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Space systems — Electromagnetic compatibility requirements

Systèmes spatiaux — Exigences relatives à la compatibilité électromagnétique

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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.

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ISO 14302 was prepared by Technical Committee ISO/TC 20, *Aircraft and space vehicles*, Subcommittee SC 14, *Space systems and operations*.

Introduction

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

This International Standard 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 International Standard 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 International Standard may be tailored based on contractual agreements.

This International Standard references civilian equipment-level electromagnetic interference (EMI) test methods to minimize cost and allow the use of standard test methods. This International Standard 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 International Standard for individual programmes.

Space systems — Electromagnetic compatibility requirements

1 Scope

This International Standard establishes 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.

2 Normative references

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

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*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

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

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
normally the spacecraft or launch vehicle itself, but more generally a suite of equipment, subsystems, skills, and techniques capable of performing or supporting an operational role

NOTE A complete 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.

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 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, transmission, channel, or system caused by an electromagnetic disturbance

3.1.6
equipment/subsystem
any electrical, electronic, or electromechanical device or integration of such devices intended to operate as an individual unit and performing a specific set of functions

NOTE Generally, a piece of equipment is housed within a single enclosure, while a subsystem may consist of several interconnected units.

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

3.1.9
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

3.1.10
intersystem interference
harmful interaction between two different systems

EXAMPLE A launch vehicle docking with a space station.

3.1.11
intrasystem interference
harmful interaction between two different subsystems or between equipment of different subsystems that are all part of the same space system

EXAMPLE Uncommanded operation of a flight control subsystem due to a radio frequency (RF) transmission originating on the same spacecraft.

3.1.12
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

3.1.13
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

3.1.14
procuring activity
agency or organization funding or administering a contract for the development of the space system

3.1.15
radio frequency interference
RFI
degradation of the reception of a wanted signal caused by a radio frequency disturbance

3.1.16
safety margin
ratio of circuit threshold of susceptibility to induced circuit noise under worse-case expected environmental conditions (intrasystem and intersystem)

3.1.17
spacecraft
space vehicle which includes launcher, orbiting platform and probe(s)

3.2 Abbreviated terms

ACS	attitude control system
AM	amplitude modulation
AWG	American wire gage
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
EMC	electromagnetic compatibility
EMCAB	electromagnetic compatibility advisory board
EME	electromagnetic environment
EMEVP	electromagnetic effects verification plan
EMEVR	electromagnetic effects verification report
EMI	electromagnetic interference
EMISM	electromagnetic interference safety margin
ESD	electrostatic discharge
EUT	equipment under test
FFT	fast Fourier transform
FMEA	failure mode effects analysis
GEO	geosynchronous Earth orbit
HF	high frequency
ICD	interface control document
LEO	low Earth orbit

LISN	line impedance stabilization network
Mil-Std	military standard
NASA	National Aeronautics and Space Administration
PDR	preliminary design review
RDR	requirements definition review
RE	radiated emissions
RF	radio frequency
RFI	radio frequency interference
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 activity and prime contractor shall establish an overall EMC programme based on requirements of this International Standard, 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 activity for an alternate means of equipment-level conformance, providing that the system-level interface requirements of this International Standard are met.

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 activity 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. 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 activity, 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 the 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) electroexplosive 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 International Standard;

    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.

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 could result in loss of life and/or loss of space platform;

- b) Category II, mission critical:

    EMI problems could 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 could 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 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 payloads. 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 activity 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.

4.2.4.2 Wiring

Wiring, cable separation, and signal category design guidelines for the space system shall be established.

4.2.5 Electrical bonding

4.2.5.1 General

Electrical bonding measures shall be implemented for management of 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 could 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 could experience degraded operation or could 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 (ac) 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 Static discharge

Any isolated conducting items 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.

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 will be 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 static 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 to the extent necessary to protect against personnel shock hazard, fuel ignition hazard, radio frequency interference (RFI) and destruction of dielectric materials due to static discharge.

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

Plasma/payload-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.

4.2.9 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, subsystem, or spacecraft 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.