems. Functional criticality categories include the following:

a) category I, safety critical:

EMI problems can result in loss of life and/or loss of space platform;

b) category II, mission critical:

EMI problems can result in injury, damage to space platform, mission abort or delay, or performance degradation which unacceptably reduces mission effectiveness;

c) category III, non-critical:

EMI problems can result only in annoyance, minor discomfort, or loss of performance which does not reduce desired spacecraft effectiveness.

4.1.4 Safety margins

Design safety margins shall be established by the EMCAB for both critical functions and EED circuits. Design margins shall consider likely degradation modes of circuits and circuit protection methods over projected spacecraft lifetime.

4.2 Specific system requirements

4.2.1 External electromagnetic environment

The space system shall operate without performance degradation in the electromagnetic environment, not only self-induced but that due to external sources (intersystem EMI) such as other radio frequency sources, high-energy charged particles of space environment or plasma effects. The EMCAB shall determine the electromagnetic environment based on mission requirements.

4.2.2 Intrasystem EMC

The space system shall not interfere with key requirements of a subsystem. Each equipment/subsystem shall operate without performance degradation during concurrent operation of any combination of the remaining equipment/subsystems, subject to mission requirements.

4.2.3 EMI control

The prime contractor shall be responsible for translating system-level EMC goals into equipment/subsystem-level EMI performance requirements. Test limits and test methods may be tailored if required, with procuring authority approval, to meet programme needs. EMI characteristics (emissions and susceptibility) shall be controlled to the extent necessary to ensure intrasystem EMC and compatibility with the predicted external electromagnetic environment. Equipment/subsystem-level EMI performance requirements and test methods shall be in accordance with 4.3 and 5.3.

4.2.4 Grounding and wiring design

4.2.4.1 Grounding

A controlled ground reference concept shall be established for the space system prior to initial release of the EMC control plan or other EMC contract documentation. Both power and signal returns and references shall be considered. Impedance magnitudes of these connections over the affected signal spectrum shall be considered in determining which kinds of power and signals may share common paths (wire or structure). Resistance and inductance values for each element of the ground return circuit architecture may be assigned; the common-mode voltages that develop at circuit reference points can then be computed. These computed values may be compared to conducted susceptibility requirements for equipment.

For one architecture assumption, and knowing the noisy signals and EM environments, the computation of the reported energies from sources to receivers should be performed at the system scale. The architecture definition includes materials nature, grounding choices and harnesses locations. Then the EMC objectives can be defined with the margins for all equipment under sources of the same level that the ones considered with their shields in the computation.

4.2.4.2 Wiring

Wiring, cable separation, shielding, and signal category design guidelines for the space system shall be established. Pigtail shield connections shall not be used.

4.2.5 Electrical bonding

4.2.5.1 General

Electrical bonding measures shall be implemented for management of intentional electrical current paths and control of voltage potentials to ensure required space system performance and protection of personnel. Bonding provisions shall be compatible with other requirements imposed on the space system for corrosion control.

4.2.5.2 Power current feeder and return paths

If the structure is used as the current return path, bonding provisions shall be provided so that current paths of electrical power sources are such that the total direct current (d.c.) voltage drops between the power subsystem point of regulation and the electrical loads are within applicable power quality standard tolerances.

4.2.5.3 Shock and safety hazard

To prevent shock hazards to personnel, all exposed conductive items subject to fault condition charging shall be bonded as necessary to limit potentials to prevent shock to personnel. In order to clear faults or provide against accidental discharge of fault current to ground through a conductor, all exposed conductive items, which can become charged due to an electrical fault condition, shall be bonded to the ground subsystem. Bonding impedance shall be sufficiently low to ensure enough current to clear the fault by tripping a circuit protection device.

4.2.5.4 Antenna counterpoise

Antenna structures relying on a counterpoise connected to (or implemented on) the spacecraft skin shall have an RF bond to structure such that RF currents flowing on the skin have a low impedance path to and through the counterpoise.

4.2.5.5 RF potentials

All electronic and electrical items, which can experience degraded operation or can degrade the operation of other electronic or electrical items in response to external electromagnetic energy, shall be bonded to the ground subsystem with a faying surface bond to present a low impedance at the frequencies of interest. For composite materials, bonding shall be alternating current (a.c.) accomplished at impedance levels consistent with the materials in use. Where vibration or thermal isolation is required, bond straps may be used. The bond straps shall be as short as possible and maintain a low inductance path. Bond straps should only be used as a last resort.

4.2.5.6 Electrostatic discharge

Any isolated conducting items larger than 3 cm^2 shall be bonded to the ground subsystem in order to avoid a differential build-up of charge that would result in an electrostatic discharge, unless it is shown that there would not be enough charge build-up to cause a hazard. Refer to NASA-HDBK-4002A dated 03-03-2011 for further guidance.

4.2.5.7 Explosive atmosphere protection

Conducting elements in the vicinity of explosive and flammable materials shall be bonded to the ground subsystem such that arcing or heat rise due to fault currents or lightning currents (either directly applied or induced) is insufficient to cause ignition of the flammable substance. In space plasma environments, fault currents may occur across pins of separated (exposed pins) connectors. Dead-facing shall be employed before demating connectors in an explosive atmosphere and in a plasma environment of thrusters.

4.2.6 Antenna-to-antenna (RF) compatibility

The space system shall exhibit RF compatibility among all antenna-connected equipment/subsystems. This requirement is also applicable on an intersystem basis when there is a required intersystem interface. The RF compatibility analysis, if used in lieu of a test, shall include the effects of intermodulation products.

4.2.7 Lightning

The space system shall be protected against both direct and indirect effects of lightning such that the mission can be completed without degradation of performance after exposure to the lightning environment. Use test procedure ISO 7137:1995, 3.8 (Section 22) for demonstrating compatibility with the lightning indirect-effects environment and test procedure ISO 7137:1995, 3.10 (Section 23) for the direct-effects environment. Protection may be a combination of operational avoidance of the lightning environment and electrical overstress design techniques.

4.2.8 Spacecraft and electrostatic charging

4.2.8.1 General

The space system shall control and dissipate build-up of electrostatic charges both from prelaunch ground sources and from on-orbit energetic plasma environments and effects of high-energy charged particles to the extent necessary to protect against personnel shock hazard, fuel ignition hazard, radio frequency interference (RFI), and destruction of dielectric materials and electronic components due to static discharge.

4.2.8.2 Plasma-generated/payload-induced differential charging/discharges

Plasma-induced differential charging, occurrence of electrical discharges and degrading effects upon the space system nominal performances shall be minimized to prevent such occurrences by design and integration precautions. Because the elimination of all discharges cannot be guaranteed, the full system shall be hardened and verified so that no malfunctions, degradation of performances, or deviation from identified parameters beyond tolerances given by corresponding specifications occur when the spacecraft is exposed to repetitive electrostatic arc-discharges representative of expected transient phenomena.

4.2.8.3 Internal charging

If the orbit parameters are such that the incident electron flux is high enough to cause internal charging, hardening techniques shall be applied to minimize the charging of these surfaces, preventing them from reaching the electrostatic discharge (ESD) discharging threshold.

4.2.8.4 Charging of fluid lines

All pipes, tubes, and hoses that carry fluids shall have a method of discharging the fluid and its transport system without producing arcs.

4.2.8.5 External wiring

Wire cables consist of individually shielded twisted pairs, triples, or quads. Braid shields shall cover the twisted pair or twisted group rather than individual wires. Shields should not be used as an intentional power or signal return conductor, except for coaxial cables, which handle RF signals. Pyro circuits should be double shielded (20 dB to 40 dB of attenuation). Connector backshells are used. Individual braid shields should be terminated to the connector using halo rings or equivalent. All cable bundles should have an overbraid RF shield (90 % or better coverage) with a 360 degree termination into the backshell on both ends. This ensures that the subsystem box Faraday cage is carried from box to box at the subsystem level.

All intersubsystem wires and wire shields should be isolated from each other and from structure by insulation providing not less than 2 MΩ and not more than 100 MΩ DC resistance. Intersubsystem wiring should be assigned to cable bundles in the system wiring harnesses in accordance with the type of circuit, signal level, and noise susceptibility of the circuit. Outgoing and return wires should be of equal length and routed together. The space vehicle should have five bundle classifications:

a) power;

b) quiet;

c) noisy;

d) pyrotechnic;

e) radio frequency.

Wire bundles within the system wiring harnesses should be routed separately so as to provide electromagnetic isolation between wires in different bundles. Where bundles enter a common connector, the separation should be maintained until as close to the connector as possible. Transfer impedance parameters shall be specified and characterized.

EMI designers shall analyse the families of signals used in the system to identify the hazard of crosstalk that they represent towards others. The role of the board is to establish a board that defines the families of signals that can be associated together in bundles or if a protection is necessary (shielding).

4.2.8.6 Enclosures

Enclosures for all electronic equipment should be electrically conducting and should be designed to minimize electromagnetic propagation and pickup from external sources. Except for instrument sensor openings, outboard (external to bus structure or thermal blankets) electronic assemblies need to be 100 % electrically shielded with a Faraday cage. The design goal for any enclosure, including penetrations, should be 40 dB at 10 GHz; a minimum 20 dB is required. Composite enclosures should have a conductive coating, such as electroless nickel, applied to all their surfaces for this purpose. The provisions for installation should be such that there is a continuous, low-impedance path from the conductive surfaces equipment enclosure to the basic structure of the space vehicle to permit bonding of the equipment. The direct current resistance from enclosure to structure should not exceed 2,5 mΩ. Mechanical discontinuities in the enclosure, such as covers, inspection plates, and joints, should be kept to a minimum. A low-impedance (2,5 mΩ or less) current path should be provided across the interface of each discontinuity, leaving no nonconductive seams or joints at the mating edges, so as not to degrade the electromagnetic shielding effectiveness of the enclosure.

EMC designers shall ensure that electronics casing shall be designed so as to reach performances of in-case electromagnetic field which is less than electronics immunity threshold. The protection Shall be adapted to reliability or to safety levels.

4.2.9 Hazards of electromagnetic radiation

The space system shall be designed so that fuels, humans, explosive systems, and electronically actuated thrusters are not exposed to unsafe levels of electromagnetic radiation. All four concerns shall address the entire electromagnetic environment, including interference sources from possible external transmitters.

4.2.10 Life cycle considerations

Electromagnetic environment (EME) protection designs shall include full consideration of life-cycle aspects of the protection.

EXAMPLE Life cycle considerations include identification of protection components and processes, reliability, maintainability and serviceability, verification or inspection requirements.

Space system protection shall include, but not be limited to, the following life-cycle considerations.

a) Reliability:

The EME protection scheme shall be at least as reliable as the equipment, or subsystem it protects.

b) Maintainability:

The EME protection schemes shall either be accessible and maintainable or shall be designed to survive the design lifetime of the space system without mandatory maintenance or inspection. Bonding, shielding, or other protection techniques, which can be disconnected, unplugged, or otherwise deactivated during maintenance shall be addressed in maintenance documentation, including required actions to restore their effectiveness. Those protection schemes likely to be repaired during the space system life cycle shall have their performance so specified that it can be tested or inspected as needed.

c) Serviceability:

On potentially repairable systems, protection schemes shall be serviceable or replaceable without degradation of the initial level of protection.

4.2.11 External grounds

A method shall be implemented on space systems to permit connection of grounding cables for charge equalization prior to implementing other procedures or the application of power across the interface.

4.2.12 Spacecraft d.c. magnetic emissions

The spacecraft magnetic moment and resulting diurnal and secular disturbance torques shall be limited to values with the control authority of the attitude control subsystem (ACS). Static and dynamic magnetic fields from all spacecraft-generated sources shall not exceed the sensitivity level of the spacecraft instrumentation.

4.2.13 Electric propulsion systems

Electrical propulsion systems are becoming more commonplace in interplanetary systems. It is a high-powered system that produces interference due high power, large strong magnets and high current coil systems.

Utilization of electrical propulsion systems produces an issue for EMI, especially if science instruments are included in a spacecraft package.

— The electrical propulsion systems produces noise that encompasses a broadband spectrum profile.

— The impacts of electrical propulsion systems on spacecraft equipment include the generation of conductive noise and radiated noise.

— Since those noise can exceed general conducted and radiated emissions limits, it is necessary to measure the noise generated by the electrical propulsion systems and evaluate and verify its effect as EMC of the system.

4.3 Equipment-level EMI requirements

4.3.1 General

System-level EMC requirements shall be sub-allocated to equipment-level EMI requirements. Equipment-level EMI requirements shall be derived for each space system development based on, but not limited to, the following considerations in 4.3.2 to 4.3.17. Where applicable, appropriate test procedures listed in ISO 7137 shall be used as default techniques. Matrices showing equipment-level requirements, their applicability, and the test procedure reference specification are provided in Tables 1 and 2. Immunity requirements, which simulate effects of RF transmissions, shall utilize modulation schemes that simulate actual spacecraft RF transmissions.

4.3.2 Power bus conducted interference, time and frequency domain, source induced

This requirement shall apply to the electrical power subsystem only. The requirement is based on the power bus being loaded resistively. Power bus voltage ripple shall meet power quality requirements at all levels of loading. Consideration shall also be given to control of conducted emissions for the purpose of limiting power bus radiated emissions.

4.3.3 Power bus conducted interference, load induced, frequency domain

This requirement shall be imposed on equipment/subsystems operating from a power bus that can be shared with payloads. When developing the conducted emissions requirements, the sum of all load-induced power bus voltage ripple shall meet power quality requirements. Differential and common mode ripple noise requirements shall be imposed on each equipment/subsystem such that the noise contribution from subsystems does not exceed the power quality specification. Conducted noise limits shall also consider the RF radiated noise effects on victims such as receivers.

Table 1 — Equipment-level test applicability matrix (emissions)

Test type	Requirement/ verification clause	Applicability	Test procedure reference	Alternate method Mil-Std-461[1]
Power bus conducted interference, time and frequency domain, source induced	4.3.2/5.3.2	Required for electrical power subsystem	Guidelines in A.2.3.2	—
Power bus conducted interference, load induced, frequency domain	4.3.3/5.3.3	Required	ISO 7137:1995, 3.7 (Section 21.3a) (voltage ripple, 150 kHz to 30 MHz)	CE101 and CE102
Control of long duration load induced switching transients	4.3.4.2/5.3.4.2	Case-by-case[a]	Guidelines in A.2.3.4.2	—
Control of fast load induced switching transients	4.3.4.3/5.3.4.3	Required	Guidelines in A.2.3.4.2	—
Power bus load induced time domain ripple	4.3.5/5.3.5	Case-by-case[a]	Guidelines in A.2.3.5	—
Signal cable conducted interference, frequency domain	4.3.6/5.3.6	Case-by-case[a]	ISO 7137:1995, 3.7 (Section 21.3b)	—
Antenna connection port spurious emissions	4.3.7/5.3.7	Required for antennas	Guidelines in A.2.3.7	—

[a] Case-by-case means the procuring authority or EMCAB shall specify the applicability.

Table 1 *(continued)*

Test type	Requirement/ verification clause	Applicability	Test procedure reference	Alternate method Mil-Std-461[1]
Magnetic field radiated emissions	4.3.8/5.3.8	Case-by-case[a]	Guidelines in A.2.3.8	RE101
Radiated electric field emissions	4.3.9/5.3.9	Required	ISO 7137:1995, 3.7 (Section 21.4)	RE102

[a] Case-by-case means the procuring authority or EMCAB shall specify the applicability.

Table 2 — Equipment-level test applicability matrix (immunity)

Test type	Requirement/ verification clause	Applicability	Test procedure reference	Alternate method Mil-Std-461[1]
Immunity to audio frequency power-line ripple	4.3.10/5.3.10	Required	ISO 7137:1995, 3.4 (Section 18) Guidelines in A.2.3.10	CS101
Immunity to power-line switching transients	4.3.11/5.3.11	Required	ISO 7137:1995, 3.3 (Section 17)	—
Immunity to the conducted effects of radiated electromagnetic fields	4.3.12/5.3.12	Case-by-case[a]	ISO 7137:1995, 3.6 (Section 20.4)	CS114
Immunity to audio frequency radiated magnetic fields	4.3.13/5.3.13	Case-by-case[a]	Guidelines in A.2.3.13 ISO 7137:1995, 3.5 (Section 19.3.1)	RS101
Immunity to radiated electromagnetic fields	4.3.14/5.3.14	Required	ISO 7137:1995, 3.6 (Section 20.5)	RS103
Immunity to magnetic fields induced signals to cabling	4.3.15/5.3.15	Case-by-case[a]	ISO 7137:1995, 3.5 (Section 19.3.2 and 19.3.4)	—
Control of antenna port immunity to out-of-band interference	4.3.16/5.3.16	Receivers	Depends on receiver type	—
Immunity to electrostatic discharge	4.3.17/5.3.17	Required or handling procedure	IEC-61000-4–2	—

[a] Case-by-case means the procuring authority or EMCAB shall specify the applicability.

4.3.4 Power bus load-induced switching transient emissions

4.3.4.1 General

Effects from two types of switching transients shall be controlled. These are long-duration transients (of millisecond duration) and fast transients (of sub-millisecond duration).

4.3.4.2 Control of long-duration load-induced switching transients

Transient inrush current shall be limited so that the power subsystem is able to maintain voltage levels within power quality specification tolerances.

4.3.4.3 Control of fast load-induced switching transients

Switching transient envelopes shall be controlled so the power quality specification can provide accurate envelopes of normal transients. Both magnitude and duration of turn-on, turn-off, and mode-switching transients shall be controlled. Each transient can be evaluated separately unless they are frequently repeating transients, in which case they are measured in the frequency domain.

4.3.5 Power bus load-induced time domain ripple

This requirement may be imposed in addition to 4.3.2. The envelope of time domain rms and/or peak-to-peak ripple developed across the power source impedance by the test article shall be controlled so the power quality specification provides an accurate accounting of load-induced effects.

4.3.6 Signal cable conducted interference, frequency domain

Cable bundle common mode current shall be controlled at mission-peculiar frequencies when needed to avoid interference with in-band receivers and other sensitive electronics.

4.3.7 Antenna connection port spurious emissions

Control of antenna port spurious emissions shall be imposed for antenna-antenna RF compatibility. When specifying limits and frequency ranges, the following issues shall be considered:

a) sensitivity of possible victim receiver subsystems (receiver, transmission line, antenna) including out-of-band response;

b) exclusion of transmit frequency and information carrying modulation bandwidth (for transmitters, transceivers);

c) highest and lowest intentional frequency used by space system receivers;

d) antenna port attachments, gain/loss characteristics.

4.3.8 Magnetic field radiated emissions

The a.c. magnetic field emissions shall be limited to levels that do not degrade operation of any part of the space system. This is to protect sensitive hardware, such as very low frequencies (VLF) receivers or low-frequency magnetic field measuring experiments as well as other sensitive science instruments or equipment operating at high frequencies.

4.3.9 Radiated electric field emissions

Radiated electric field emissions of any equipment/subsystems shall be controlled. Frequency bands used by spacecraft/payload receivers and launchers shall receive special emphasis. Additionally, equipment/subsystems procured for a reusable system shall meet radiated electric field emission requirements from the frequency range of intended payload sensitivity through receiver bands. Limits shall reflect possible victim receivers operationally required sensitivity, gain, direction, and location of the victim's antenna.

4.3.10 Immunity to audio frequency power-line ripple

Equipment shall be immune to audio frequency ripple at levels allowed to exist by the governing power quality specification and according to the conducted emissions levels. Appropriate margins shall be applied between allowable bus ripple and equipment susceptibility.

4.3.11 Immunity to power-line switching transients

Equipment shall be immune to power bus load-induced switching transients, as identified in the power quality specification.

4.3.12 Immunity to the conducted effects of radiated electromagnetic fields

Equipment operating in a space system subjected to intentional RF transmission shall be immune to common mode currents coupled onto equipment connected cables and power conductors. This requirement is only applicable in bands where intentional RF transmission is likely or expected. This requirement may be met by performing bulk current injection tests at frequencies up to 400 MHz.

4.3.13 Immunity to audio frequency radiated magnetic fields

Immunity to magnetic fields shall be controlled if there an a.c. magnetic field environments is generated that can disturb the space system equipment.

4.3.14 Immunity to radiated electromagnetic fields

Equipment immunity to unintentional and intentional transmitted RF fields shall be controlled to the degree necessary to ensure space-system-level EMC. Special emphasis shall be given to bands where spacecraft transmitters operate and in bands where transmitters external to the space system illuminate it at sufficient intensity that immunity shall be controlled.

4.3.15 Immunity to magnetic fields induced signals to cabling

When high-density cabling is used on a space system, induced signal susceptibility testing may be used to verify immunity from cable coupling. When used, the audio frequency magnetic field coupling and transient coupling shall be applied.

4.3.16 Control of antenna port immunity to out-of-band interference

Control of radio receiver response to out-of-band interference shall be imposed. Responses to spurious signals, as well as cross and inter-modulation effects, shall be controlled.

4.3.17 Immunity to electrostatic discharge

An ESD control process for equipment immunity and personnel handling shall be implemented. Actual levels of ESD qualification shall reflect the entire life-cycle environment of the equipment, from final assembly through mission completion. Considerations for spacecraft charging are in 4.2.8.

4.3.18 Passive Intermodulation (PIM)

Space vehicle design shall ensure that RF transmissions from on-board or external transmitters, when incident on the platform, do not result in unintentional signals as a result of PIM, which can interfere with on-board receivers. Conformity shall be verified by system-level test, analysis, or a combination thereof.

4.3.19 Multipaction

Space and launch vehicle equipment and subsystems shall be free of multipaction effects. Conformity shall be verified by test using worst case VSWR using test methods from ECSS-E-20-01A or the United States Standard Aerospace Report No. TOR-2014-02198.

5 Verification

5.1 General system requirements

5.1.1 General

The EMC programme management shall specify the organization, contractor, etc. that has overall responsibility for ensuring that all requirements of this document are met. Specific tasks may be delegated to associate contractors via the EMCAB as necessary. Verification shall be accomplished by qualification tests, analyses, inspections, and similarity, as appropriate, subject to procuring authority approval.

5.1.2 System-level electromagnetic effects verification plan (EMEVP)

5.1.2.1 General

The prime contractor or developer shall prepare a space-system-level EMEVP that specifies in detail the methodology to be employed for verifying each electromagnetic effects requirement as well as success criteria for each subsystem and equipment. The detailed plans for space-system-level EMC demonstration shall be provided in this document. Procuring authority approval of the EMEVP shall precede start of qualification testing. EMEVP shall include, but not be limited to system-level verification methods and test conditions.

Verification plan should specify how electronics are tested. Indeed, simulations realized during development on the basis of these hypotheses allow to have a reference. It allows to analyse fast the consequence of no complaint.

It would be good to ask equipment manufacturer to supply electronic scheme of equivalent I/O interface. These schemes would be integrated in simulations and would give the opportunity to well know the EMC behaviour of electric chains before final qualification.

5.1.2.2 System-level verification methods

The verification activity, if performed by test, can be split between the engineering model and the flight model, depending on the fidelity of the engineering model and the degree of success of the engineering model test campaign. Elements of system verification shall include the methods, procedures, and instrumentation required to document the test results.

5.1.2.3 Test conditions

Required personnel shall be specified, including procuring authority, contractor, associate contractor, and quality control representatives. In addition, required test equipment shall be specified, including a description of unique EMC instrumentation for stimulating and measuring electrical, electronic, and mechanical outputs of equipment and subsystems to be monitored during the test programme, including measured characteristics of any line impedance stabilization networks (LISN's) used for the system-level test.

5.1.3 Electromagnetic effects verification report (EMEVR)

The prime contractor or developer shall prepare an EMEVR. The EMEVR shall provide documentation demonstrating that each requirement of this International Standard has been met. The report shall include each separate test/test objective documented in the report. Test reporting shall be in accordance with ISO 24637.

NOTE A summary of results and pointers to reports of equipment-level verification is acceptable for lower-level requirements.

5.1.4 Safety margin demonstration of critical/EED circuit

Safety margins that have not been previously determined by equipment-level test or analysis shall be demonstrated at system-level integration, operating the space system suite of equipment/subsystems in a manner simulating actual operations. Monitored circuits shall either be instrumented for direct measurement of induced noise or activating signal-to-noise ratio shall be reduced by the safety margin factor, whichever is technically correct and practical to implement. Safety margin demonstration for something that is susceptible to a time domain circuit (including EED's) shall use time domain methods to verify safety margins.

5.2 Specific system requirements

5.2.1 External electromagnetic environment

The space system shall be exposed to those external electromagnetic environments identified in conformance to 4.2.1. When exposure of the space system is not feasible, an analysis of equipment and subsystem-level test data may be performed to satisfy this requirement.

5.2.2 Intrasystem electromagnetic compatibility

Intrasystem compatibility shall be demonstrated by a suitable combination of test and analysis. All equipment/subsystems shall meet the requirements of its functional acceptance test procedure, as installed on the platform, prior to system-level EMC testing.

5.2.3 Electromagnetic interference control

Prior verification of equipment/subsystem performance in accordance with the requirements of 4.3 supports the system-level test requirements. Mission-peculiar or specialized test procedures for operation of all matrix equipment shall be included to support test execution.

5.2.4 Grounding and wiring design

5.2.4.1 Grounding

The system-level electrical grounding and isolation shall be verified with respect to the grounding and isolation design by a system-level grounding diagram (one-line diagrams are not sufficient) and test at system assembly.

5.2.4.2 Wiring

Wiring category implementation shall be verified by review of design and inspection.

5.2.5 Electrical bonding

5.2.5.1 General

Conformance to electrical bonding requirements shall be verified by test, analysis, or inspection as appropriate for the particular bonding provision. Compatibility with corrosion control techniques shall be verified by demonstration that the manufacturing processes that address corrosion control have been implemented.

5.2.5.2 Power current feeder and return paths

Bonding for power current paths shall be demonstrated through analysis of electrical current paths, electrical current levels and measurement of bonding resistance levels.

5.2.5.3 Shock and safety hazards

Bonding for shock/safety hazards shall be verified through test, analysis, and inspection as appropriate for the particular application.

5.2.5.4 Antenna counterpoise

Bonding of an antenna counterpoise to structure shall be verified through test, analysis, and inspection as appropriate for the particular application.

5.2.5.5 RF potentials

Verification of milliohm-level bonds imposed for RFI control purposes shall be by special low a.c. voltage output measured by milliohmmeters. Meter voltage output shall be a.c. in order to make an effective measurement without disturbance from galvanic voltages. If only a d.c. meter is available, then two measurements shall be made, with the second measurement having ohmmeter probes reversed from the first measurement and both measurements shall be averaged to determine true bond resistance. If the same bond path is used as a fault return path, it may be tested for that requirement using the system-voltage, high-current ohmmeter, but only after low-voltage, low-current measurements have been completed.

5.2.5.6 Static discharge

Bonding of discharge elements, thermal blankets, or metallic items requiring a bond for static potential equalization shall be verified by test at assembly into structure.

5.2.5.7 Explosive atmosphere protection

Bonding of conducting elements in the vicinity of possible explosive atmospheres shall be verified by a combination of analysis, test, and inspection. Dead-face design shall be verified by inspection of drawings and control logic and by test as appropriate.

5.2.6 Antenna-to-antenna (RF) compatibility

An analysis shall be prepared as part of the EMC control plan which shall identify risk frequencies. These shall be checked to demonstrated compatible operation. In general, each culprit and victim pair shall be operated in such a manner as to maximize likelihood of interference. This shall be subject, however, to the restriction that operating modes are simulations of mission operations. Demonstration that a victim receiver is compatible with the culprit shall consist of the ability to receive an intended signal at its low signal condition. Lack of intermodulation interference shall be verified by a combination of analysis and test.

5.2.7 Lightning

Lightning protection for both direct and indirect effects shall be verified by a suitable combination of test, analysis and inspection as appropriate.

5.2.8 Spacecraft and static charging

5.2.8.1 General

Adequate control of static charging effects shall be verified by test, analysis, or inspection, as appropriate.

5.2.8.2 Plasma/payload-induced differential charging/discharges

Adequate control of induced differential charging/discharging effects shall be verified by a suitable combination of test, analysis, and inspection as appropriate. Influence of discharging may be verified as conductive susceptibility.

5.2.8.3 Internal charging

Adequate control of internal charging effects shall be verified by test, analysis, or inspection as appropriate.

5.2.8.4 Charging of fluid lines

Adequate control of charging on fluid lines shall be verified by showing the conductivity of the fluid, the fluid lines, and/or the additives is sufficient to prevent arcing.

5.2.9 Hazards of electromagnetic radiation

Safety with regard to RF effects fuels, human, explosive devices (including EED's), and flight/engine/thruster controls shall be demonstrated by a suitable combination of test, analysis and inspection.

5.2.10 Life cycle

System design features implemented for EMC purposes shall be inspected for conformance to life cycle requirements for reliability, maintainability, and serviceability. Demonstrations of serviceability, testability, and the ability to detect degradations shall be performed. Maintenance methodology and tools shall be identified in the EMEVR and appropriate maintenance publications.

5.2.11 External grounds

Proper placement and marking of space system external ground provisions shall be verified by inspection. Conformance to bonding requirements shall be verified by test.

5.2.12 Spacecraft d.c. magnetic emissions

Conformance to these requirements shall be demonstrated by a combination of analysis and test.

5.3 Equipment-level EMI testing

5.3.1 General

To the maximum extent possible, ISO 7137 test procedures shall be used for verifying conformance to 4.3.1 to 4.3.17. See Table 1 and Table 2 for specific ISO 7137 test procedure references. This is to minimize test cost (minimize procurement of test equipment not commonly available at EMI test facilities). In some cases, standard test procedures may be inappropriate for the EMC requirement. Also, in some cases, standard EMI test methods do not address space-related EMC issues. These special concerns are documented in 5.3.2 to 5.3.17. Alternate standards may be used as long as the 1 m antenna-to-equipment-under-test (EUT) test distance for radiated emissions measurements, peak detection, and equipment are positioned on a ground plane similar to that of actual flight. Specifications that do not meet this criterion shall be reviewed by the procuring organization.

Emissions testing that requires sweeping a band of frequencies shall be controlled as to measurement bandwidth and sweep speed or step size. Sweep speed shall be slow enough to fully charge the smallest intermediate frequency bandpass filter, and step size shall be limited to one-half of the measurement bandwidth. Operation of the test article shall be considered in determining frequency sweep times. Equipment/subsystems that perform a cycle of operations require several iterations of emission scans to catch all possible emissions.

Immunity testing that requires sweeping a band of frequencies shall be controlled as to number of test frequencies and dwell time. If the equipment performs a cycle of operations, the noisiest cycle shall be identified and operated for conducted emissions and radiated emissions frequency domain testing.

Test procedures for equipment-level testing shall be evaluated by the prime contractor.

When it is not possible to perform representative tests, it is necessary to be able to master the method and conditions of these tests. By this way, if necessary, results can be extrapolated in any case.

Software sequences that allow to activate the equipment or the functional chain in configurations that induce disturbances (noisy mode) or be in a position to be sensitive or quiet mode (EMC point of view CEM) shall be included into the test plan.

5.3.2 Power bus conducted interference, time and frequency domain, source induced

Power bus conducted interference, time and frequency domain, shall be verified by test. Time domain voltage ripple shall be measured directly across a resistive load using an oscilloscope. Frequency domain voltage ripple can be measured similarly (see Annex A). The oscilloscope bandwidth shall be compatible with that called out in the power quality standard.

5.3.3 Power bus conducted interference, load induced, frequency domain

Power bus conducted interference, load induced, frequency domain shall be verified by test. The requirement may be stated as a voltage and/or current ripple limit. A frequency domain line impedance stabilization network is specified. The ISO 7137 LISN does not provide adequate control at frequencies below 150 kHz. When conducted emission control is exerted below 150 kHz, it shall be exclusively current control.

Below 150 kHz the bandwidth shall be less than 2 % of tuned frequency, except very near d.c. where the bandwidth requirement is such that noise floor pollution by the local oscillator is controlled to a level at least 6 dB below the specification limit.

5.3.4 Power bus load-induced switching transients

5.3.4.1 Applicability

Both long-duration (drop due to current and resistance) and fast inclusive drop due to change in current with respect to time voltage transient measurement techniques are discussed in 5.3.4.2 to 5.3.4.3.

5.3.4.2 Control of long-duration load-induced switching transients

Inrush current shall be verified by test. Guidelines for measurement are provided in Annex A.

5.3.4.3 Control of fast load-induced switching transients

Fast load-induced switching transients shall be verified by test. Voltage transient limits lasting less than 50 µs may be measured with the same ISO 7137 LISN used for frequency domain voltage conducted emissions measurements. If transient voltages longer than 50 µs are to be measured, then a space system unique source impedance model shall be constructed. In order to measure a time domain transient accurately from onset to steady-state transition, the LISN impedance shall be specified to d.c. The test set-up power source impedance across which the transient is dropped shall exceed the impedance of the expected system power bus wiring. The test set-up and procedural details are offered in Annex A. When the power switch is not contained within the EUT, the turn-off transient data are for information only.

5.3.5 Power bus load-induced time domain ripple

The power bus load-induced time domain ripple shall be verified by test. The default procedure is shown in Annex A. If the bus is a.c. or a guaranteed source impedance over a wider frequency range is necessary, then the Annex A simple approximation to a LISN shall be replaced by a LISN representative of the actual power bus.

5.3.6 Signal cable conducted interference, frequency domain

Signal cable conducted interference, frequency domain shall be verified by test. Conformity to this requirement shall be verified by placing an EMI current probe around each individual cable under test. Alternate methods for verification can be used if agreement is reached with the procuring organization.

5.3.7 Antenna connection port spurious emissions

Antenna connection port spurious emissions shall be verified by test. Whenever possible, conformance shall be verified by direct coaxial/waveguide connection between the antenna port and an EMI meter. Impedance mismatches shall be addressed by impedance transformers or matching networks; and associated losses shall be accounted for. If a directly connected measurement cannot be affected; then a two-antenna test shall be performed. In this case, the test article antenna shall be used, and receive antennas shall as closely as possible simulate possible victim receivers.

5.3.8 Magnetic field radiated emissions

Low-frequency magnetic emissions shall be verified by test. Guidelines for this procedure are in Annex A.

5.3.9 Radiated electric field emissions

Radiated electric field emissions shall be verified by test. Guidelines for this procedure are in Annex A.

5.3.10 Immunity to audio frequency power-line ripple

Immunity to audio frequency power-line ripple shall be verified by test. Guidelines are given in Annex A.

5.3.11 Immunity to power-line switching transients

Immunity to power-line switching transients shall be verified by test. Guidelines for this procedure are in Annex A.

5.3.12 Immunity to the conducted effects of radiated electromagnetic fields

Immunity to the conducted effects of radiated electromagnetic fields shall be verified by test. Specification-level currents/voltages shall be injected via bulk current injection (BCI) clamps, which are described by their insertion loss versus frequency.

5.3.13 Immunity to audio frequency radiated magnetic fields

Immunity to audio frequency radiated magnetic fields shall be verified by test. The preferred approach to conformance demonstration is the Helmholtz coil. If the test article is large, a localized source of magnetic field (hand-held loop) may be used. Both of these sources are calibrated in terms of their physical dimensions and the current they carry. Guidelines for this procedure are in Annex A.

5.3.14 Immunity to radiated electromagnetic fields

Immunity to radiated electromagnetic fields shall be verified by test.

5.3.15 Immunity to magnetic fields induced signals to cabling

Immunity to magnetic fields induced signals to cabling shall be verified by test.

5.3.16 Control of antenna port immunity to out-of-band interference

Control of antenna port immunity to out-of-band interference shall be verified by test. Verification techniques depend strongly upon the type of receiver being qualified. Techniques shall be submitted in the appropriate section of the EMC control plan prior to test start.

5.3.17 Immunity to electrostatic discharge

Immunity to electrostatic discharge shall be verified by test or controlled by the use of approved handling procedures. Test methods shall be based on those specified in IEC 61000-4-2. Because

ESD testing can cause catastrophic failure of test article (and even more insidiously, latent failures), verification is only possible on engineering or prototype models, not the flight article. Guidelines for this test procedure are contained in Annex A. Additional ESD test methods that can be referenced are in the MIL-STD-461G CS117 and RTCA DO-160G Section 22, which are tests to see resistance to lightning surges.

Annex A
(informative)

Rationale behind requirements and tests

A.1 General

This annex provides requirement rationale, explanation, and/or guidance where necessary. In addition, test procedures are provided where applicable reference test procedures are not available or complete.

A.2 Rationale for requirements

A.2.1 General system requirements

A.2.1.1 General

EMC implementation should have emphasis in the design phase of a programme rather than after the design is complete. System-level documentation, such as EMC control plans, aids in the technical management of the EMC programme.

A.2.1.2 System-level EMC programme

A.2.1.2.1 General

Typical programme milestones and corresponding EMC data/deliverables are shown in Table A.1.

A.2.1.2.2 Electromagnetic compatibility advisory board

The EMCAB is established to report directly to the programme manager. This provides efficient decision making of design trade-offs that affect other engineering disciplines.

A.2.1.2.3 EMC programme

More specific details of the contents of the EMC programme and EMC control plan are as follows:

a) subsystem/equipment EMI performance requirements and verification:

   1) tailoring should consider, as a minimum:

      i) radiated electromagnetic environment from on-board/external transmitters;

      ii) antenna-connected electronics sensitivity levels;

      iii) assignment of power quality voltage ripple limits among space system electrical/electronic loads;

   1) safety-critical circuit identification;

b) electro-explosive devices (EED);

   1) EED requirements;

      i) ISO 26871;

ii) other appropriate requirements;

2) design techniques;

i) wiring (including shielding and shield termination);

ii) power, circuitry, signal integrity;

iii) static discharge;

iv) safety margins;

c) verification:

1) safety margin demonstration;

2) requirement;

3) test techniques.

Initial release and subsequent updates should be prepared and submitted in accordance with contractual terms. Normally, the EMC control plan is not finalised until procurement is complete. In some institutions, however, the control plan is a management document that is finalized early in the programme and a design analysis report or other EMC documentation is used for EMC implementation.

A.2.1.3 Equipment/subsystem criticality categories

Programme failure mode effects analysis (FMEA), which is normally produced in the safety organization, may be used to identify equipment/subsystem criticality. The criticality category definitions may vary depending on the safety organization.

A.2.1.4 Safety margins

Safety margins have traditionally been invoked to account for variability in system hardware and uncertainties in verification techniques. Hardware variability is not an important factor at present since systems are acquired in very small quantities. However, space system lifetime degradation is an important factor in variability since maintenance and repair, either routine or emergency, are more complex and expensive. Safety margin establishment should consider circuit and circuit protection lifetime degradation.

EXAMPLE Many space programmes require a 20 dB safety margin between the induced noise in an EED and the EED d.c. no-fire level. If a wire harness shield is used to provide part or all of that margin, then deterioration of the shield termination can easily negate the entire margin. It can be desirable to demonstrate a lower safety margin with an artificially degraded shield termination (pigtail instead of 360° peripheral termination). The traditionally used margin for non-EED safety critical circuits is 6 dB.

An example of a circuit threshold of susceptibility is a transistor-to-transistor logic (TTL) circuit that may have logic “1” levels of 2,5 V to 5 V, and logic “0” levels from 0 V to 1 V. A 6 dB safety margin implies a 0,5 V limit for induced noise for logic “0” level.

A.2.2 Specific system requirements

A.2.2.1 External electromagnetic environment

Environments that the EMCAB should consider are ground-based RF transmitters, RF transmissions from other spacecraft, plasma (including geomagnetic storms), and electromagnetic effects due to travelling through the Earth's magnetic field.

Table A.1 — Programmatic guidelines for EMC design

Programme milestones[a]	EMC data/deliverables
Request for proposal (RFP) issue	— Define EMC performance specifications. — Define system interface requirements. — Define known operational environments. — Establish EMCAB (contractors are included when contract begins).
Requirements definition review (RDR)	— Define system-level EMC requirements. — Define power distribution system requirements. — Define conducted emissions and radiated emissions equipment-level requirements. — Define conducted and radiated susceptibility equipment-level requirements. — Define system-level verification methods for margin demonstration. — Define preliminary power distribution and grounding/isolation architecture.
Preliminary design review (PDR)	— Complete EMI environmental study-radiated and conducted requirements in ICD's. — Present power distribution and grounding/isolation architecture drawing. — Define power conditioning (power converter) physical locations. — Define all loads and locations of single point grounds. — Submit first EMC control plan or EMC contract documentation identifying EMC control techniques. — Assign the cable design engineering function and responsibility for box/system interconnect issues. — Breadboard test results for power line conducted emissions — need not pass, but defines filtering needs. — Identify items of risk. — Define connector layouts/power wiring and signal routing/shielding considerations. — Describe proposed commercial off-the-shelf (COTS) use (if any). — Identify transient suppression locations. — Identify electrostatic charging approach/issues.
Critical design review (CDR)	— Review of engineering model test data. — Perform verification of ICD requirements. — Submit revised EMC control plan. — Provide closure list of EMC outstanding issues. — Define system tests or demonstrations for system EMC assurance.
Flight hardware delivery and test	— Support as required. — Implement the waiver process as needed.

[a] Programmatic milestones may change depending on programme structure.

Table A.1 *(continued)*

Programme milestones[a]	EMC data/deliverables
First flight article systems tests	— Review flight unit test data. — Perform EMC conformity verification. — Resolve conformity verification discrepancies with project. — Review need for update in final EMC control plan.
[a] Programmatic milestones may change depending on programme structure.	

A.2.2.2 Intrasystem electromagnetic compatibility

Equipment/subsystems that are not operated concurrently may be exempted from this requirement. An example would be co-channel operation of two radios, one in transmit mode and one in receive mode.

A.2.2.3 Electromagnetic interference control

Any general and comprehensive EMI controls are of necessity a collection of the most severe requirements drawn from a large and varied user community. As such, applicability to and impact of these requirements on space system effectiveness, cost, mass, and schedule should be considered.

A.2.2.4 Grounding and wiring design

A controlled grounding concept is of critical importance in cost-effectively achieving system-level EMC. Such issues as the use of space system structure for current return or the use of a wire return (allowing for the possibility of twisted feeder and return) and the wiring configuration for single-ended, multi-conductor and balanced signals have a strong bearing on the interference control techniques. These system-level practices should be established prior to inception of the equipment EMC design process. At a more detailed level, the EMCAB should decide reasonable trade-offs between circuit sensitivity, EMI immunity concerns, and wiring protection techniques such as twisting, shielding, filtering, and separation. Cable separation and signal grouping requirements/strategies are a part of the EMC control plan. Low-level and/or high-impedance signals may require hardening/buffering prior to wire transmission over cable interfaces. See NASA Handbook 4001[3] for additional information on unmanned spacecraft grounding.

A.2.2.5 Electrical bonding

A.2.2.5.1 General

SAE ARP 1870[4] or NASA-STD-4003[15] may be used as a guide for bonding techniques.

A.2.2.5.2 Power current feeder and return paths

When structure is used as the current return path, consideration should be given to the need for a mission-unique LISN.

A.2.2.5.3 Shock and safety hazard

Typically, to prevent shock hazards, potential between equipment and the ground subsystem should be limited to 30 V d.c. or 10 V a.c. (r.m.s.).

An example of an unintentional ground can be personnel making a ground connection to equipment via a metallic hand tool. Possible arcing and high current flow can result in a safety problem unrelated to shock hazard. Attention should be paid to charged battery systems and illuminated solar arrays.

A.2.2.5.4 Antenna counterpoise

A low-impedance bond on an antenna counterpoise prevents spacecraft structure RF currents from inducing noise potentials across the counterpoise. An example of how this requirement applies is a spacecraft skin about a quarter-wave stub antenna working against the skin, but this requirement does not apply to antenna elements separate from spacecraft skin, such as a horn-fed microwave dish.

A.2.2.5.5 RF potentials

The traditional value used for a workmanship check on a faying surface bond is 2,5 mΩ between metallic surfaces. The purpose of this requirement is to facilitate termination of cable shields and filter line-to-ground shunt elements. Nevertheless, for the RF impedance, inductance plays a major role. RF voltages across a bond strap should be taken into account by physical geometry design.

A common design criterion for bond straps is to have no greater than a 5:1 length-to-width ratio.

A.2.2.5.6 Static discharge

There are several reasons for avoiding electrostatic discharges:

— to prevent an ignition source in an explosive atmosphere;

— to avoid RFI to high frequency (HF)/very high frequency (VHF)/military ultrahigh frequency (UHF) 225 MHz to 400 MHz radios;

— to prevent damage to spacecraft structure and ESD-sensitive electronics, and to prevent personnel shock hazard.

When there is no credible hazard or no risk to the mission that can result from an ESD, this requirement can be waived.

A.2.2.5.7 Explosive atmosphere protection

Dead-facing is necessary when sufficient current flows in a circuit that a demating can result in a spark of sufficient energy to ignite an explosive atmosphere. Traditionally, such calculations have tended to be very conservative, using 10 dB or 20 dB safety margins.

A.2.2.6 Antenna-to-antenna (RF) compatibility

An example of an intersystem interface is a launch vehicle docking with an orbiting space station.

A.2.2.7 Lightning

In order to minimize the impact of programme cost and mass, consideration should be given to the portion of the mission profile during which lightning activity is possible, protection schemes based on ground-based protection and the extent of launch window available.

A.2.2.8 Spacecraft and static charging

A.2.2.8.1 General

A protection plan for spacecraft charging should include:

a) developing design guidelines with the purpose of reducing or eliminating the detrimental effects attributed to spacecraft charging;

b) performing computer analyses to model the charging level of the spacecraft and to determine how spacecraft-charging related effects can interfere with mission goals and objectives.

An important aspect of this plan is to establish the appropriate electron environments for the particular satellite orbit and the phase of the solar cycle. See NASA Reference Publication 1396[5] for additional information.

A.2.2.8.2 Plasma/payload-induced differential charging/discharges

In some regions of space, there are energetic plasma environments, of which the electron content is the driver for space charging. The charging can occur on the surface for electron energies of 0 keV to 20 keV, with resultant discharges. NASA TP-2361[6] discusses this surface charging. See NASA-HDBK-4006[17] for additional information.

A.2.2.8.3 Internal charging

Charging can occur on interior parts of the space system if the electron energies are above 200 keV. Additional grounding and/or shielding may be required typically for cables, circuit boards, device radiation shields, if located outside the space system structure and/or separated by space environment by thin equivalent aluminium cover and/or used as uncovered boards containing electronic circuits. See NASA Handbook 4002[7] for additional information (NASA-HDBK-4002A dated 03-03-2011).

A.2.2.9 Hazards of electromagnetic radiation

ANSI C95.1[8] may be used as a reference for human exposure thermal concerns. ISO 26871 may be used as a reference for explosive system designs.

A.2.2.10 Life cycle

The equipment/subsystem/space system performance should be no worse off with a failed EME protection scheme than with no EME protection scheme at all. This implies that line-to-ground (shunt) filter elements fail open, and in-line (series) filter elements fail short. Software filtering, where possible to implement, is preferable to passive filtering or can be used in addition to passive filtering to decrease attenuation requirements, increase reliability, or a combination of both.

For irretrievable systems, such as geosynchronous satellites or planetary probes, lifetime design has to be considered since maintenance is not an option.

A.2.2.11 External grounds

Charge equalization is necessary when mating separate parts of a space system or when mating separate space systems. A typical resistance used for the initial contact with structures isolated from the space system is 10 kΩ to limit current in the electrostatic discharge between the attached item and the contacting structure. Grounding jack bonds to space system structure should be built to maintain performance for the life of the space system.

A.2.2.12 Spacecraft d.c. magnetic emissions

A.2.2.12.1 General

The space vehicle magnetic moment is used to determine the impact of the space vehicle on two main areas:

— the attitude control system (ACS);

— the magnetic sensors in scientific payloads.

The ACS effort required to balance this effect, thus the torque about the centre of gravity, should be the most important parameter.

Functionally, the space vehicle may be using a magnetic sensor either as part of the ACS or as part of its payload; thus, the field intensity at that sensor location should be the most important parameter. The

ACS sensors are not as critical in terms of an accurate value being required and the scientific payloads are more critical as the magnetic content of the spacecraft can de-sensitize the mission.

The first activity is to identify the critical design requirements, i.e. whether it is for ACS torque budget or for magnetic cleanliness due to on-board sensitivity.

A.2.2.12.2 ACS budget reasons

Perform the following:

a) make a magnetic budget based on major equipment;

b) assign a general magnetic moment requirement to equipment, categorizing it by type.

EXAMPLE Permanent magnets inside, standard electronic equipment or inherent large current loop topology.

A.2.2.12.3 Sensor reasons

Perform the following:

a) calculate the maximum allowable disturbance at its location from known sensor constraints (which becomes the overall space vehicle requirement);

b) assign equipment level requirements according to the same categories as a), ensuring every unit is specifically called out;

c) adopt a magnetic cleanliness programme and if very low magnetic content is essential

   1) ensure no “perm-up” of space vehicle or components during manufacture or integration,

   2) use nonmagnetic materials in as many components as possible, and

   3) use tools made of non-ferrous material or demagnetize them before use.

A.2.2.12.4 Magnetic dipole typical values

The magnetic dipole moment of the spacecraft should be less than 30 A·m^2 at the beginning of life for all nominal configurations.

A.2.2.12.5 Specific cases and tailoring

A.2.2.12.5.1 Depending on the attitude control actuators and the altitude of the spacecraft, the maximum value of magnetic dipole momentum may be tailored. The value of 30 A·m^2 is a common value both for geosynchronous Earth orbit (GEO) and low Earth orbit (LEO) orbits. The requirement should be tailored for out-of-magnetosphere probes in the interplanetary magnetic field intensity (H-field).

A.2.2.12.5.2 For magnetic systems such as magnetic unloading systems with magnetic moment exceeding 30 A·m^2, the issues of torque balance determination should be especially analysed.

A.2.2.12.5.3 For spacecraft on equatorial orbits with a north–south stabilized axis, which is the general case for geosynchronous spacecraft, the requirement applies only for the projection of the momentum on the equatorial plan, fixed in spacecraft axis.

A.2.2.12.5.4 For geosynchronous 3-axis stabilized spacecraft, the solar array magnetic torque has a null mean in a 24-h period in spacecraft axis. The contribution of the solar array may be specified separately; and the general requirement can be written as:

— Solar array: 20 A·m^2

— Spacecraft structure: 10 A·m^2

A.2.2.12.5.5 For electrical propulsion, some electrical thrusters use electromagnets with high-level magnetic momentum during firing. The magnetic component of the resultant parasitic torque due to the electrical propulsion can be neglected with respect to other components (misalignment, for example). Therefore, the general requirement does not apply in this configuration. Magnetic compatibility between torquers and sensitive equipment should be analysed.

A.2.2.12.5.6 For magnetic torquers for attitude control, the general requirement does not apply when magnetic torquers used for magnetic control are in the "ON-state". Magnetic compatibility between torquers and sensitive equipment should be analysed. A radiated susceptibility to d.c. An *H*-field requirement for sensitive equipment should be defined after system analysis.

A.2.2.12.5.7 Fields at nearby hardware may be as much as 0,2 mT to 0,5 mT when current is applied to torquer bars with a moment of 30 A·m^2. Care should be taken to decrease the stray magnetic field from such torquers during design.

A.2.3 Equipment-level EMI requirements

A.2.3.1 General

Many equipment-level EMI requirements are customarily specified in the frequency domain. The reason for this is that frequency-tunable electronics are most commonly the victims of EMI. Employment of stringent frequency domain equipment-level EMI requirements should closely match the system's intentional electromagnetic spectrum usage.

The tailoring of intelligent system/mission-specific requirements is the backbone of a cost-effective EMC programme.

Usually tailoring implies taking exception to some portion of a suite of traditional requirements. For multiple mission or reusable space vehicles, the process should be to apply the entire set of all possible EMI controls to the space system procurement. The reason for the more stringent set of requirements for the space system suite of equipment is that future missions cannot be foreseen during the original procurement process. It is sensible to build maximum flexibility into a space system that is used for extended periods. Finally, a robust EMC design of a space system allows maximum relaxation of EMI requirements levied on payloads that the space system carries.

For space systems, it is the very act of levying an equipment-level EMI performance requirement that generates cost and schedule impact, not the actual type of limit (commercial or military). This is because in a single item procurement, all expense and time are in design and conformance verification. Actual cost of parts procured for the purpose of conforming to requirements is negligible compared to the design/conformance verification.

There is a common misconception that levying commercial standards is more cost effective than military or aerospace standards because commercial equipment generally costs less than military or aerospace equipment. This is a totally invalid comparison. Commercial equipment costs less because of sales volume relative to smaller military/aerospace procurements. Engineering design is optimized to reduce recurring costs when designing for large production runs. Small procurements cannot afford nonrecurring costs of a design optimized for low recurring costs. The only way to take advantage of low commercial costs is to buy a purely commercial item in which nonrecurring, engineering costs have been spread over thousands of articles. As soon as a special requirement is levied on the commercial article, cost savings are lost. In the same manner, when procuring a new single item procurement, it is the number, not the type, of EMI requirements levied, which determine the cost. The cost-effective approach is to levy only those requirements absolutely necessary.

These modulation schemes, required in ISO 7137, are consistent with test equipment capabilities and are applicable to audio, video, radar, and many information links. When testing flight or engine controls, or other critical subsystems with small physical bandwidths of operation, the 1 kHz modulation should be augmented by another lower frequency square wave modulation within the test article's bandwidth.

A.2.3.2 Power bus conducted interference, time and frequency domain, source induced

The power source designer does not normally know the exact filter characteristics, capacitor and inductor values, of the power loads; therefore, the assumption is made for the voltage ripple requirement that the power bus is loaded resistively. Resistive loading should allow the full rated current of the power source to be demonstrated.

Electronics tunable over the range of VLF to HF that are included in the space system or, in the case of a reusable space system power bus, can at any time be included in a payload, should have stringent ripple control through the HF band. Conducted emissions are typically controlled below HF and sometimes into a portion of the VHF band.

A.2.3.3 Power bus conducted interference, load-induced, frequency domain

The total of all load-induced ripple can be allocated on a percentage load basis to the total bus current; that is, the ripple voltage budget can be allocated on a volts per ampere basis. This approach yields an optimum limit for each piece of equipment, resulting in lower system masses for filter components. Furthermore, limit non-conformances may be viewed in a total system setting. If another equipment conducted emission in-band to the specification non-conformance is below the limit by the same or greater amount than the non-conformance, the non-conformance may be waived. If conducted emission currents are to be controlled by the equipment-level requirement, then the voltage ripple limit is adjusted for the power bus impedance to yield allowable current emissions. The budgeted ripple current limit is given in amperes of ripple current per ampere of load current. If conducted emission control is exerted below 10 kHz, it should be specified as a current limit, or a special bus impedance simulation should be developed uniquely for the programme and be adjustable for different load currents.

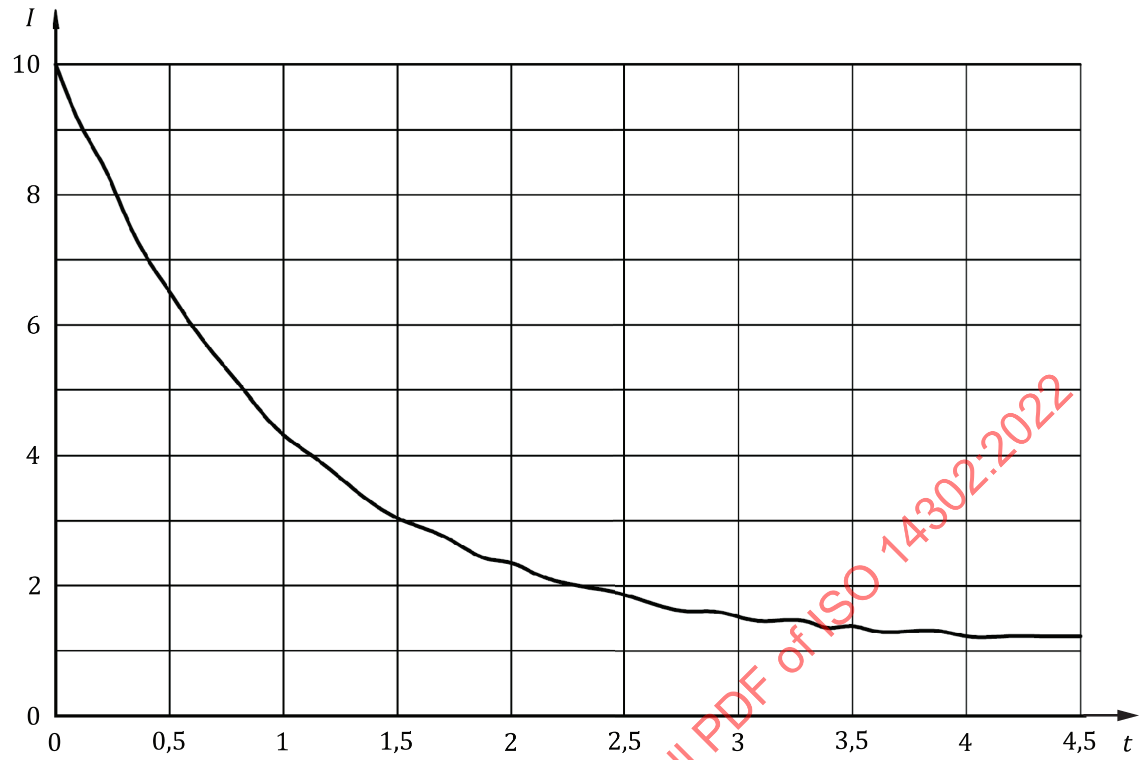
A.2.3.4 Power bus load-induced switching transient

A.2.3.4.1 General

The effects of two types of switching transients merit consideration. The first effect, termed a long-duration transient, is line voltage sag on the order of milliseconds due to an insufficiently stiff power source. This is an important consideration for a space system whose power subsystem relies on solar cells or any other current limited source. The second effect, termed a fast transient, is due not to the power source impedance but to the reactance of the power bus wiring. In this case the relevant factor is the time rate of change of the load current draw more than the magnitude of the current drawn that is the culprit.

A.2.3.4.2 Control of long-duration load-induced switching transients

Inrush current control should only be exerted if the current of the power subsystem is limited enough that individual load cycling can reasonably be expected to result in bus voltage sags. Inrush current limits should consider the power source stored energy capacity, its capability to supply transient current in excess of its steady-state maximum. This determines magnitude and duration of the inrush current limit. Figure A.1 illustrates a sample limit. Transient current limits are normalized to steady-state current draw. The curve is often approximated by a stair-step to ease conformance verification. Inrush current is measured from a stiff source; i.e. one in which voltage across the power source does not drop significantly when energizing the test article. Therefore, the test power source should not simulate the space system power subsystem. The point of the requirement is to control and measure the test article transient current with the power bus voltage kept constant in order to calculate the test article load characteristics during the inrush event.



Key

I transient/steady-state current, expressed in ampere

t time, expressed in milliseconds

Figure A.1 — Transient inrush current sample limit

A.2.3.4.3 Control of fast load-induced switching transients

The limit for fast load-induced switching transients should be set such that low-power loads may meet the limit without the use of a soft-start switch. The limit is a trade-off between requiring a soft-start switch and requiring large amounts of energy storage in victim power supplies. The test set-up power source impedance across which the transient is dropped should exceed the impedance of expected system power bus wiring. Turn-off transients should be limited only in magnitude. The turn-off transient waveform is solely a function of source impedance and time rate of change of the switched current. The designer has no other recourse to passing the test besides limiting the switch rise-time. If the switch is external to equipment, the designer has no means to meet the requirement, and the EMCAB should be careful about levying a reasonable requirement that does not generate numerous waiver requests. For a structure return bus, the inductance is on the order of 1 μH/m, whereas for an aboveground return, the inductance is less than 300 nH/m. Usually a value of 50 Ω is used for the LISN inductor bypass resistance in order to model high-frequency transmission line characteristics of a power bus. Transient durations of longer than 50 μs are typically measured against a current limit, for the same reason that steady-state conducted emissions are specified as a current below 10 kHz. Voltage control longer than 50 μs requires a programme-specific bus impedance simulation.

The criteria commonly used to identify frequently repeating transients are transients > 10/s.

A.2.3.5 Power bus load-induced time domain ripple

True r.m.s. ripple should be controlled to a level defined by the power quality ripple limit multiplied by the ratio of test article load current divided by total power source available current. The measurement instrument, preferably a digital storage oscilloscope with true r.m.s. capability, bandwidth should match that of the power quality specification when it states a certain ripple voltage with a specified bandwidth. Specified bandwidth corresponds to digital storage oscilloscope (DSO) effective repetitive bandwidth.

The DSO single-shot bandwidth should be able to capture a 100 ns waveform. If the equipment under test operates off an a.c. bus, then some means of nulling or reducing the power frequency waveform is necessary.

Another reason for performing this test is to verify stability of power bus with the equipment interface. Switched mode power supplies (SMPS's), which are common on space system power buses, draw a current waveform spectrum that occupies a band at which the power bus is a high impedance. If an adequate local low-impedance voltage source is not provided by the SMPS designer, large voltage oscillations across the power source may occur.

A.2.3.6 Signal cable conducted interference, frequency domain

Control of common mode currents on signal cables is an effective means of controlling radiation at frequencies below 1 GHz. This requirement refers to net current flowing in an entire bundle, in flight configuration.

A point of departure for determining a signal cable conducted emission limit is the conducted emission limit placed on power bus loads. The common mode emissions limit for signal cables needs to be only as required to control radiated emissions threats to receivers and/or cable coupling. This test adds programme cost and should only be done as an aid to troubleshooting because of the large number of cables on some equipment.

A.2.3.7 Antenna connection port spurious emissions

Antenna port spurious emissions may be measured either by injection at the connection of the antenna port to an EMI meter via coaxial cable or wave guide or by measuring radiated emissions from the subsystem antenna connected to the port (simulation of in situ condition). The former method has the advantage of simplicity and measurement accuracy, while the latter method more accurately accounts for antenna out-of-band gain and transmission line losses. The latter method is also indicated if the antenna is hardwired to the antenna port or if the transmit power out is too high to filter or to eliminate it otherwise from the EMI meter input in a direct connection.

A.2.3.8 Magnetic field radiated emissions

Control may be exerted either via directly limiting magnetic field emissions, zoning, or a combination of both. Zoning refers to separation of potential victims and culprits. Because low-frequency magnetic emissions from equipment enclosures fall off rapidly with distance, it may be most economical to limit magnetic emissions at a distance larger than the traditional 7 cm from the EUT. This is facilitated via zoning.

A.2.3.9 Radiated electric field emissions

Because traditional space system test methods measure field emissions at 1 m, the limit should be adjusted downward if any possible victim antenna or antenna-connected unshielded transmission line can be placed closer to the EUT than 1 m. Limits should reflect possible victim receivers operationally required sensitivity. Limits should also reflect the equipment proximity to the victim. If the space system is such that

a) there exists a clearly defined electromagnetic environment inside and outside of a shielded enclosure,

b) all antennas are mounted externally, and

c) shielded transmission lines connect internal receivers to bulkhead-mounted RF connectors,

then radiated emission limits imposed on internal equipment should reflect shielding/shading expected from the space system enclosure.

This limit is relaxed from the limit on externally installed equipment mounted in immediate proximity to victim antennas or unshielded transmission lines. If a space system contains a broadband source (ion thruster for example), care should be taken to characterize the noise over the bandwidth of the communications receiver bandpass. Internal use of a wireless intercom would necessitate a more stringent internal than external radiated emission limit in the band occupied by that transceiver subsystem.

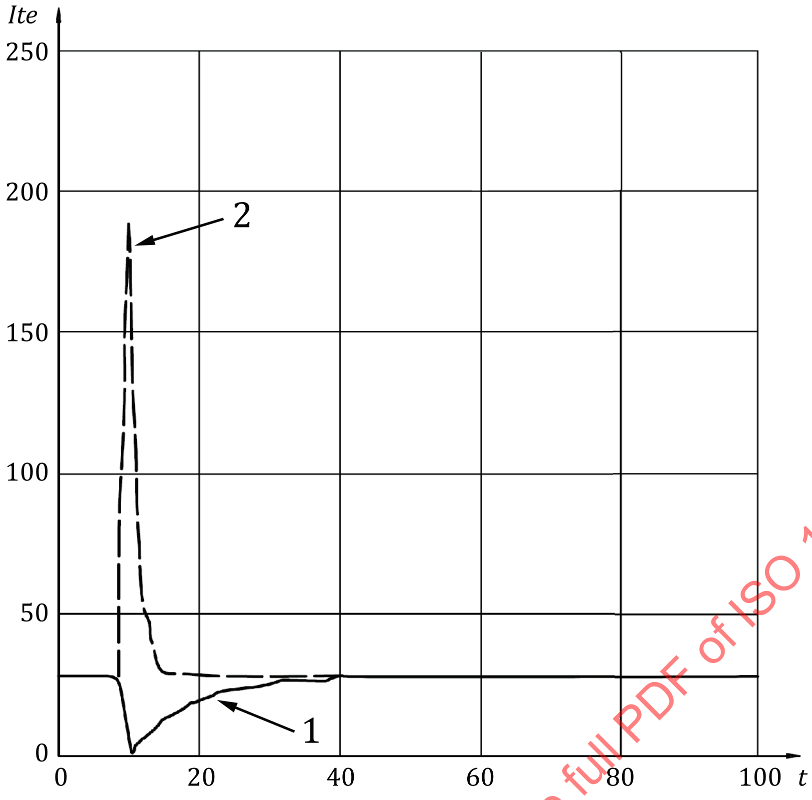
A.2.3.10 Immunity to audio frequency power-line ripple

The purpose of this requirement is to evaluate immunity of equipment to audio frequency power-line ripple. RF ripple immunity is evaluated using bulk current injection on power and signal lines as specified in 5.3.12.

A.2.3.11 Immunity to power-line switching transients

Although power quality specifications often show symmetrical (with respect to nominal voltage) positive and negative (turn-off and turn-on) waveforms, this is not an accurate representation. The turn-off transient is typically shorter in duration and higher in amplitude and source impedance than the turn-on transient if the switch time is shorter than 1 µs. The turn-off transient magnitude may be estimated by multiplying the maximum load current that can be switched in 1 µs by 50 Ω. The turn-on transient is the response of the power bus source impedance simulated circuit to the largest load that can be turned on without the benefit of a soft-start switch.

Figure A.2 shows a qualitative comparison of turn-on and turn-off transients from a 4 A load with a 100 µF input capacitor in parallel with a 7 Ω resistor operating from a 28 V d.c. bus. The source impedance is modelled by the CISPR 50 µH, 50 Ω LISN. Details of this LISN can be found in CISPR 16-1-2[9].



100 µF// 7 Ω, switched in 100 ns, from 50 µH, 50 Ω CISPR LISN.

Key

Ite transient excursions from 28 V d.c.

t time, expressed in microseconds

1 turn-off transient

2 turn-on transient

Figure A.2 — Switching transient envelopes on a 28 V d.c. bus

A.2.3.12 Immunity to the conducted effects of radiated electromagnetic fields

The coupled current limit may be computed from a knowledge of the field intensity, cable length, cable height above the ground plan and termination impedance. For the configuration assumed under ISO 7137, the limit is 1,5 mA/V·m at frequencies above which the cable length is one-half wavelength. At lower frequencies, the limit decreases linearly with frequency. It is suggested that a correlation be made by test to verify the 1,5 mA/V·m injection factor in critical applications. It is customary, for the sake of simplicity, to invoke a single limit based on a frequency independent maximum field intensity and the longest possible cable length for the space system. Care should be taken to ensure such simplifying assumptions do not result in a severe over test.

A.2.3.13 Immunity to audio frequency radiated magnetic fields

This requirement is normally applied to equipment designed to process audio frequency (30 Hz to 100 kHz) signals at microvolt levels. It can also be applied as an interface control, together with a companion magnetic emission limit, when two pieces of equipment, that operate in immediate proximity, are qualified by separate contractors.

The limit should be chosen such that the total impact to design for immunity and emission control is minimized. If, as is typical, the space system complement of victims requiring such protection is limited, the effort should be slanted towards maximum immunity levels and minimal control of magnetic emissions. Limits may be determined analytically if the victim is a magnetometer-type device; i.e. one which measures magnetic fields and whose sensitivity is specified. In this case, the culprit magnetic emissions should be less than the signal to be measured. If the sensor is mounted remotely from possible culprit emitters, immunity of the sensor-connected equipment should still be controlled. Because magnetic field intensity from small sources decreases rapidly with distance, zoning is a complementary approach to controlling susceptibility. See A.2.3.8.

If there are requirements for low-intensity magnetic field locations, the space vehicle integration defines such locations and environments and verify by test or analysis that these equipment threshold sensitivity levels are not exceeded.

A.2.3.14 Immunity to radiated electromagnetic fields

A very important consideration in radiated immunity limit setting for spacecraft is that many antennas used are extremely directional. When setting immunity limits, the side-lobe power density that can actually illuminate space system equipment/subsystems should be considered. This important caveat does not apply to electromagnetic fields originating on other platforms and which can possibly illuminate the space system with an antenna main lobe.

If the space system is such that there exists a clearly defined electromagnetic environment inside and outside (a shielded enclosure) and all antennas are mounted externally, then the radiated immunity limit imposed on internally mounted equipment should reflect the amount of shielding/shading expected from the space system enclosure. This limit is necessarily reduced from the limit on externally installed equipment mounted in immediate proximity to culprit antennas. This requirement should take into account also the close proximity of equipment and cables and their unintentional radiated fields.

NOTE The internal use of a wireless intercom necessitates a more stringent internal than external radiated immunity limit in the particular band occupied by that transceiver subsystem.

A.2.3.15 Immunity to magnetic fields induced signals to cabling

The limits for induced magnetic fields to cabling are normally set in accordance with typical system culprit cable signals (both current levels and transients levels are defined). Also, any circuits sensitive to magnetic coupling (cable to cable) should be identified. A test should be imposed only if sources are determined to be of a magnitude that would induce cross talk in sensitive circuits. Magnetic torquers may be the source of such fields.

A.2.3.16 Control of antenna port immunity to out-of-band interference

The requirement is easily tailored to the necessary pass band of a tuned super heterodyne receiver. For non-traditional receivers, such as frequency hoppers and spread spectrum receivers, tailored limits and test methods should be devised that address pertinent technical issues. Repetitive broadband RFI may be especially detrimental to spread spectrum receivers.

A.2.3.17 Immunity to electrostatic discharge

Due to the potentially destructive nature of ESD testing, especially the possibility of inducing latent failures, and the small production runs inherent in space system procurements, serious consideration should be given to the ESD control process, especially the type and degree of verification desired.