General

DESIGN STANDARD

EMC

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Japan Aerospace Exploration Agency

This is an English translation of JERG-2-241. Whenever there is anything ambiguous in this document, the original document (the Japanese version) shall be used to clarify the intent of the requirement.

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Contents

1. General provisions

The general requirements and design policy related to the design of electromagnetic compatibility (hereinafter referred to as EMC) of the spacecrafts developed by the Japan Aerospace Exploration Agency (hereinafter referred to as JAXA) are specified to the electric design standard (JERG-2-200). This EMC Design Standard (hereinafter referred to as "this design standard") is a summary of unified descriptions of electric design standard as a design standard for achieving EMC and specifies the details of the EMC requirements, general test conditions, test methods and verification requirements in the system-level and subsystem/component level for achieving the spacecraft EMC.

This design standard is reestablished based on the JAXA technological requirements/guideline document "EMC Design Standard (JERG-0-028)" in light of the latest technological information and the international trend of the Europe standards (such as ECSS) and international standards (such as ISO). It is expected that this standard will be utilized as a development guideline for future development.

1. 1 Objective

This design standard aims at defining the common process related to the EMC design, control, analysis, test and verification of the system, subsystem and component for ensuring the electromagnetic compatibility (EMC: Electro Magnetic Compatibility) of the spacecrafts developed by JAXA.

The requirement values and standard values during test, which are not specified in this design standard, shall be specified properly in the EMC control plan in individual projects.

1. 2 Scope

This design standard establishes the basic requirements related to the EMC design and verification of the spacecrafts developed by JAXA as a common standard related to EMC and is applied to the spacecraft development, launch vehicle, ground support facility and test equipment interface. However, if the JAXA specifications or other documents are applied in the scope to which this design standard is called and the details contradict between the two, the former shall deserve higher priority unless otherwise specified.

2 Related documents

2. 1 Applicable documents

The following documents shall be applied to the range to which this design standard is called. If a contradiction arises, this design standard shall deserve higher priority unless otherwise specified.

(1) JMR-001
System safety standard
(2) JMR-002A
Rocket payload safety standard
(3) JERG-2-200
Electric design standard
(4) JERG-2-211
Charge/discharge design standard
(5) JERG-2-213
Insulation design standard
(6) JERG-2-410
RF communication system design standard
(7) ISO14302
Electromagnetic compatibility requirements
(8) IEC 61002-4-2
Electromagnetic compatibility (EMC) 4-2 Electrostatic discharge immunity test method

2. 2 Reference document

The reference documents related to this design standard shall be as follows.

(1) ANSI/TIA/EIA-422-B-1994
Electrical Characteristics of Balanced Voltage Digital Interface Circuit
(2) MIL-HDBK-83575
GENERAL HANDBOOK FOR SPACE VEHICLE WIRING HARNESS DESIGN AND TESTING
(3) JERG-2-400
Communication design standard
(4) JERG-2-143
Radiation-proof design standard
(5) DOD-E-8983C
Electronic Equipment, Aerospace, Extended Space Environment, General Specification for
(6) JAXA-QTS-2060D
Reliability assurance connector common specification for space development
(7) SAE-AS50881
WIRING, AEROSPACE VEHICLE
(8) SAE ARP 1172:1972 (R1991)
Filters, conventional, electromagnetic interference reduction, general specification
(9) MIL-W-16878/4
WIRE, ELECTRICAL, POLYTETRAFLUOROETHYLENE(PTFE) INSULATED, 200 DEG. C, 600 VOLTS, EXTRUDED INSULATION
(10) MIL-HDBK-4001
ELECTRICAL GROUNDING ARCHITECTURE FOR UNMANNED SPACECRAFT
(11) MIL-STD-464A
ELECTROMAGNETIC ENVIROMENTAL EFFECTS REQUIREMENTS FOR SYSTEMS
(12) NASA-HDBK-4002
AVOIDING PROBLEMS CAUSED BY SPACECRAFT ON-ORBIT INTERNAL CHARGING EFFECTS
(13) NASA Technical Paper 2361
DESIGN GUIDELINES FOR ASSESSING AND CONTROLLING SPACECRAFT CHARGING EFFECTS
(14) NASA H-29919D [12]
SCIENTIFICA AND TECHNICAL AEROSPACE REPORTS VOLUME 38
(15) MIL-STD-1686C
ELECTROSTATIC DISCHARGE CONTROL PROGRAM FOR PROTECTION OF ELECTRICAL AND ELECTRONIC PARTS, ASSEMBLIES AND EQUIPMENT (EXCLUDING ELECTRICALLY INITIATED EXPLOSIVE DEVICES)
(16) JIS C 0617
Graphical symbols for electrical apparatus
(17) ISO/TC20/SC14 international space standard
  (a) ISO/DIS 24637 Electromagnetic interference (EMI) test reporting requirements

  - (b) ISO/DIS 26871 Explosive systems and devices
  - (c) ISO 14621-1 EEE parts - Parts Management
  - (d) ISO 14621-2 EEE parts - Control program requirement
  - (e) ISO 15389 Flight-to-ground umbilical

(18) ISO 7137-3.6 (Section 20.5)
Aircraft - environmental conditions and test procedures for airborne equipment

3 Definition of terms and abbreviated terms

3. 1 Definition of terms

The definition of terms related to this design standard shall be as follows.

(1) Electromagnetic compatibility (EMC)
The ability of a space equipment or system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment.

(2) Electromagnetic environment (EME)
Electromagnetic environment formed by natural phenomenon and other equipment.

(3) Electromagnetic interference (EMI)
Degradation of the performance of a space equipment, transmission, channel, or system caused by an electromagnetic disturbance

(4) Immunity
The ability of a device, equipment, or system to perform without degradation in the presence of an electromagnetic disturbance (insusceptibility to interference). Susceptibility used in MIL-STD-461 is the degree of sensibility to interference. Immunity is used in this design standard.

(5) Emission
Electromagnetic energy transmitted from equipment by radiated emission or conduction.

(6) Radio frequency interference (RFI)
Degradation of the reception of a fundamental signal caused by a radio frequency disturbance.

(7) Safety margin
Ratio of circuit threshold of immunity to induced circuit noise under worst-case expected environmental conditions (intra and intersystem).

(8) Spacecraft
The space vehicles including artificial satellites and probes.

(9) Space system
Normally the spacecraft or launch vehicle itself but used as a generic term for spacecrafts and related facilities and test equipment in this design standard.

(10) Bus equipment

Generic term for primary subsystem configuring the space system.

(11) Mission equipment

Generic term for the primary subsystem that governs observation and communication, which are objectives of spacecrafts.

(12) Subsystem

Functionally-partitioned system elements that configure the spacecraft. From the point of EMC, no significant differences exist between the bus-subsystem and mission-subsystem in this design standard. Both are referred to as subsystems.

(13) Component

Generic term for units configuring the subsystems in this design standard.

(14) Electric power system

Subsystems that govern such functions as power generation, power control, power storage, and power distribution (except for harnesses supplying power to loading units). (The electric power system does not necessarily mean the combination of the solar cell paddle system and the power source system.)

(15) Primary power source

Power source that is generated/controlled in the electric power system of the spacecraft and distributed commonly to loading units in the spacecraft. (The power that is stepped down or boosted from the primary power source bus in the electric power system and distributed commonly to the loading units in the spacecraft shall be the secondary power source.)

(16) Secondary power source

The power that is stepped down or boosted from the primary power source bus in and outside the electric power system of the spacecraft.

(17) Multibus

The multibus is the system having more than one power source bus that is functional independently. Other methods are available to connect or disconnect more than one bus.

(18) Hazard

Human damage, physical damage to public or third-party private property, system, range facility, and environmental implications.

(19) Malfunction/damage

Malfunction means the degradation of the performance and damage means the loss of the function.

(20) Breakout box

A piece of non-flight test equipment that is connected in series with the cables and allows the measuring external connections (normally, connection terminals) or serial-parallel test networks to be connected to the cables.

(21) Internal charging

Static charging phenomenon generated in metallics or dielectrics having no electrical interconnection with the surrounding. A phenomenon when secondary radioactive rays, which are caused by penetration of cosmic radiation or cosmic radiation through spacecraft structures and/or component walls, are remained in the object or electrons in the object are ejected outside.

(22) Power source quality requirement

Requirements for power subsystems in the spacecraft defining the supply voltage, noise (caused by load stabilization, spike or hanging), and impedance required by power source users.

(23) Intermodulation characteristic

A characteristic that the amplitude of fundamental wave is influenced by the change in the amplitude of the distorted wave component (third-order harmonics component in particular) of the interfering wave generated by the nonlinearity of the amplifier in the receiver when both desired wave and interfering wave are input at the same time to the receiver input.

(24) Spurious modulation characteristic

A characteristic that a new unremovable frequency component is formed in the reception bandwidth by the distorted wave component of the interfering wave generated by the nonlinearity of the amplifier in the receiver when both desired wave and interfering wave are input at the same time to the receiver input.

3. 2 Abbreviated terms

Abbreviated terms related to this design standard shall be as follows.

AC	Alternative Current
BCI	Bulk Current Injection
CE	Conducted Emissions
CS	Conducted Susceptibility
DC	Direct Current
DSO	Digital Storage Oscilloscope
EED	Electro Explosive Device
EMC	Electro-Magnetic Compatibility
EME	Electro-Magnetic Environment
EMI	Electro-Magnetic Interference
ESD	Electrostatic Discharge
EUT	Equipment Under Test
FFT	Fast Fourier Transform
GSE	Ground Support Equipment
I/F FMEA	Interface Failure Mode Effects Analysis
LISN	Line Impedance Simulation Network
RE	Radiated Emissions
RF	Radio Frequency
RFI	Radio Frequency interference
RS	Radiated Susceptibility
SDR	System Design Review
SRR	System Requirement Review

4 Basic requirements

The space system shall be electromagnetically compatible with the spacecraft itself and predefined external facilities/other systems, and electromagnetic environment in nature during all phases and orbital operations of its mission including design, manufacturing, test and launching. The EMC control of the space system shall be achieved by designing of all subsystems/components within the space system and of the interface design with external electromagnetic environment.

The objectives of EMC control are to maintain the cost and schedule for manufacturing and testing of the spacecraft and eliminate electromagnetic interference during operation, ensuring the spacecraft-level function and performance.

In this chapter, general requirements for EMC control related to the entire space system are specified. Individual design requirements are specified in chapter 5: space system-level EMC requirements and subsystem/component-level EMC requirements are specified in Section 5. 1 and 5. 2, respectively. Requirements on verification are specified in Chapter 6.

4. 1 Total EMC control

4. 1. 1 Summary

In the spacecraft project, the EMC program shall be specified in its early stage.

The program shall be a comprehensive plan based on suitable interface control specifications in consideration of requirements from the bus equipment to the mission equipment, requirements from the mission equipment to the bus equipment, all other related external facilities/other systems, and electromagnetic environment in nature.

The EMC between these mission equipment/bus equipment (intersubsystem) and systems/subsystems shall be proved to be free from functional problems with a suitable safety margins.

The EMC control shall be implemented based on the EMC plan by the EMC control organization. The EMC control organization shall be specified in the following section.

4. 1. 2 EMC control organization

Comprising an organization mainly to investigate the system-level EMC plan, total requirements and verification plans, and solve the issues over the entire period of the project ranging from the initial phase of the space system development to the integration phase, implementing the EMC control program smoothly. The organization shall consist of spacecraft project and spacecraft developers (including the manufacturer), mission equipment developers and independent intellectuals under the supervision of the project manager and be committed to solving the issues in implementing the entire EMC control program. The EMC control organization shall select and organize well-equipped personnel for performing EMC control as appropriate according to the spacecraft development phase and the size and complexity of the system.

4. 1. 3 EMC program

The EMC program in the spacecraft project shall be developed in the following steps and controlled by the EMC control organization.

a) EMC program control requirements

The EMC program shall be documented as an EMC control plan. The EMC control plan shall include the following control requirements.

1) Each constituent component in the space system shall be controlled by relating the responsibility of EMC requirements to the manufacturing and verification plans and required design change process.
2) The EMC control plan shall include the following items;
   (a) The structure of facilities and personnel required for succeeding the EMC program
   (b) The method and procedure for implementing the design review and adjustment related to EMC
   (c) Specify EMC requirements and standards (including the setting of specific domain protection related to radio communication equipment)
   (d) Weber, deviation process
3) Program and schedule:
   The EMC program, schedule and milestone in the program development master schedule shall be specified.

b) System-level function and design requirements

To achieve EMC as a space system, the following requirements shall be considered.

1) Identification of related environment
   As spacecraft-level EMC requirements, consideration shall be given to all electronic devices in the system, test facilities used in testing and electronic devices in the launch site, launch vehicle and risk of electromagnetic radiation to explosive devices including launch site environment.
2) Allocation of EMC performance
   EMC performance shall be allocated to each component from the standpoint of system feasibility in the light of space system-level EMC requirements.

c) Subsystem/component requirements

In deciding subsystem/component EMC requirements, consideration shall be given to the following points.

1) Space system-level requirements shall be allocated properly to systems/subsystems/components and ground support facilities defined in this design standard. In light of these performance requirements, the EMC test level for EMC test facilities shall be set.
2) In conducting EMC verification, the conditions including the procedure and method for

adjusting the verification test range and test method with the EMC test facility side shall be specified.

3) Subsystem/component EMC test result summary
    (a) Subsystem/component-level EMC test results shall be summarized.
    (b) All problems judged to be acceptable shall be recorded in detail. The analysis results in light of conditions of general EMC performance shall be presented as a criterion for decision. The test results shall be investigated in consideration of cost, schedule, reliability, system operability and other factors.

d) EMC analysis requirements

Subsystem/component EMC analysis shall be conducted as follows:

1) For possible interference in the space system, EMC analysis shall be conducted at the system, subsystem and component levels to check for interrupted operation.
2) In performing design to cope with possible or actual interferences, environment at the test facility level shall be considered as conditions for input impedance coupling (conductivity radiated emissions) and electromagnetic field radiation of cables and wiring harness to be wired.
3) In all modes in which the on-orbit space system is expected to be operated, EMC analysis based on the actual presented values shall be conducted on the interface of EMI characteristics of the facilities, subsystems and components. The EMI safety coefficient of the space system EMC shall be determined.
4) If judged to be necessary to achieve the EMI safety coefficient according to the analysis results, it shall be appropriate to request for addition of filtering and shielding to subsystems/components and design change with respect to EMI.

e) Verification plan requirements

EMC verification shall be conducted in a comprehensive plan on items necessary for ensuring the interfaces, functions and performances in phases including designing, manufacturing and testing of systems, subsystems and components without any omission. Notes for EMC analysis shall be included in the verification plan.

This shall include identification and selection evidences of critical portions which are subject of safety margins validation, and measurement technology of sensitivity to critical portions and EED equipment/circuits.

f) Weber related

Even if the results of confirmation and verification after manufacturing subsystems/components (including supplied parts) cannot satisfy the requirements for the EMC standard established in the space system project, the equipment concerned can be applied to the system as long as the system side judges that it is allowable. However, judgment validity on the system side shall be discussed by the EMC control organization.

g) Charge/discharge analysis

1) Electrostatic discharge
   It shall be verified in analysis or testing that nonenergized electronic devices are not damaged by electrostatic discharge to the pin or external connector.
2) Charge/discharge
   The subsystems/components shall be designed not to be damaged by plasma in any operational environment of the space system. It shall be indicated in analysis that corona will not damage the subsystems/components. See Charge/discharge design standard (JERG-2-211) for details.

h) Requirements related to explosive articles

For equipment related to explosive articles, particular attention shall be given to the following requirements. See Section 5. 5 of Rocket payload safety standard (JMR-002B) for details.

1) Extraction and evaluation of requirements and setting of margin for proper explosive article-related EMC
2) Design-related technological requirements
3) Verification-related technological requirements

4. 1. 4 Identification of critical portions

The EMC control organization shall identify functional criticality for all subsystems/components. 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 that could results in injury, damage to space platform, mission abort or delay, or performance degradation which unacceptably reduces mission effectiveness
C) Category III, Noncritical - EMI problems that could result only in annoyance, minor discomfort, or loss of performance which does not reduce desired spacecraft effectiveness

To ensure the success of EMC control, items that should be identified to be of special importance and verified as a space system shall be extracted. Identification of some critical portions must be done from the stages before starting designing. Consultation shall be held in full by the EMC control organization from the initial phase of the project.

4. 1. 5 Securing safety margins

Design safety margins (system margins) for important circuits and EED circuits shall be reviewed and specified by the EMC control organization. Safety margins shall be specified properly in consideration of the degradation of functions and performance, degradation mode due to secular change and protection method of the systems, subsystems and components in the spacecraft over the entire planning period. The safety margins related to electromagnetic interference in critical portions shall be defined based on the comparison of noise level and sensitivity level in these portions.

5. Individual design requirements

5. 1 System requirements

EMC requirements shall be divided into the following two categories according to the purpose:

(1) Equipment malfunction prevention
Requirements to prevent equipment malfunction due to electromagnetic interference and meet equipment functions. Requirements common to a number of spacecrafts.
(2) Mission requirement achievement
Requirements that are not at the level causing malfunction but required to achieve mission requirements and meet equipment performance. Requirements unique to spacecrafts.

System requirements and design standard shall be specified by making a close investigation as to which is stricter in the phases (such as SRR and SDR) before designing.

5. 1. 1 External electromagnetic environment

In system design, the electromagnetic environment due to external interference sources shall be discussed. The degree of degradation of the system validity caused by external environment shall be discussed in consideration of mission profile and available electromagnetic environment data.

5. 1. 2 Intrasystem EMC

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

5. 1. 3 EMI control

In EMI control, it is important that the system controls the entire spacecraft in a cross sectional manner. The presence of a piece of equipment with a significant noise emission will affect the entire spacecraft. The project EMC control plan shall be observed.

5. 1. 4 Grounding and wiring design

5. 1. 4. 1 Grounding

As intrasystem grounding points, metal structure portions and grounding bus bars that can be used as the zero potential reference points provided properly in the spacecraft structure shall be specified. Details shall be clarified in the EMC control plan. The following items shall be included:

(1) Relationship with the return/standard electrode potential of both power system and signal system shall be indicated.
(2) The impedance of connections related to the preceding paragraph shall be indicated. Impedance magnitudes of these connections over the affected signal spectrum shall be considered in determining which kind of power and signals share common paths (wire or structure/enclosure).

Specific resistance and inductance values for each element of electric networks provided as ground points can be assigned. (See Section A1. 1.) The use of these values allows you to calculate the common mode voltage at each circuit reference point and compare with conductivity sensitivity requirements of each equipment.

5. 1. 4. 1. 1 Grounding/insulation system diagram

Because grounding and insulation are related closely to the space system EMC, the grounding and insulation system diagram for space systems, subsystems and components shall be created to check for compatibility in the entire system.

5. 1. 4. 1. 2 Grounding and insulation of power source

(1) Primary power source

The grounding of power source shall be determined based on the power design policy. The grounding point to the structure shall be single so that the structure is not used as the current return path.

(2) Secondary power source

The return path of the secondary power source shall be controlled as the space system and grounded with any of the on-board equipment, subsystem or system.

Grounding points shall be determined in perspective of EMC control including function/performance requirements for on-board equipment, requirements for other pieces of on-board equipment to be interfaced with or inter-equipment interfaces as the subsystem and interfaces in the system. A proper insulation resistance shall be secured between the primary power source and secondary power source as a rule.

(3) Multibus power source

When setting a multibus power source, grounding policy shall be clarified for each independent power source system. When each power system is provided with a single-point grounding as a policy, a single-point grounding shall be provided for each system. A proper insulation resistance shall be ensured between power systems.

5. 1. 4. 2 Wiring

The design guideline for system wiring and cable separation/signal classification shall be specified.

5. 1. 5 Electrical bonding

5. 1. 5. 1 General

This paragraph is intended to ensure the equipment performance. The main point is to ensure a proper current path and voltage distribution in the electric circuit to be installed.

5. 1. 5. 2 Power current feeder and return paths

Twist pair wires shall be used for the power current feeder and return paths. Attention shall be given so that direct current magnetic field and electromagnetic wave will not be radiated. The structure shall not be used as the current return path.

5. 1. 5. 3 Shock and safety hazards

Not applicable.

5. 1. 5. 4 Antenna counterpoise

The structure with the counterpoise attached shall be bonded so that RF currents have a low impedance path.

5. 1. 5. 5 RF potentials

It is desirable that portions, except for antenna, that are possible subject to electromagnetic radiation to outside or electromagnetic interference from outside be bonded to the grounding point with a faying surface bond to present a low impedance. The bonding straps shall be as short as possible and maintain a low inductance path.

5. 1. 5. 6 Electrostatic discharge

JERG-2-211 shall be applied.

5. 1. 5. 7 Explosive atmosphere protection

Not applicable.

5. 1. 5. 8 Structure shielding

The structure discontinuous portions (such as cover, inspection holes and joints) shall be limited to the minimum. For discontinuous portions at important points with respect to RF interference noise and interference sensitivity, a low impedance conductive path shall be provided for conduction of electricity.

Note that the wire harness having an imperfect EMI shield may act as a discontinuous portion of the structure.

5. 1. 5. 9 Filtering

(1) For filtering spacecraft noise, the signal interface cable establishing connection between on-board components shall be provided with an EMI shield as needed in consideration of the signal level, interface circuit filter characteristics and radiated electromagnetic field.
(2) The attenuation level of the radiated electromagnetic field with respect to the on-board equipment shall be analyzed by a standard measurement method or at typical places in the internal shielding enclosure. The shielding may be done by providing a spacecraft basic structure designed as a Faraday cage (box) having a minimum number of openings or through-hole portions, or an enclosure for electronic device, or using the combination of these shields.
(3) The electronic devices and cables outside the structure shall be shielded so that proper margins are ensured in consideration of the uncertainty of spacecraft electromagnetic environment.

To allow the filter to produce an effect, it shall be noted that the impedance at before and behind the insertion point and the relation between electromagnetic environment characteristics and impedance are proper. Prepare a mechanism for letting the noise and radiated emissions that should be cut off escape to another path or for heating. (See Section A1. 2.)

5. 1. 6 Antenna-to-antenna (RF) compatibility

Designing and inspection shall be implemented so that no unexpected interference occurs between any RF devices. This shall be realized not only in the single system but also between the systems when interface requirements are made. Intermodulation characteristics shall be included when doing with not inspection but analysis.

5. 1. 7 Lightning discharge

The space system shall be protected from direct and indirect effects of lightning discharge to accomplish the mission without any performance degradation after exposed to lightning discharge. A combination of elimination of lighting discharge through operation and electric overstress design technology shall be used as protective measures.

5. 1. 8 Spacecraft and static charging

5. 1. 8. 1 General

In order to avoid any risk of the human electric shock, fuel ignition, radio wave interference (RFI), dielectric material breakout, and other caused by ground operation or environment prior to launch and in-orbit high energy plasma environment, the space system shall be controlled its charging and eliminated.

5. 1. 8. 2 Differential charge/discharge

Differential static charging phenomenon in components due to plasma, electric discharge phenomenon and degraded performance of the space system shall be minimized through preventive measures for design and integration. However, because complete elimination of electric discharge cannot be assured, it shall be required that tolerance of the satellite system be reinforced and that the spacecraft be verified to be operative without malfunction, performance degradation and out-of-spec parameter under repeated electrostatic arc discharge, which is a typical disturbance phenomenon of possible exposure.

5. 1. 8. 3 Internal charging

When the electronic flux event is an orbit parameter enough to cause internal charging, the tolerance reinforcement technology for preventing electrostatic discharge (ESD) from reaching the limit value shall be adopted to minimize static charging to these surfaces.

5. 1. 8. 4 Charging of fluid lines (liquid fuel lines)

To prevent the pipes, tubes and hoses for liquid from developing arc discharge, static charging preventive measures shall be implemented on the liquid and its transportation system.

5. 1. 8. 5 Electric discharge prevention under low vacuum environment

For the on-board equipment that may develop glow discharge during vacuum transition (critical pressure), consideration shall be given to electric discharge prevention. The examples shall be as follows:

(a) On-board equipment with the primary power source turned on during launching
(b) Any component that may be charged in the capacitor bank, etc
(c) Transmission filter (or diplexer) during high-power transmitter output

Consideration shall be given to the interrelation between the emission rate of outgas volume discharged from the air vent and the vacuum transition rate due to rocket launching elevation.

5. 1. 9 Hazards of electromagnetic radiation

The space system shall be designed so that fuels, personnel, explosive systems (including EED), and electronically actuated engine/thruster are not exposed to electromagnetic radiation at a dangerous level. Safety shall be ensured in consideration of possible electromagnetic interference from the external transmitter.

5. 1. 10 Consideration of life cycle

The electromagnetic environment (EME) protection design shall include the concept of protection life cycle (e.g., identification, method, reliability, maintainability, serviceability, verification and inspection requirements of protection elements).

For maintainability in particular, the EME protection mechanism shall be designed so that it can be easily accessed, maintained or complete the operating life of the space system without essential maintenance or inspection. Bonding, shielding and other protection technologies to be disconnected, pulled out or cancelled during maintenance shall be specified in the maintenance document with operation required for reassembly. These protection mechanisms that need to be repaired during life cycle of the space system shall have the function to test or inspect specified performance.

5. 1. 11 External grounds

Be sure that the grounding cable can be connected to the space system to equalize the electrode potential (or diffuse static charging) before applying electric power by other procedures or through the interface.

5. 1. 12 Test equipment/facility interface

For the test equipment/facility to be electrically interfaced with the spacecraft, consideration shall be given to the following points:

For the power lines, there shall be protection function on the test equipment/facility side.

The regulations on disturbance during testing shall be complied with.

Grasp the measures for spacecraft installation facility during lightning in advance and ensure a proper connection.

Grasp the mutual grounding system of spacecraft, test equipment and facility and ensure a proper connection.

Implement I/F-FMEA on the circuit to be interfaced with the spacecraft as needed.

Grasp the electric limitations on the test equipment/facility in advance and clarify the interface with the spacecraft.

5. 1. 13 Spacecraft magnetic emissions

Control on magnetic emissions shall be required when a small magnetic field of the earth, planet surrounding or inter-planet space is observed, or equipment sensitive to magnetic field is installed, or satellite position disturbance must be strictly avoided or controlled under a relatively strong magnetic field environment (low elevation around the earth). Depending on the purpose of control, proper standards of DC and AC magnetic fields shall be defined for each component in the spacecraft. It will be necessary to perform control not only on the spacecraft design and magnetism inherent to parts concerned but also on prevention of subsequent magnetization. Thus, regulations shall be specified as needed for the magnetic field environment for spacecraft testing and the tools used for manufacturing and testing. Appendix A2 shows specific reference information on measures against spacecraft magnetic field.

5. 1. 13. 1 Magnetic material

The spacecraft with magnetic field requirements shall be designed to use magnetic materials to a minimum. Employed materials shall be specified in the design standard. The EMC control organization shall grasp and control the use of magnetic materials as well as its countermeasures if there is no other choice but to use them. (See Section A2. 1.)

5. 1. 13. 2 Current loop

If current loop exists in the spacecraft, magnetic field is developed according to the current strength and loop area. When designing a spacecraft with magnetic field requirements, proper consideration shall be given. Adequate care shall be given to the harness wiring between devices and the loop through the ground. (See Section A2. 2. 3.)

5. 1. 13. 3 Magnetic moment

When it is necessary to control the satellite position disturbance due to the environment magnetic field after launching, the magnetic moment of the spacecraft may be controlled. Criteria shall be specified in the project EMC control plan to control the magnetic moment. Measures shall be taken to offset the magnetic moment as needed. (See Section A2. 2. 2.)

5. 2 Subsystem/component requirement

5. 2. 1 General requirement

System-level EMC requirements shall be distributed to EMI requirements at the subsystem/component level. Subsystem/component-level EMI requirements shall be specified basically for each space system development based on the following concepts.

The matrix of the applicability, reference test method and standard for subsystem/component-level requirements shall be shown in Tables 5. 2-1 and 5. 2-2.

For the immunity requirements for evaluating the effects of radio wave transmission, the radio modulation system used in actual spacecrafts shall be simulated.

5. 2. 2 Grounding and insulation of on-board equipment

Grounding and insulation of on-board equipment shall be designed as follows: (See Section A1. 1.)

(1) When the on-board equipment is not connected to the spacecraft power source, proper insulation resistance shall be provided between the primary power source input line of each on-board equipment and the chassis of the on-board equipment.

(2) Proper insulation shall be provided between the primary power line and the low frequency signal line.

(3) Proper insulation resistance shall be provided between primary power source return and the signal or secondary power source return of the on-board equipment that generates high frequency or operates at high frequency.

5. 2. 3 Primary power line conduction emissions for power source

These requirements shall be applied only to the power subsystem. These requirements are predicated on the power bus characteristics under resistive load.

The power source bus voltage ripple (time domain, frequency domain) shall satisfy the power source quality requirements under all load conditions. To limit radioactive emission from the power source bus, consideration shall be given to the control of conductivity emission.

5. 2. 4 Primary power line conduction emissions for load

These requirements shall be applied from the power source bus to subsystem/component operation.

When specifying requirements for conductivity emission, the total voltage noise of load-induced power source bus shall meet the power source quality requirements. The normal and common mode ripple noise requirements shall be applied to each subsystem/component as long as the effect of noise generated by the subsystem will not exceed the power source quality standard. When specifying the upper limit of conductivity noise, consideration shall be given to radio emission noise having effect on the receiver.

Table 5. 2-1 Subsystem/component level test application matrix (emission)

Test category	Requirement/verification Item number	Applicability	Basis for test method
Power-source induced power line conductivity emission, time and frequency domain characteristics	5.2.3/6.3.2	Applied to power subsystem	Appendix
Load-induced power line conductivity emission, frequency domain characteristics	5.2.4/6.3.3	Application	MIL-STD-461 CE101、CE102
Control of long-duration load-induced switching transients	5.2.5.2/6.3.4.2	Specified individually	Appendix
Control of fast load-induced switching transients	5.2.5.3/6.3.4.3	Application	Appendix
Load-generating power-line ripple	5.2.6/6.3.5	Specified individually	Appendix
Signal line/conductivity emission	5.2.7/6.3.6	Specified individually	Appendix
Antenna connection port spurious emissions	5.2.8/6.3.7	Applied to antenna connection terminal	Guideline is described in Appendix.
Magnetic field/radioactive emission	5.2.9/6.3.8	Specified individually	MIL-STD-461 RE101
Electric field/radioactive emission	5.2.10/6.3.9	Application	MIL-STD-461 RE102

Note: For items indicated as "specified individually", the necessity of application shall be specified according to the EMC control plan.

Table 5.2-2 Subsystem/component level test application matrix (immunity)

Test category	Requirement/verification Item number	Applicability	Basis for test method
Audio frequency power line/ripple immunity	5.2.11/6.3.10	Application	MIL-STD-461 CS101
Power line/switching transient/immunity	5.2.12/6.3.11	Application	Appendix
Radioactive electromagnetic field conductivity effect immunity	5.2.13/6.3.12	Specified individually	MIL-STD-461 CS114
Audio frequency radioactive electromagnetic field immunity	5.2.14/6.3.13	Specified individually	MIL-STD-461 RS101
Radioactive electromagnetic field immunity	5.2.15/6.3.14	Application	MIL-STD-461 RE103
Magnetic field induced signal immunity to cable	5.2.16/6.3.15	Specified individually	Appendix
Antenna connection port immunity to out-of-band interference	5.2.17/6.3.16	Receiver	Depending on the receiver type
Immunity to electrostatic discharge	5.2.18/6.3.17	Application or handling procedure	MIL-STD-1541

Note: For items indicated as "specified individually", the necessity of application shall be specified according to the EMC control plan.

5. 2. 5 Primary power line switching transient

5. 2. 5. 1 General requirement

The effect of two types of switching transients shall be controlled.

Among the two types of switching transients are long-duration switching transient (duration of order of millisecond or more) and rapid switching transient (duration of order of millisecond or less).

(1) Output impedance
For the power subsystem, specify the power source side output impedance in the loading unit input terminal and define the LISN (Line Impedance Simulation Network) model.

(2) Maximum input current
The maximum value of on-board equipment side consumption current including the operational transient during steady operation (excluding during inrush) shall be specified.

5. 2. 5. 2 Inrush current

The load-induced long-duration switching transient (inrush current) shall be restricted so that the voltage level will be maintained within the power source quality allowable range of the power subsystem.

5. 2. 5. 3 Current changing rate

The envelope range of the rapid switching transient shall be controlled so that an accurate envelope range of the steady transient current can be specified by the power source quality specification. The size and duration of both the operational transient and turn-on transient shall be controlled. These transients can be evaluated separately unless they are repeated transient disturbance that can be observed in the frequency domain.

5. 2. 6 Primary power-line ripple

The primary power-line ripple induced by load ripple shall be controlled. In consideration of the power source supply impedance, specify the ripple requirements for components, conduct time domain ripple measurement using test piece and check that the envelope line satisfies the requirements.

5. 2. 7 Signal line conduction emissions

When emission to the receiver and high-sensitivity electronic devices must be prevented at the mission-specific working frequency, the common mode current of the cable bundle shall be controlled.

5. 2. 8 Antenna terminal spurious emissions

To ensure radio wave frequency domain (RF) compatibility between antennas, control shall be performed on the spurious emissions at the antenna connection terminal.

When defining the allowable limit and frequency range, consideration shall be given to the following items.

a) Sensitivity including the out-of-band response of the interfered receiver subsystem (receiver, transmission line, antenna)
b) Exemption of transmission frequency (of transmitter and transceiver) and modulation bandwidth for information transmission
c) Highest and lowest frequency used intentionally by the spacecraft intrasystem receiver
d) Gain/loss characteristics of antenna connection terminal accessory

5. 2. 9 Magnetic field radiated emissions

When the magnetic field of the spacecraft must be controlled, magnetic emission reduction measures shall be implemented from the design phase at the subsystem and component level. When deciding service parts and design, magnetic effect on the spacecraft performance shall be verified. It is useful, in view of test verification, to simply set a uniform standard (magnetic field strength generated at a certain distance from each subsystem or component) for allowable magnetic emission strength used in verification to each subsystem or component. However, the effects on the spacecraft performance shall be verified eventually in consideration of characteristics (such as spacecraft on-board position and orbital operation method) of each subsystem/component. When magnetic field control is implemented, it shall be required to prevent the radiation of magnetic field and perform control for preventing magnetization. Thus, it may be necessary to set specifications on the magnetic field environment of the test site for subsystems/components and the tools for manufacturing and testing.

Specific reference information on subsystems/components magnetic field control shall be shown in Appendix A2.

5. 2. 9. 1 Magnetic material

Same as Section 5. 1. 12. 1. (See Section A2. 1.)

5. 2. 9. 2 Current loop

The presence of current loop in the subsystem/component leads to the development of a magnetic field in accordance with the current and loop area. When designing subsystems/components installed to the spacecraft with magnetic field requirements, due consideration shall be given. Special care must be taken with the equipment requiring large current or large-area equipment.

(See Section A2. 2. 3.)

5. 2. 9. 3 Magnetic moment

Magnetic components have a large magnetic moment in many cases. In consideration of the level to be reduced, presence or absence of time variation in magnetic moment, effect of time variation in magnetic moment on the spacecraft performance and available weight budget, an appropriate method shall be selected from magnetism offset between components, magnetic shield or cancel magnet.

(See Section A2. 2. 2 for specific method for reducing magnetic moment.)

5. 2. 10 Radiated electric field emissions

The radioactive electric field emission of all subsystems/components shall be controlled.

Special care shall be taken with the receiver frequency bandwidth of the spacecraft and launch vehicle. For subsystems/components commonly used, radioactive electric field emission requirements for the target system side receiver sensitivity bandwidth shall be satisfied. The regulations for allowable range shall reflect the operational sensitivity of the interfered receiver, the gain, directivity and installation position of the interfered antenna.

5. 2. 11 Immunity to power-line ripple

Subsystems/components shall have immunity to the allowable audio bandwidth ripple in accordance with the applicable power source quality specifications and conductivity emission requirements. A proper margin shall be provided between the allowable ripple level on the power source bus and the sensitivity level of subsystems/components.

5. 2. 12 Immunity to power line switching transient

All subsystems/components shall have immunity to the load-induced switching transient defined in the power source quality specification.

5. 2. 13 Immunity to the conducted effects of radiated electromagnetic fields

Subsystems/components operated in the spacecraft system exposed to intentional radio emission shall have immunity to the common mode current induced by equipment-to-equipment connection cables or power lines. These requirements shall only be applied to the frequency of possible intentional radio wave transmission. These requirements shall be verified by implementing the bulk current injection (BCI) test up to 400 MHz.

5. 2. 14 Immunity to magnetic field emissions

The immunity to magnetic field shall be controlled without any hindrance in the presence of AC magnetic field environment that may cause hindrance to the subsystems/components in the space system.

5. 2. 15 Immunity to electric field emission

Whether transmission is intentional or not, the immunity of subsystem/component to radio wave transmission shall be controlled so that space system-level electromagnetic compatibility is ensured.

Special consideration shall be given to providing immunity to the electromagnetic field radiated from other than the spacecraft transmitter operation bandwidth and the space system when the electromagnetic field must be controlled.

5. 2. 16 Immunity to signal line magnetic field conduction

When high-density wiring cables are used in the space system, immunity to cable-to-cable coupling shall be verified in inductive noise sensitivity test. In that case, audio bandwidth magnetic field coupling and transient disturbance coupling shall be applied.

5. 2. 17 Antenna terminal out-of-band immunity

The out-of-band radiation interference characteristics of the radio receiver shall be controlled. Spurious signal characteristics, cross-modulation characteristics and intermodulation characteristics shall be controlled.

5. 2. 18 Immunity to electrostatic discharge

In consideration of electrostatic discharge, the ESD control method for subsystem/component immunity and subsystem/component handling shall be introduced. The actual ESD level at the time of approval shall reflect the environment for the equipment from the final assembly to mission completion. Consideration of spacecraft static charging is shown in Section 5. 1. 8.

6 Verification

6. 1 General requirement

6. 1. 1 General

The prime contractor or developer shall be responsible to verify the conformance to all requirements specified in this standard. Specific tasks may be delegated to the sub-contractor through the EMC control organization as needed. Verification shall be performed properly in the qualification testing, analysis and inspection and equivalent test.

6. 1. 2 Verification scenario

It shall be required to make and implement a verification plan for verifying that each subsystem and each on-board component individually meet the electromagnetic compatibility standard. It shall also be necessary to make and implement a verification plan for the entire space system.

6. 1. 2. 1 Subsystem/component level

(1) All verifications related to electromagnetic compatibility standard shall be conducted on each subsystem/component under the responsibility of the person in charge of manufacturing and development before installation to the space system.

(2) Verification shall be conducted in the development phase of the engineering model before the flight model so that design can be modified. The verification of the flight model shall be performed as the last confirmation as far as possible.

(3) If the person in charge of manufacturing and development cannot prepare the special facility and sensor for radiation noise measurement in conducting verification, verification shall be performed using the facility owned by JAXA or others.

(4) For deviation from the accepted electromagnetic compatibility standard level in verification, the person in charge of manufacturing and development shall perform analysis of verification results and modify each subsystem/component based on the results so that the compatibility level is satisfied before the installation of the space system. However, as for the flight model, the necessity of modification shall be discussed in consultation with the EMC control organization before modification.

(5) Each subsystem/component developer (including manufacturer) shall report the results of verification on the electric compatibility standard to the EMC control organization before installation to the spacecraft.

6. 1. 2. 2 Space system-level

(1) Verification of the conformity to the electromagnetic compatibility standard shall be conducted on the entire space system with all the subsystems/components assembled under the responsibility of the JAXA project.

(2) In verifying the electromagnetic compatibility in the entire space system, the operation

quality shall be verified using on-board components themselves in addition to measurement using the EMC measurement sensor to check for interference between components installed in the spacecraft.

(3) The necessity of component modification shall be discussed based on the verification results by the EMC control organization.

6. 1. 3 System-level EMC verification plan

The prime contractor or developer (including manufacturer) shall develop the EMC verification planning paper specifying the space system-level EMC verification plan. The details of the verification method for each EMC requirement and the acceptance standard for each subsystem/component shall be specified. Before starting the EMC verification test, confirmation for EMC verification plan shall be performed in the spacecraft project.

The EMC verification plan shall at least include the following.

6. 1. 3. 1 System-level verification method

Depending on the fidelity of the engineering model, verification may be conducted separately in the test for engineering model and the test for flight model/protoflight model.

The method, procedure and measurement equipment for recording the test results shall be included in system verification target. (See Section A3. 1. 3. 1.)

6. 1. 3. 2 Test condition

The necessary personnel shall be defined. The procurement activity, contractor, sub-contractor, and quality control representative shall be included. The required test equipment shall be defined. It shall include the description of specific EMC measurement equipment such as electric, electronic and mechanical input-output equipment to the test piece, measurement equipment and LISN used in system-level test. (See Section A3. 1. 3. 2.)

6. 1. 4 EMC verification report

The prime contractor or developer (including the manufacturer) shall create the EMC verification report. The EMC verification report shall provide evidence of acceptance in each requirement defined in this standard. The procedure and objective of each test shall be described in the report. The summary of results and evaluation indicating the acceptance in the component/subsystem-level verification shall be included. (See Section A3. 1. 4.)

6. 2 System-level verification

6. 2. 1 General

Each subsystem/component shall be assembled in the system to satisfy the acceptance function test procedure.

6. 2. 2 Safety margins of critical/EED circuit

When the safety margin is not determined in advance by the component level test or analysis, validation shall be performed in combination of components and subsystems by simulation of actual operation in the system-level integration. The test piece shall be measured by either directly measuring the actual induced noise or measuring the noise injection that reduces the S/N ratio to the safety margin (indirect measurement). Select the more appropriate method in view of technicality and actuality. To validate the safety margin of the circuit (including EED) having sensitivity to time domain phenomenon, the time domain method shall be used. (See Section A3. 2. 2.)

6. 2. 3 External electromagnetic field environment

The space system shall be exposed to the external electromagnetic environment defined to comply with Section 5. 1. 1. When it is not practical to expose the space system to the external electromagnetic environment, the compatibility to this requirement can be verified by analyzing the component/subsystem-level test data.

6. 2. 4 Intrasystem EMC

The intrasystem EMC shall be validated by means of a proper combination of the test and analysis. Before carrying out the system-level EMC test, all component/subsystem shall be assembled in the system and meet the function/performance requirements. (See Section A3. 2. 4.)

6. 2. 5 EMI control

The advance verification results of component/subsystem performance based on the requirement (subsystem design requirement) in Section 5. 2 shall be the basis for system-level test requirements. The mission-specific or special test procedure for operation for all devices composing the intrasystem EMC matrix (See Section A3. 2. 4) shall be control target, if any.

6. 2. 6 Grounding and wiring design

6. 2. 6. 1 Grounding

System-level electric grounding and insulation shall be verified by the system-level grounding and insulation design and testing during system assembly illustrated in the grounding diagram (single phase connection diagram is not sufficient).

6. 2. 6. 2 Wiring design

The wiring classification category shall be verified by design review and inspection.

6. 2. 7 Electrical bonding

6. 2. 7. 1 General

The compatibility to bonding requirements shall be verified by test, analysis, or inspection appropriate to individual bonding measures. The compatibility to corrosion-proofing control technology shall be verified by demonstrating that corrosion-proofing treatment is performed as a part of manufacturing process. (See Section A3. 2. 7. 1.)

6. 2. 7. 2 Power current feeder and return paths

The bonding of power current feeder line shall be validated by analytic measurement of the current path, current level and bonding resistance. (See Section A3. 2. 7. 2.)

6. 2. 7. 3 Shock and safety hazards

Not applicable.

6. 2. 7. 4 Antenna counterpoise

The bonding to the antenna counterpoise shall be verified by test, analysis and inspection appropriate to individual bonding. (See Section A3. 2. 7. 4.)

6. 2. 7. 5 RF potential

Verification on milliohm-level bonding for RF interference control shall be carried out using the milliohm meter of special AC low voltage output. The meter voltage output shall be alternating current to eliminate the effect of contact electrode potential. If only the DC output meter is available, the true value of bonding resistance can be obtained by using the average of two measured values with different polarity. The multimeter may be used when the bonding path is fault/return/pass. However, in that case, measurement at low voltage and low current shall be finished first. (See Section A3. 2. 7. 5.)

6. 2. 7. 6 Electrostatic discharge

The bonding in the metal portion in which electric discharge element, thermal blanket or electrostatic potential must be the same shall be verified in testing during assembly to the structure. (See Section A3. 2. 7. 6.)

6. 2. 7. 7 Explosive atmosphere protection

Not applicable.

6. 2. 8 Antenna-to-antenna compatibility

The analysis for identifying the frequency with risk element shall be specified as a part of the EMC control plan. These shall be verified through validation under the operation about the same as the actual operation. Generally, a combination of interfering elements and interfered elements shall be operated to maximize the potential of interference development. However, the operation mode shall be limited to the simulated mission operation. In validating the compatibility between the receiver to be possibly interfered and the interfering elements, the minimum reception capacity of the wanted signal of the receivers shall be included. The absence of intermodulation interference shall be verified by a combination of analysis and testing. (See Section A3. 2. 8.)

6. 2. 9 Lightning discharge

Protection against direct and indirect effects of lightning discharge shall be verified by a proper combination of test, analysis and inspection. (See Section A3. 2. 9.)

6. 2. 10 Spacecraft and static charging

6. 2. 10. 1 General

The effects due to electrostatic charge shall be controlled properly by testing, analysis or inspection. (See Section A3. 2. 10. 1.)

6. 2. 10. 2 Differential charge/discharge

The proper control on effects of differential charge/discharge shall be verified by a proper combination of testing, analysis and inspection. (See Section A3. 2. 10. 2.)

6. 2. 10. 3 Internal charging

The proper control on effects of internal charging shall be verified properly by testing, analysis or inspection. (See Section A3. 2. 10. 3.)

6. 2. 10. 4 Charging of fluid lines (liquid fuel lines)

In the proper control on the static charging of the fluid piping lines (liquid fuel lines), it shall be verified in confirmation that the conductivity of fluid and fluid piping can prevent arc discharge. (See Section A3. 2. 10. 4.)

6. 2. 11 Hazards of electromagnetic radiation

The safety confirmation of effects due to electromagnetic radiation on the fuel, personnel, explosive article (including EED), and flight/engine /thruster control shall be validated by a proper combination of testing, analysis and inspection.

6. 2. 12 Consideration of life cycle

The concept of system design introduced for EMC shall be checked for compatibility with the life cycle requirements of reliability, maintainability and serviceability. The maintainability, ease of test and ease of degradation confirmation shall be validated. The maintenance method and tools shall be defined in the EMC verification plan and proper maintenance document.

6. 2. 13 External grounds

The proper layout and display of external ground position in the space system shall be verified by inspection. The compatibility to bonding requirements shall be verified by testing.

6. 2. 14 Test equipment/facility interface

It shall be verified by a proper combination of testing, analysis and inspection that the test equipment and facility cause no damage to the space system. It shall be verified that the measures against thunder stroke and power outage are proper in the EMC verification plan.

6. 2. 15 Spacecraft magnetic emissions

The compatibility to requirements of magnetic emission in the spacecraft shall be validated by a combination of analysis and testing. (See Section A3. 2. 15.)

6. 3 Subsystem-level verification

6. 3. 1 General

MIL-STD-461 standard test method shall be used in the compatibility verification to Section 5. 2. 1 to 5. 2. 17 (subsystem design requirements) wherever possible. See Table 5. 2-1 and Table 5. 2-2 for MIL-STD-461 application items. The purpose is to minimize the test cost (normally to minimize the procurement of the hard-to-get EMI test equipment).

The standard test method may be inappropriate to EMC requirements in some cases. The standard test method may not respond to space system-specific EMC problems. These specific issues shall be described in the following items. The test distance between the test piece and the antenna shall be "1 m" during measurement and peak detection of radiated emissions. As long as the test piece is set onto the ground plane as in the case with the actual flight, another standard may be used. Any specification not conforming to this evaluation standard shall be reviewed by the EMC control organization.

In the electromagnetic field emission and immunity tests, the form in which the harness to be connected to the test piece is installed to the actual system shall be simulated to the extent possible.

The measurement bandwidth, sweep rate, or step width shall be controlled in emission measurement in which the frequency band must be swept. The sweep rate shall be slow enough so that the band-pass filter of the minimum intermediate frequency can respond properly. The step width shall be less than half the measurement bandwidth. For the operation of the test piece, the frequency sweep time shall be taken into consideration. Unwanted radiation sweep must be repeated several times for all unwanted radiation measurements in components/subsystems repeatedly operated.

The test frequency point and application time shall be controlled in the immunity test requiring frequency band sweep. For the equipment operated repeatedly, the operation mode with the maximum noise shall be identified before conducting the frequency domain test of conductivity emission and radioactive emission.

The test procedure for component-level test (including setup) shall be evaluated by the EMC control organization.

6. 3. 2 Power-induced power line conductivity emission, time and frequency domain characteristics
(Primary power line conduction emissions and power source)

The power-induced power line conductivity interference time domain and frequency domain characteristics shall be verified by testing. The voltage ripple time domain characteristics shall be measured at the both ends of the resistance load using the oscilloscope directly. The voltage ripple frequency domain characteristics can be measured similarly. (See Section A3. 3. 2.)

6. 3. 3 Load-induced power line conductivity emission, frequency domain characteristics
(Primary power line conduction emissions and load)

The frequency domain characteristics of load-induced power line conductivity interference shall be verified by testing. The requirements may be defined as the voltage or current ripple standard. The frequency domain LISN shall be specified. LISN cannot operate properly at 150 kHz or less. Conducted emissions at 150 kHz or less shall be controlled solely by current control. At a frequency of 150 kHz or less, the bandwidth shall be 2% or less of the tuning frequency. However, the bandwidth shall be set so that the noise floor (lowest observable noise level) caused by the local oscillator near the DC domain will be at least 6 dB below the requirement specification standard. (See Section A3. 3. 3.)

6. 3. 4 Load-induced power line switching transient
(primary power line switching transient)

6. 3. 4. 1 Application

Both the long-duration switching transient caused by current change and resistance change and the rapid switching transient caused by current change shall be examined. (See Section A3. 3. 4. 1.)

6. 3. 4. 2 Control of long-duration load-induced switching transients (inrush current)

Verification shall be conducted by the load-induced long-duration switching transient. (See Section A3. 3. 4. 2.)

6. 3. 4. 3 Control of fast load-induced switching transients (current changing rate)

The load-induced rapid switching transient shall be verified by testing. The transient voltage within 50 microseconds (μs) can be measured by using the LISN used for measuring the frequency domain characteristics of conductive emissions. When measuring the transient voltage of 50 μs or more, the space system-specific power source impedance model shall be established. To measure the time domain disturbance from voltage application to steady state with accuracy, the LISN impedance shall be defined to the DC domain.

The power source impedance in the transient-producing portion of test setup shall be larger than the estimated impedance of the power line. When the power source switching is not included in the test piece, the transient data when the power is turned off shall be regarded as reference. (See A3. 3. 4. 3)

6. 3. 5 Load-induced power-line ripple (primary power-line ripple)

The load-induced power-line ripple shall be verified by testing. (See Section A3. 3. 5.)

6. 3. 6 Signal line conduction emissions

The signal line conduction emissions and frequency domain characteristics shall be verified by testing. The compatibility to this requirement shall be verified by mounting the current probe around each cable to be tested. Other verification methods may be adopted as long as the EMC control organization agrees. (See Section A3. 3. 6.)

6. 3. 7 Antenna connection port spurious emissions

The antenna connection port spurious emissions shall be verified by testing. If possible, the compatibility to the requirement shall be verified by connecting the coaxial cable/wave guide directly between the antenna connection port and the EMI meter. Impedance mismatch shall be dealt with the impedance conversion transformer or correlation network in consideration of the loss in the relevant portions. If direct connection measurement is not effective, the 2 antenna test method shall be implemented. In that case, the reception antenna used in the test shall have characteristics similar to those of the interfered antenna to the extent possible. (See Section A3. 3. 7.)

6. 3. 8 Magnetic field radiated emissions

Magnetic field radiated emissions shall be verified by testing. (See Section A3. 3. 8.)

6. 3. 9 Radiated electric field emissions

Radiated electric field emissions shall be verified by testing. (See Section A3. 3. 9.)

6. 3. 10 Immunity to power-line ripple

Immunity to power-line ripple shall be verified by testing. (See Section A3. 3. 9)

6. 3. 11 Immunity to power line switching transient

Immunity to power line switching transient shall be verified by testing.

6. 3. 12 Immunity to the conducted effects of radiated electromagnetic fields

The induction effect immunity in the radiated electromagnetic field shall be verified by testing. The current/voltage set in the specification shall be injected by the current probe of which loss frequency characteristics are known.

6. 3. 13 Immunity to magnetic emissions

Immunity to magnetic emissions shall be verified by testing. It is desirable that compatibility be validated by the Helmholtz coil. The local magnetic field source (portable type) may be used when the test target is large. These two magnetic field sources shall be calibrated by the physical dimensions and electric current.

6. 3. 14 Immunity to field emission

Immunity to field emission shall be verified by testing. It is desirable that testing be carried out in the anechoic chamber.

6. 3. 15 Immunity to signal line magnetic field conduction

Immunity to signal line magnetic field conduction shall be verified by testing.

6. 3. 16 Antenna terminal out-of-band immunity

Antenna terminal out-of-band immunity shall be verified by testing. The test method largely depends on the types of receivers to be certified. The test method shall be described in a proper chapter in the EMC control plan before starting the test.

6. 3. 17 Immunity to electrostatic discharge

Immunity to electrostatic discharge shall be verified by testing or controlled by approved handling procedure. The testing shall be conducted according to IEC 61000-4-2. Because the ESD test may cause devastating damage to the test target (including progressive and potential damage elements), verification shall not be implemented with the flight model but only with engineering model or the prototype model.

6. 4 Measurement instrument

The EMC verification shall be conducted using the proper measurement sensor under the environment with the background noise reduced properly.

6. 4. 1 Immunity test equipment

6. 4. 1. 1 Immunity to conduction

To superimpose the conductivity noise with the power line to be measured, the signal generator of required frequency band, audio isolation transformer (a few tens of kHz or less), high pass filter (a few tens of kHz or more) or current probe for injecting bulk current shall be used. The power amplifier shall be required depending on the required noise level.

6. 4. 1. 2 Immunity to field emission

The power amplifier shall be necessary depending on the signal source, antenna and level of the required frequency band. At a low frequency of a few tens of MHz or less, the parallel element antenna is used in many cases. The biconical antenna is used at a frequency of a few tens of MHz to a few hundreds of MHz band while the log periodic antenna or horn antenna is used at higher frequency. The electric field probe for monitoring the applied electric field value shall be required in measurement. To control the electric field strength loaded to the test piece, the power supplied to the antenna performs feedback control on the electric field strength obtained from the electric field sensor placed near the test piece.

6. 4. 1. 3 Immunity to magnetic emissions

For the immunity to the magnetic field, the measurement device comprising of the Helmholtz coil and the signal source for driving the alternating current shall be used. The magnetic field sensor for monitoring the magnetic field applied shall be required in measurement.

6. 4. 1. 4 Immunity to electrostatic discharge

The ESD gun shall be used in the immunity test to electrostatic discharge.

6. 4. 2 EMC sensor

6. 4. 2. 1 Conduction emissions

The current probe having a proper sensitivity to the required frequency bandwidth shall be used for measuring conduction emissions.

6. 4. 2. 2 Radiated electric field emissions

In measuring the electric field radiation, it is of importance that the sensor in accordance with the frequency bandwidth is used. Generally, the monopole antenna shall be used in the low frequency domain of a few tens of MHz or less. The dipole antenna and biconical antenna shall be used at a few hundreds of MHz or less. In GHz band, the horn antenna, spiral antenna or log periodic antenna shall be used.

6. 4. 2. 3 Magnetic field radiated emissions

In measuring the magnetic field radiation, it is of importance that the sensor in accordance with the frequency bandwidth is used. The flux gate magnet meter shall be used in the frequency ranging from direct current to a super low frequency of a few Hz. In the bandwidth of 100 kHz or less, the search coil magnet meter shall be used. In any higher frequency bandwidth, the loop antenna shall be used.

6. 4. 3 Shield room/anechoic chamber

EMC measurement shall be carried out under the measurement environment that can realize the electromagnetic environment satisfying the EMC standard.

6. 4. 3. 1 Shield room

Measurement of radiation noise from the direct current magnetic field to the low frequency magnetic field shall be conducted in the magnetic shield room that can attenuate the low frequency magnetic field from the direct current including the magnetic field of earth. When the measurement of low frequency magnetic field is not necessary, measurement may be conducted in the radio wave shield room having no magnetic field shield effect.

6. 4. 3. 2 Anechoic chamber

In field emission at a few tens of MHz or more and immunity measurement, measurement shall be conducted in the anechoic chamber to suppress the wall reflection of radio wave from the noise source or radiation source for immunity measurement.

6. 4. 4 Background noise reduction

Background noise shall be reduced enough so that measurement at a level specified in the EMC standard can be conducted. Depending on the measurement target, the power lines, data and control lines from the shield room and external anechoic chamber must be drawn and the signal lines exist for the EMC sensor. After arranging these required cables, measure the background noise in advance and check that the noise is enough to carry out the EMC measurement. If the noise is so large that the measurement is interfered, check the ground connection and power source grounding method for the shield of the cables drawn from the outside to reduce the background noise.

Appendix

A1 system requirements

A1. 1 Grounding and insulation requirement

Specific values are defined in MIL-STD-1541A and MIL-STD-464C.
An insulation resistance of 1 MΩ is used typically.

A1. 2 Filtering criteria

As a shield margin for the structure external, 6 dB or more is typically required.

A2 Measures against magnetic field of spacecraft

The reference information for spacecraft magnetic field measures shall be as follows:

A2. 1 Magnetic material

A2. 1. 1 General magnetism

Magnet (used for interior of motor, valve and relay) and iron.

Stainless has magnetism depending on the type (such as martensite system) and must be treated as a magnetic material in some cases.

A2. 1. 2 Magnetism requiring care in handling (spacecraft-specific)

Pure nickel (used for coating and plating on the hood of battery electrode and optical equipment) and magnetic nickel alloy (invar (used for CIC board, etc)). Used for enclosures of equipment with a high calorific value.)

A2. 1. 3 Non-magnetism

Copper, aluminum, titanium, magnesium alloy

A2. 2 Magnetic field reduction measures

A2. 2. 1 Magnetic shield

By surrounding the source of magnetic field with high-magnetic permeability material, magnetic emissions can be trapped. Steady reduction is possible with the magnetic field source of which magnetic field fluctuates. Materials having a high magnetic permeability and relatively low coercive force (magnetization) such as permalloy are most effective. To suppress the mass of shield material, it is effective to cover the minimum portion including the magnetic field source. Even when using a material having a low coercive force, control on magnetization prevention is necessary because magnetization is not reduced to zero. When using soft iron having a relatively high coercive force, pre-operation demagnetization and more careful control on magnetization prevention are necessary.

A2. 2. 2 Cancel magnet

The force exerted on the spacecraft can be reduced with the external magnetic field by mounting the magnet in the opposite polarity direction of the spacecraft magnetic moment to cancel the force exerted between the external magnetic field and the magnetic moment of the spacecraft. By mounting a magnet having the same magnetic moment and opposite polarity with respect to the magnetic field source in the vicinity, the magnetic field placed far enough in comparison with the distance between the source and the added magnet can be limited to minute. However, when developed magnetic field changes in terms of time, the cancel magnet shall be selected and installed in accordance with the case in which the magnetic field must be canceled more often.

A2. 2. 3 Cancel loop

By arranging wiring with the current on the hot side balanced with that on the return side so that the current follows the same path, the current loop area can be downsized, which leads to reduction in magnetic field developed. If possible, it is desirable that the twist pair wire be employed. If the current is not balanced, by adding the current path having the same current strength inversely, the magnetic field developed can be canceled. It is effective as magnetic field measures by means of current loop with varying current strength.

A2. 2. 4 Scheme of design and installation method

When installing more than one device generating magnetic field, magnetic field can be reduced by mounting a pair of devices inversely each other. When using more than one magnet in the component, magnetic field developed can be reduced by arranging the magnets so that they can cancel out the magnetic moment each other. For example, it is effective to install the relay and circulator opposite in the equipment. The magnetic field can be canceled out more effectively by selectively using the magnet having similar strength from plural magnets having varied strength. Unless the devices are arranged antiparallelly, components will be left uncanceled despite the same magnetic moment strength. Thus, the mechanism to fine-tune the installation direction shall be provided as needed.

For the layout in the spacecraft for measuring weak magnetic field, a proper distance shall be ensured between the source of the magnetic field and the magnetic field sensor.

A2. 3 Magnetization prevention control

(1) On-board equipment may be magnetized depending on the tooling. All tools and dies used shall be made of non-magnetic material or demagnetized. The use of a driver using magnet on the tip shall be strictly prohibited. To prevent the demagnetized tooling from becoming magnetized, the tooling shall be stored and kept in a non-magnetic tool box such as plastic box. The demagnetized tooling shall be distinguished with a label from others. Magnetization level shall be measured on the contact surface of the tooling (such as torque wrench having a ratchet in particular) by using the gauss meter/tesla meter before use as needed.

(2) Among manufacturing or testing facilities, some are magnetized or generating magnetic field; care must be exercised. Check the magnetic field strength in advance and ensure the distance according to the strength.

(3) Special care must be exercised with the carry-on items of workers getting near the spacecraft. Carry-on items shall be determined depending on the magnetic field requirements.

A2. 4 Equipment apt to radiate magnetic field

(1) Power source system equipment (small loop can become a large magnetic field source due to large current)

(2) Battery (large-current loop is formed when assembled in the unit)

(3) Solar cell panel (The panel routing becomes the loop.)

(4) Isolation valve (Strong magnet is used generally.)

(5) Communication system circulator (Strong magnet is used generally.)

(6) Propellant valve (Magnetic material is used in some cases.)
(7) Communication system switch (Magnet is used in some cases.)
(8) Large current relay (Magnet is used in some cases.)
(9) Step motor, solar cell paddle or antenna motor (Note that the magnetic field direction changes according to the drive.)

A3 System verification/test related

A3. 1. 3 System-level EMC verification plan

A3. 1. 3. 1 System-level verification method

The general system-level verification method shall include the following details:

(1) Selection method for the critical circuit of which compatibility to degradation standard and safety margins must be monitored.
(2) Malfunction judgment criterion and limit determination procedure
(Example: In addition to checking that the signal of known strength can be received during interference verification of the receiver, it is of importance to check the noise suppression sensitivity without the signal input.)
(3) System-level EMC verification method
(4) Power line conductivity margin verification method in normal/common mode. (About distribution output and critical circuit in particular)
(5) Verification method for common mode margin of cable bundle. (The cable bundle of the critical circuit and bundle arranged near the sensor or critical circuit in particular)
(6) RF self-compatibility (compatibility between the transmitter, receiver and entire spacecraft in all operation modes) verification method
(7) Static charging measures design verification method and lightning strike measures program
(Advance planning for ensuring the safety margins of EED with the safety margins supersensitized or mounted is necessary for timely implementation of EMC verification.)
(8) Simulation/test method for electro-explosive device (EED)
(9) Power quality verification and power bus monitoring method
(10) EMC verification method in system-to-system interface such as rocket interface.
(11) Effect due to cavity resonance

A3. 1. 3. 2 Test condition

The parameters required for setting test conditions shall include the following:

(1) Test conditions for all electric/electronic devices that are assembled in the space system or required for test procedures. (The intrasystem EMC matrix shown in Section A3. 2. 4 shall be included in a part of system verification.)
(2) Implementation and application of test procedure including monitor points for operation mode and each subsystem/component
(3) Utilization of test results that are obtained and judged to be valid in interference test for subsystem/component.
(4) Data report/record method and analysis method
(5) Description on the equivalent test implementation location and installation method when the operation of the actual unit is unrealistic.
(6) Configuration of subsystem/component operation mode for testing the interfered subsystems/components at the maximum sensitivity mode and for testing the interfering subsystems/components at the maximum noise level mode. (Because each subsystem/component can be interfered or interfering, it is necessary to conduct testing

in more than one operation mode.)

(7) Details on the frequency range, channel and specific combination of test targets. (Example: Image frequency, intermediate frequency, local exciter frequency, transmitter fundamental wave and higher harmonics-related frequency, and reception bandwidth and sweep rate of measurement equipment (The high-sensitivity frequency of the subsystem confirmed in test phase shall be included.))

A3. 1. 4 EMC verification report

The items to be included in the EMC verification report shall be as follows:

(1) Setting of specific test purpose in consideration of applicable requirements and EMC verification plan reference.
(2) Test piece information including serial numbers, configurations, figures and pictures.
(3) Description about repair and configuration change of the test piece proved to be incompatible in verification
(4) Summary of verification results. (Including the summary of the degree of compatibility to requirement)
(5) Differences from the test facility, analysis method/tool and inspection equipment specified in the EMC verification plan.
(6) Differences from the test procedure specified in the EMC verification plan.
(7) Figures and pictures representing the test setting
(8) List of test equipment including adjustment information
(9) Record data and log. (Including the measurement equipment measurement value, correction coefficient, and integrated data (The data integration method shall be described. If the data is compromising due to restriction of test conditions, the reasons and effect on the data shall be described.))
(10) Specification of surrounding and other test conditions.

A3. 2. 2 Safety margins of critical/EED circuit

When the SN ratio can be reduced during operation by applying the safety margin coefficient, the EUT circuit may not be measured directly. The presence of safety margins shall be validated when the subsystems/components are operated properly. The typical method is that the EED circuit is replaced with a high-sensitivity EED (Bridge wire fuse is provided at 1/10 current level with the EED unit turned off.) and devices related to thermocouple and other temperature measurement are connected to the real bridge wire.

A3. 2. 4 Intrasystem EMC

As an effective verification method for intrasystem EMC, the intrasystem EMC matrix is created. The intrasystem EMC matrix represents a combination of all subsystems/components of the intrasystem EMC to be verified. An example of the basic format of the concerned matrix shall be shown in Table A3. 2. 4. The test procedure for all matrix equipment shall be included to conduct testing smoothly. Special equipment required for operation of interfered/interfering equipment shall be included if any. In any combination of interfered /interfering equipment, it shall be verified before compatibility validation that the interfering equipment can operate properly and that the interfered equipment can operate properly when the interfering equipment is turned off.

Table A3. 2. 4 - Intrasystem EMC matrix

Interfering/interfered	Component A	Component B	Component C	---	Component N
Component A	N/A	Test	Test	---	Test
Component B	Test not required	N/A	Test not required	---	Test
Component C	Test	Test	N/A	---	Test not required
- - -	- - -	- - -	- - -	N／A	- - -
Component　N	Test	Test not required	Test	---	N/A

a "N/A" means "not applicable".
b "Test not required” means that the two concerned devices cannot be operated at the same time or there is no operation leading to mutual interference. Thus, validation is not required.

A3. 2. 7 Electrical bonding

A3. 2. 7. 1 General

When verifying a metal or conductive composite structure, verification shall be normally carried out according to the validated bonding process. For the verification of the dielectric surface with conductive treatment, the surface electric resistance ratio measurement and the electric contact of conduction pass shall be required.

A3. 2. 7. 2 Power current feeder and return paths

The final item in power bus power source supply capacity verification is to check all the on-board equipment for application of proper voltage with all the power subsystems installed.

A3. 2. 7. 3 Shock and safety hazards

Not applicable.

A3. 2. 7. 4 Antenna counterpoise

The antenna counterpoise can be verified by operating the system in the compact range which is an antenna pattern measurement facility.

A3. 2. 7. 5 RF potential

Low voltage output shall be applied to the milliohm meter so that the bonding causing effect on the EMI induced current is simulated to the bonding measurement value. A high-voltage source may penetrate the oxide film or contamination layer and supply an excessively high impedance to EMI signal on milliampere/millivolt scale. Thus, the high voltage short circuit current test shall be conducted after the low voltage RF bonding test. This test procedure must be observed. Even if the short circuit current bonding measurement value is below the specified limit value of the RFI bonding, the bonding proved to be compatible to the short circuit current requirements may not be compatible to the RFI bonding requirements. The maximum output voltage of the low voltage output meter is 20 mV, the typical output is 200 μV and the test current range is 1 μA to 10 mA.

A3. 2. 7. 6 Electrostatic discharge

The bonding shall be verified for compatibility to preventive requirements of electrode potential formation that serves as the electrostatic discharge source. To ensure that proper bonding can be maintained, inspection shall be conducted on the surface treatment applied to all materials connected to the structure.

A3. 2. 7. 7 Explosive atmosphere protection

Not applicable.

A3. 2. 8 Antenna-to-antenna (RF) compatibility

When there is no signal to be received or simulation signal input, check the noise suppression sensitivity as needed in addition to checking the reception antenna for noise.

For the reception antenna in which a signal source proper to the interfered reception antenna test cannot be used or the performance evaluation cannot be completed without the signal, the reception antenna shall be removed from the feed and replaced with the test reception system having a similar reception sensitivity. Thus, the test reception system can be used for quantifying the RFI level input to the reception antenna and comparing it to the interfered reception antenna sensitivity.

However, the noise suppression capacity of the interfered reception antenna cannot be simulated in this test. Generally, to ensure that the maximum sensitivity to the reception antenna noise is grasped, each reception antenna shall be operated after setting another antenna to the maximum power /antenna direction without implementing intentional signal input.

A3. 2. 9 Lighting discharge

Refer to SAE ARP 5412[10] for space system test-related recommendation items. The SAE standard specialized to the test method includes the detailed information about lightning strike verification.

A3. 2. 10 Spacecraft and static charging

A3. 2. 10. 1 General

Applying the computer model shall be effective to evaluate the static charging degree on the spacecraft surface.

A3. 2. 10. 2 Differential charge/discharge

It is recommended to verify the differential static charging by testing. It is advisable to use the radioactive ESD source. Pulse energy shall be set in consideration of the static charging/emission risk specialized to the mission.

If current is possibly injected to the structure depending on the component, the conductive ESD source shall be applied.

(1) Immunity test of discharging electrostatic caused by static charging

The recommended test method shall be shown in Figure A3. 2. 10. 2-1.

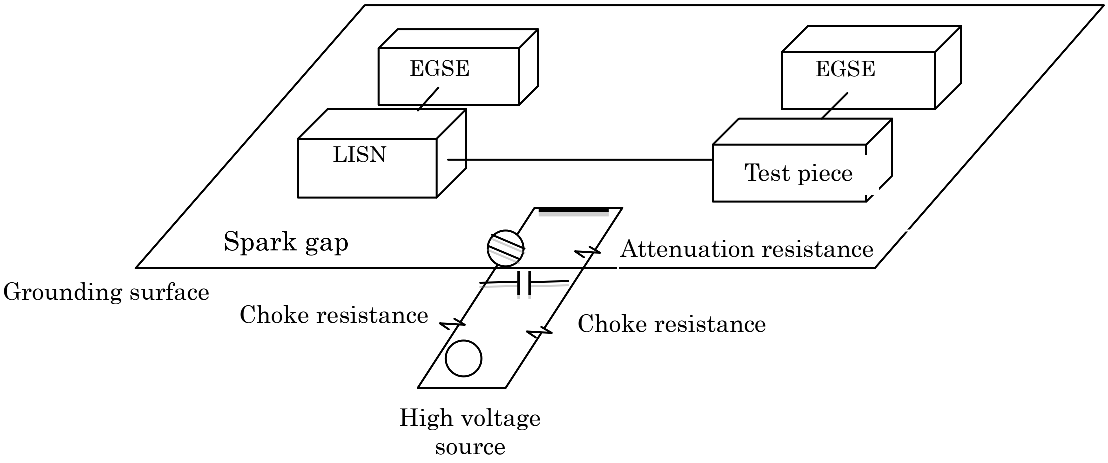


Figure A3. 2. 10. 2-1-Immunity test of discharging electrostatic caused by static charging

The explanation of circuit parameter specified in Figure A3. 2. 10. 2 shall be as follows:

a) Spark gap

The typical value shall be 6 kV. The pressurized/sealed spark gap with a short breakdown time shall be desirable. There shall be no cavities.

b) Capacitance

The typical value shall be 100 pF by the low inductance high voltage condenser.

c) Attenuation resistance

Although the typical value is 47 Ω, adjustment is possible in accordance with the critical attenuation determined by the capacitance and self inductance of the electric discharge circuit.

d) Choke resistance

It shall be used to prevent the current from flowing into the uncontrolled path due to discharging high-frequency components. If it is noted that the minimum value is 10 kΩ, the electric discharge parameter will not be dependent on the length and position of the wiring of the high voltage source.

e) High voltage source

Though the high voltage source may be direct current, a choke resistance of 10 MΩ or more shall be used. In terms of safety, it is desirable to use the ESD generator specified in the IEC 61000-4-2. This generator corresponds to aerial electric discharge mode on the precondition that the generator is connected to the electric discharge return connection of which electric discharge electrodes are connected to one choke resistance and the other choke resistance.

f) Electric discharge circuit
The circuit shall be isolated and arranged along the EUT harness by 20 cm.

g) Transient current pulse
The goal is that the half width is maintained at 30 A for 30 ns.

(2) Immunity test of field emission caused by arc discharge
Testing shall be conducted by generating pulse electric discharge having a pulse rate of 1 pps (pulse per second) and a voltage of 10 kV from the electrode at a location separated by 30 cm from the test piece. Testing shall be conducted on each surface of the test piece.

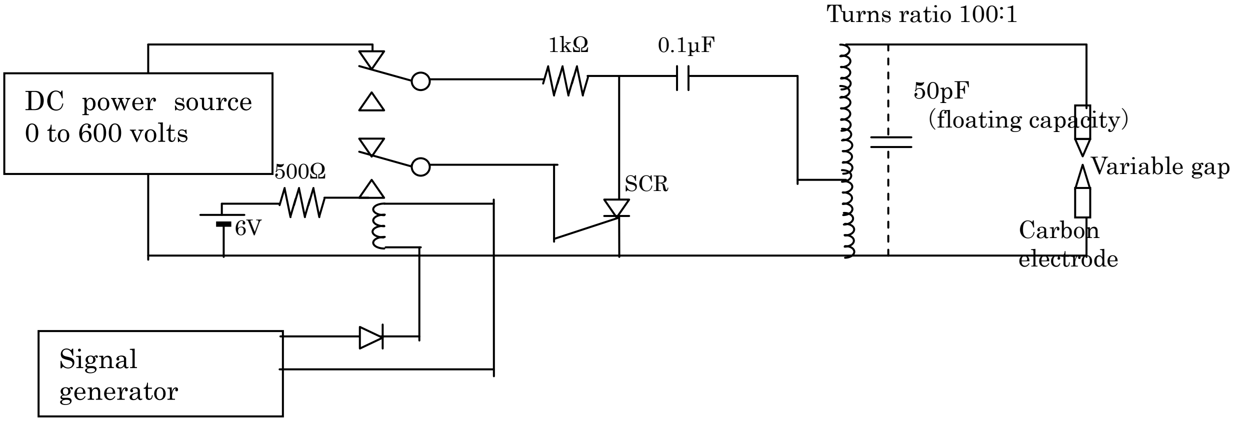
If a malfunction occurs at a voltage level of 10 kV, the voltage level shall be lowered until the device operates normally. The level shall be recorded. The test equipment that generates the required voltage and arc discharge is shown in Figure A3. 2. 10. 2- 2. When using other equivalent test equipment, indicate so in the EMC verification plan.

A3. 2. 10. 3 Internal charging

Conducting internal charging test is extremely difficult. It is required to analyze and implement the design method for shielding with the use of the grounded aluminum having a proper thickness.

A3. 2. 10. 4 Charging of fluid lines (liquid fuel lines)

If possible, the resistivity of the liquid fuel shall be controlled by using additive. All fluid pipes comprising of metal braiding (external or internal) shall be provided with clarified grounding with respect to the metal braiding.



Note 1 The signal generator shall have the capacity that can drive the relay at 1 pps.
Note 2 For the gap, the carbon electrode installed to the variable Teflon shaft shall be mounted onto the phenol plate.

Relationship between the electrode gap and breakdown voltage

Gap (mm)	Breakdown voltage (KV)	Emission energy (W・s)
1	1.5	56.5×10^{-6}
2.5	3.5	305×10^{-6}
5	6	900×10^{-6}
7.5	9	2000×10^{-6}

Figure A3. 2. 10. 2-2-Immunity of field emission caused by arc discharge

A3. 2. 15 Spacecraft magnetic emissions

(1) Constraint of cost

a) Because the total moment of the spacecraft is not so high, simplified calculation is possible. The procedure of the method is as follows: convert the moments of primary factors (equipment having high-magnetic materials known) to scalar values and then combine the values; perform simplified statistical treatment on the vector direction for other factorial equipment (Example: use of root sum square (rss)); and then add the total to the former.

b) The equipment shall be verified for compatibility to these requirements by equivalent test or "rough" test.

c) The moment of primary factorial equipment and the total of statistical distribution (rss) of other equipment shall be added.

(2) Constraint of on-board magnetic field sensor

a) Main causes related to the sensor involve the sensitivity of the sensor to the magnetic field. The sensitivity shall be specified as the maximum tolerance requirement with respect to the magnetic emissions generated from the space system. Measurement of magnetic moments of the three orthogonal axes in the unit allows you to convert the values to magnetic field strength and determine the sensor position based on the results. Conducting similar measurement and calculation on all units allows you to obtain the total magnetic field at the sensor position. It is of importance to separate the components properly from the sensor so that the component-level favorable measurement values and the inverse cube law can be used.

b) Each component shall be verified by testing using more than one Helmholtz compensation coil.

c) The magnetic flux density and magnetic moment vector at the sensor position that are obtained from all the test results shall be calculated. This allows you to obtain high-precision results.

d) As optional, it is desirable that the space system test is conducted and that the system-level calculation results are supported.

A3. 3. 2 Power-induced power line conductivity emission, time and frequency domain characteristics
(Primary power line conduction interference, power source)

The voltage ripple in the frequency domain can be measured by using the digital oscilloscope (DSO: Digital Storage Oscilloscope) having the fast Fourier transform (FFT) capacity or the interface connecting the FFT-implementing computer. Because the noise of power subsystem under pure resistance load is developed at intervals, there are no problems as long as the DSO repeated frequency bandwidth is compatible to the power quality requirements. Capturing the transient response of each single measurement is good enough for evaluating the power quality. When using the EMI meter, the high pass filter shall be used to prevent power frequency voltage from damaging the measuring device. When the limit is specified in that manner, the ripple current in the frequency domain can be measured instead. The EMI current probe having the high pass filter function inherently may be used. When applying the conductive emission limit to the frequency domain in order to control radiated emissions, the EMI current probe shall be used. Because such measurement method is more likely to be posed as a common mode requirement, the EMI current probe shall be installed near the feeder and return path.

A3. 3. 3 Load-induced power line conductivity emission, frequency domain characteristics
(primary power line conduction emissions, load)

LISN in the frequency domain shall be shown in Figure A3. 3. 3 -1. Figure A3. 3. 3 -2 is the setup of the LISN-based conductivity emission test. The register connected to the LISN EMI port is 50 Ω. Current control is required at 150 kHz or less. Because, it is impossible to standardize only the single power source impedance at such low frequency. When conductive emissions must be controlled at 150 kHz or less, refer to the guideline specified in the section for audio frequency conductivity emission in SAE ARP 1972 [11].

A3. 3. 4 Load-induced power line switching transient
(primary power line switching transient)

A3. 3. 4. 1 Application

The direct current bus is adopted in almost space system power buses. Because it allows the simplification of the transient signal measurement. In the direct current bus, the transient signal timing is not important and the transient waveform can be identified clearly. If the line-to-line electrostatic capacity is increased and the power input of the test piece is bypassed, the power supply can be controlled at will for a short period of time.

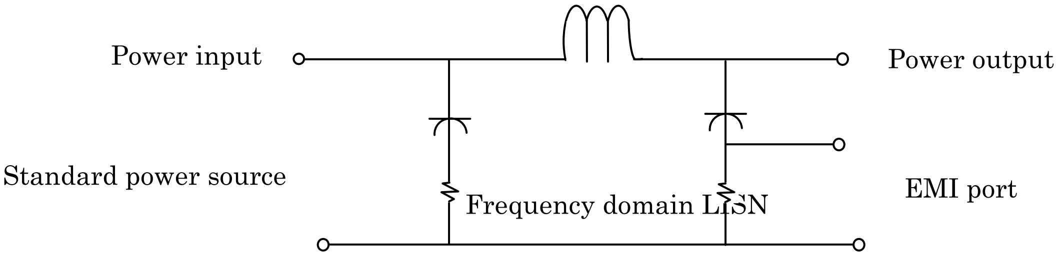


Figure A3. 3. 3 -1 LISN frequency domain

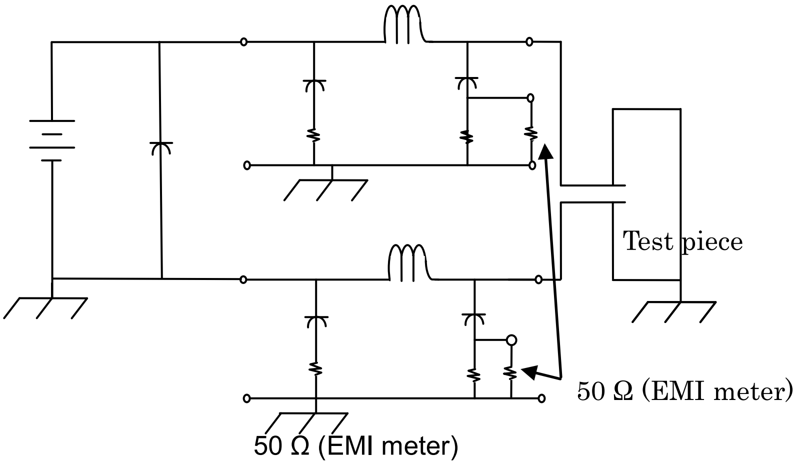


Figure A3. 3. 3 -2 Example of setup of LISN-based voltage conductive emissions test

A3. 3. 4. 2 Control of long-duration load-induced switching transients (inrush current)

The inrush current from the low impedance source shall be measured. For example, select a source that will not allow the voltage of the total power source to dive when applying power to the test piece. In other words, when specifying the resistance of the power source for testing, the resistance in the space system power subsystem must not be simulated. The test setting shall be shown in Figure A3. 3. 4. 2. The voltage drop (due to transient rush current) measured in the entire series resistance when applying power to the test piece shall be smaller than the amount below:

$$\Delta V_{trans}(V_{nom}-V_{\min}) \leq \sqrt{\frac{I_{ss}}{I_{bus}}}$$

Where,

ΔV_{trans}: maximum allowable voltage drop during rush current measurement (volt)

V_{nom}: nominal bus voltage under power quality specification (volt)

V_{nom}: minimum bus voltage under power quality specification (volt)

I_{ss}: steady-state power pulling of test piece (ampere)

I_{bus}: space system power bus steady-state maximum current load (ampere)

The internal/series resistance shall conform to the above maximum voltage drop requirements. The input power condenser of the test piece shall be discharged before transient signal measurement. By providing the entire direct current power source output with the bypass capacity, the internal resistance can be reduced effectively.

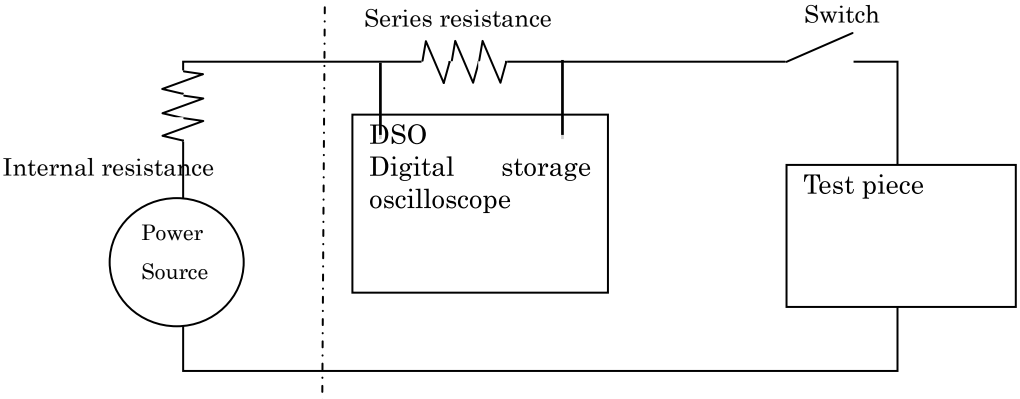


Figure A3. 3. 4. 2 An example of long-duration switching transient test setup

A3. 3. 4. 3 Control of fast load-induced switching transients (current changing rate)

The frequency lower limit is placed on the conductive emission (CE) requirements in the frequency domain. The LISN impedance cannot be defined under the limit. Figure A3. 3. 4. 3 -1 illustrates the comparison between the frequency domain LISN and time domain LISN. Because the time domain LISN has no components connecting the line with the ground, the common mode impedance of the power source cannot be controlled. Because the time domain transient signal and the line-to-line ripple of the current return power bus on the ground are regarded as normal mode phenomenon, measurement is possible. Figure A3. 3. 4. 3 -2 illustrates the measurement test setting using two types of LISN. When applying the frequency domain test setting to the time domain test, the DSO shall be used instead of the EMI meter. A load of 50 Ω shall be applied continually to each EMI port. Balanced line-to-line measurement shall be conducted not to measure the common mode effect of the EMI port. However, note that the impedance below 150 kHz cannot be controlled properly with the frequency domain LISN. (Resonance occurs.)

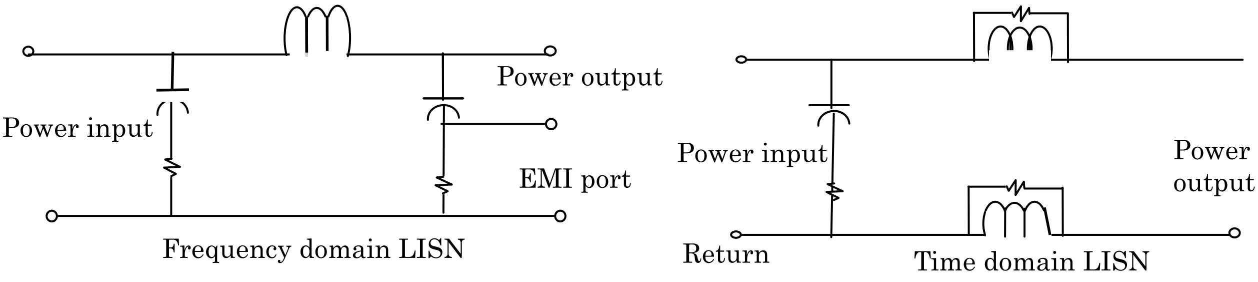


Figure A3. 3. 4. 3 -1 Comparison between the frequency domain LISN and time domain LISN

A3. 3. 5 Load-induced power-line ripple (primary power-line ripple)

When the bandwidth is referenced in the power quality specification and the specific ripple voltage is defined, the specified bandwidth shall be matched with the bandwidth of the measurement equipment (digital storage oscilloscope having true rms capacity). The repeated frequency bandwidth of DSO shall be the equal to or larger than the required bandwidth of the power quality specification. The 100-ns waveform capturing capacity is required for the single bandwidth of DSO. The power source impedance in the entire ripple measurement range shall be controlled so that it will not exceed the required bandwidth defined in the power quality specification.

Because both the maximum amplitude and the rms value of the ripple voltage are confirmed, true rms read values are required when implementing the test. For the power quality specifications requiring the test pieces receiving the power supply from the direct current bus or measurement of the time domain ripple at the bandwidth (waveform capture at 100 ns) below 10 MHz, a simplified power source impedance may be established based on the worst-case inductance and the following formula.

$$L = \frac{d^2 N^2}{0.45d + l}$$

Where,
L: inductance (nH)
d: coil diameter (mm, however, coil center distance)
l: coil length (mm)
N: number of turns

Figure A3. 3. 5 -1 shows the physical realization of the above inductance formula. The test layout for direct current equipment time domain ripple measurement shall be shown in Figure A3. 3. 5 -2. The DSO input impedance shall be 1 MΩ or more. The power source impedance shall be kept to a minimum so that the ripple voltage measured on the power source side with a combination of inductance and resistance will be negligibly small in comparison with the specification limit.

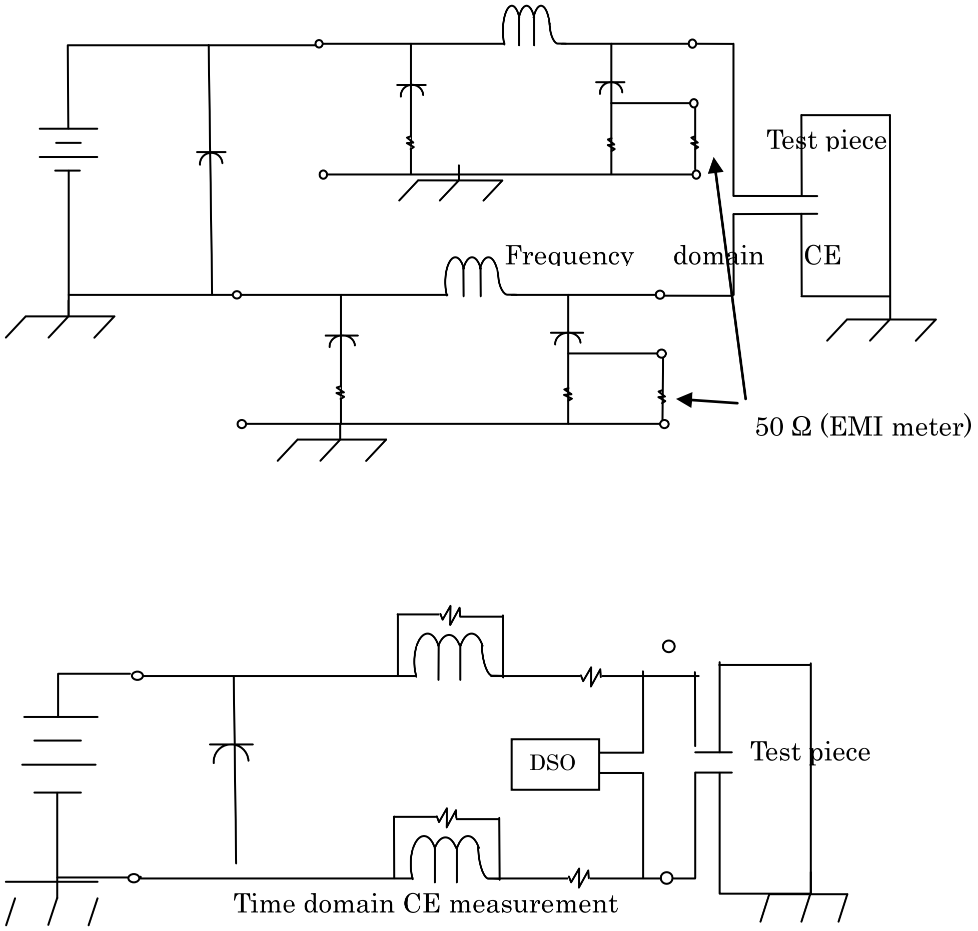


Figure A3. 3. 4. 3 -2 An example of frequency/time domain CE test setup

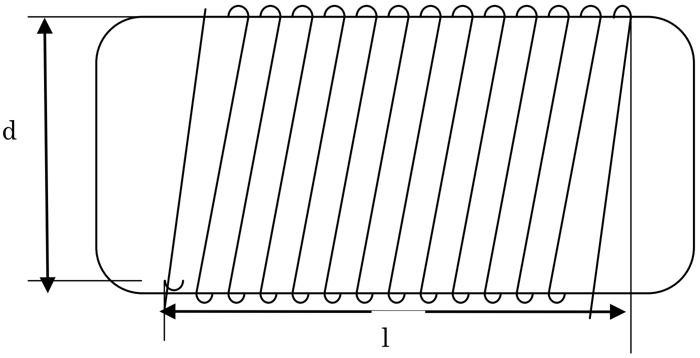


Figure A3. 3. 5 -1 Choke coil

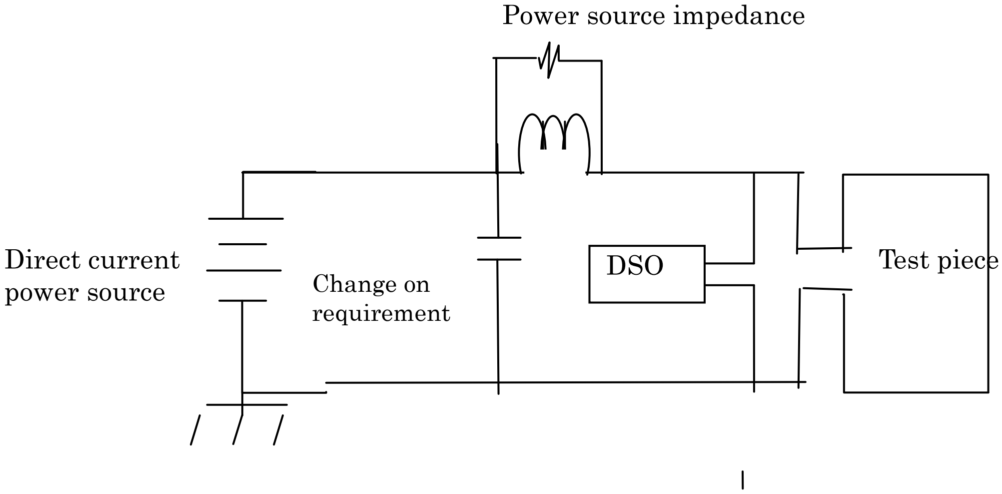


Figure A3. 3. 5 -2 An example of direct current equipment power-line ripple test setup

A3. 3. 6 Signal line conduction emissions

The bulk current shall be measured in this test. It is desirable measurement be conducted at a location 5 cm away from the test piece.

The test method shall be shown in Figure A3. 3. 6. This test method is similar to bulk current injection test method. However, only the current probe for measurement shall be mounted without mounting the injection probe.

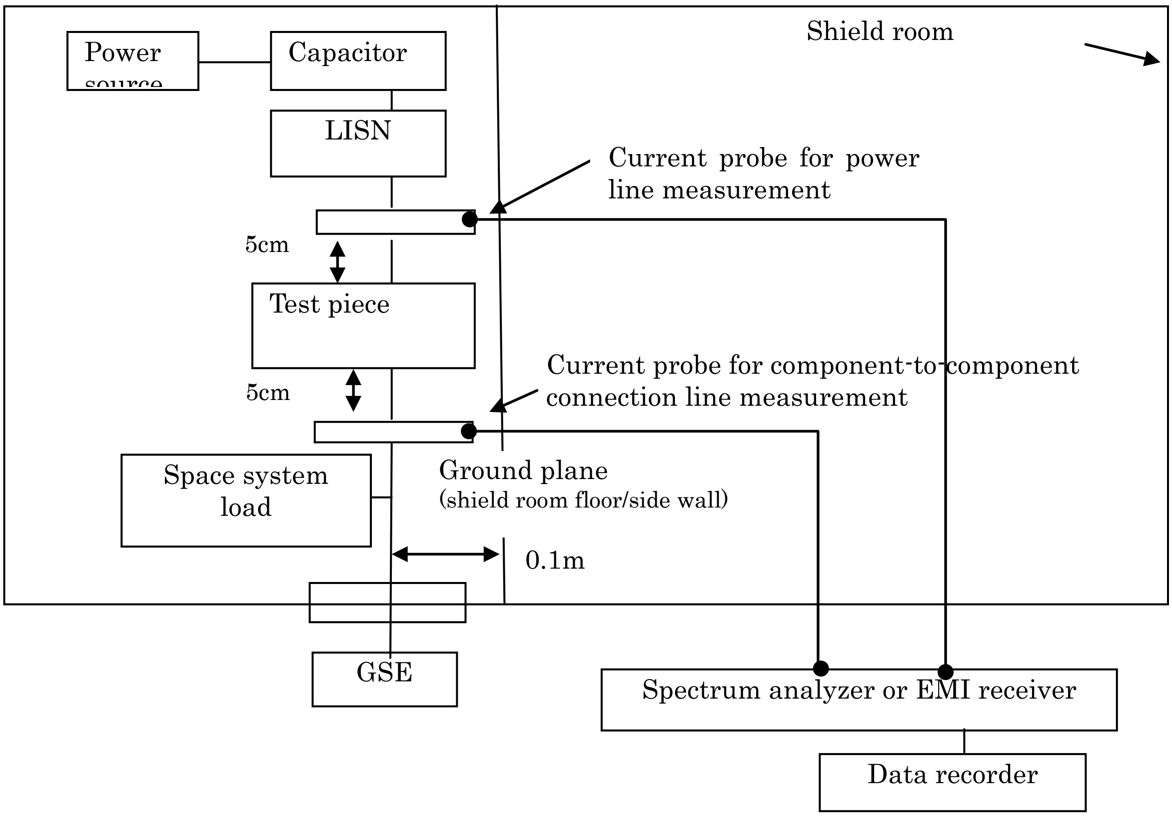


Figure A3. 3. 6 An example of signal line/conduction emissions test setup

A3. 3. 7 Antenna connection port spurious emissions

Prevent the damage caused by transmitter transmitting the current having high-voltage standing wave ratio. When testing the transmitter in the transmission mode, the notch filter shall be required. See MIL-STD-462 RE03 for test method.

As long as the antenna is selected and arranged strictly, the limit may be represented not as effective electric field strength but as the power received by the EMI receiver. This can be obtained by setting the target power to the receiver.

A3. 3. 8 Magnetic field radiated emissions

Low frequency magnetic field emission shall be measured using the electrically shielded loop antenna or AC magnetometer. The sensor size differs depending on the distance between the test piece and the loop antenna. The air-core loop having a diameter of 13 cm shall be used when the interval is 10 cm or less. For the small-sized AC magnetometer, the sensor having a diameter of 13 cm or less shall be used. The wire used, number of turns, and type of magnetic material shall be selected so that the measurement system sensitivity will be proper when connected to the EMI meter. Because the air-core loop is not effective at low frequency, the most sensitive EMI receiver that can capture the data at 1 kHz or less is required. When the sensor is separated far from the test piece, the size of the sensor shall be matched with that of the test piece circuit.

A3. 3. 9 Radiated electric field emissions

When the test frequency bandwidth significantly different from the interfered bandwidth (1.5 times or more), identification of narrow/broad bandwidth may be necessary. Unless the narrow/broad bandwidth must be identified individually (special environment), the function of peak detector shall be used. The narrow bandwidth data may be evaluated using the average value detector. When interfered antenna characteristics of the space system are adjusted during testing, the polarization of the test antenna shall be matched with that of the space system antenna. To improve the test quality, both horizontal and vertical polarization shall be applied.

See MIL-STD-462 RE02 for test method. A typical example of antenna position during measurement shall be shown in Figure A3. 3. 9. See Section 6. 4. 2. 2 for measurement antenna selection policy.

A3. 3. 10 Immunity to power-line ripple

In this test, it shall be verified through measurement that the voltage at power input terminal of the test piece is at the specified value. Injection signals shall be applied without modulation. For the impedance of the ripple generator, select the larger value of the power source impedances estimated at 0.5 Ω or 1500 Hz or less. The power source impedance increases when the frequency exceeds 1500 Hz. The requirement compatibility will be validated when any one of the two conditions is valid.

a) As long as the voltage of the power input terminal of the test piece is at the specified value, the function/performance of the test piece will not be deteriorated unacceptably.

b) Even if the current injected by the ripple generator generates the specified voltage at load impedance regardless of the voltage applied to the power input terminal of the test piece, the function/performance of the test piece will not be deteriorated unacceptably.

Note: Unless the power source having enough capacity is used in this test, it may appear that the power quality is degraded and the EUT sensitivity is high.
Modulated signals may be used. Installing the line-to-line condenser on the power source, voltage can be applied to the test piece easily.

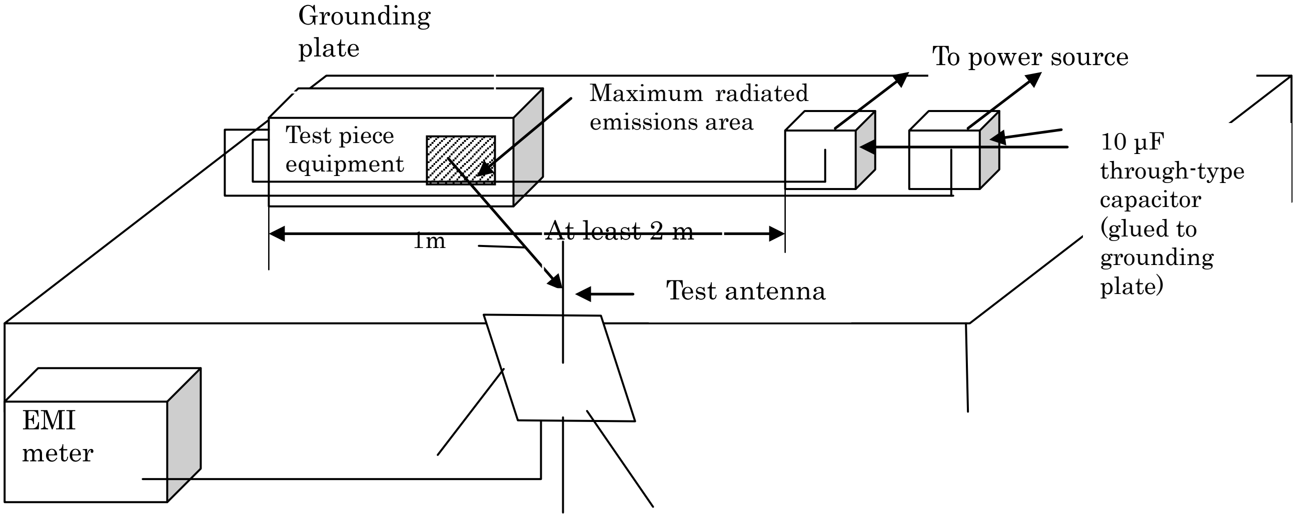


Figure A3. 3. 9 Antenna position

A3. 3. 11 Immunity to power line switching transient

The power line, switching transient and immunity shall be performed by sending transient signals from the coupling transformer. A typical test method shall be shown in Figure A3. 3.11.

However, the test method must be changed depending on the power source impedance and transient signal characteristics of the space system unit specified in the power quality specification. NASA H-29919D [12] shall be recommended as reference documents on switching transient immunity.

A3. 3. 12 Immunity to the conducted effects of radiated electromagnetic fields

Care shall be given to the insertion loss requirements of the selected test standard. To apply the current at the specified upper limit into the system at 50 Ω, the power supplied to the bulk current injection clamp shall be obtained from the insertion loss.

$$P = I_{\mathrm{lim}} + I_L - 73$$

Where,
P: target power level (decibel × meter (dB・m))
I_{lim}: specification limit (decibel ×micro ampere (dB・μA))
I_L: BCI clamp insertion loss (decibel (dB))

Supply the pre-calculated power to the bulk current injection clamp and perform monitoring. In addition, mount the current probe near the cable to be tested to monitor the injection current. For this system, set the overcurrent limit of specified upper limit + 10 dB.

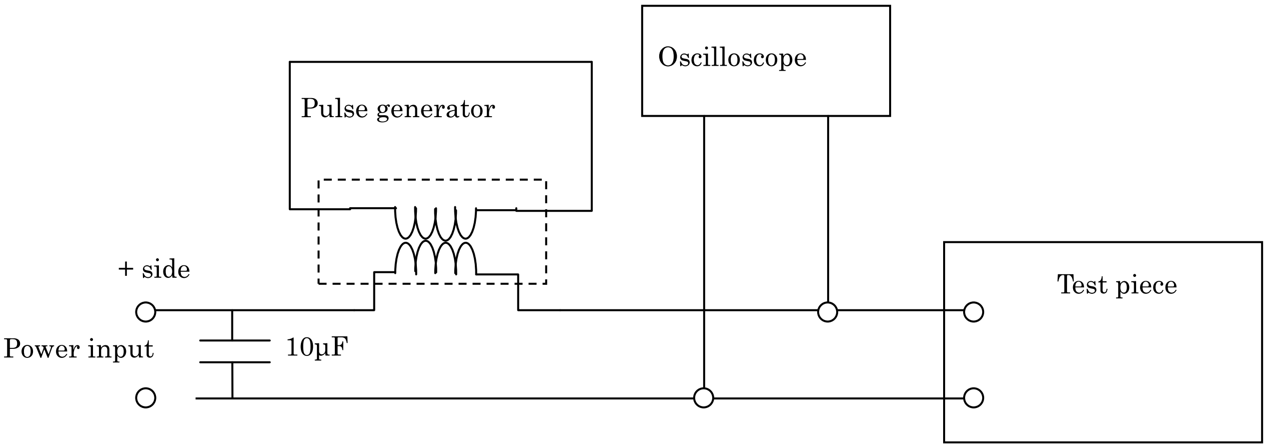


Figure A3. 3.11 Power line/switching transient/immunity test method

A3. 3. 13 Immunity to magnetic emissions

This test shall not be required normally except for science satellite tests using the magnetometer or tests for spacecrafts using the magnetic torque meter.

As long as the coil diameter is electrically shorted and electrode potential generated in the entire coil is negligible (inductive reactance is small), the magnetic field can be calculated with the current and physical parameters using the following formula. The formulas (1) and (2) shall be applied to Helmholtz coil and small-sized coil, respectively.

$$B = \frac{8\mu NI}{125d} \qquad (1)$$

$$B = \frac{\mu NId^2}{2(d^2 + r^2)^{3/2}} \qquad (2)$$

Where,
B: induction field (tesla (T))
μ: magnetic permeability in free space (=4×10^{-7} H/m)
N: number of turns, I: current (ampere (A))
d: coil diameter (meter)
r: distance along shaft from loop (meter)

The important difference between the two coils is that the internal magnetic field of the Helmholtz coil is even while the magnetic field of the small-sized loop is weakened in proportion to the distance. The formula of the small-sized loop can only be applied to on the axis because the magnetic field fluctuation is complex in places other than on the axis. The test using the Helmholtz coil has a far higher repeatability and enables verification under more strict conditions.

A3. 3. 14 Immunity to field emission

Only when the test piece is static with the course of time (no repeated cycle, only steady-state), the mode adjustment method shall be applied. Rather than continuous operation, step operation is more appropriate for the mode regulator. When the test piece is large and complex, the sensitivity can be determined early in a relatively short period of time if mode adjustment is implemented in advance.

If the sensitivity is unknown in the initial phase, the uncertainty of the aspect angle in the test stroke ISO 7137-3.6 (Section 20.5) becomes higher and irradiation is repeated often, which may prolong the test time. The mode adjustment method is useful as a preliminary diagnosis method toward more strict and higher precision technology such as test stroke ISO 7137-3.6 (Section 20.5).

When adjusting the antenna characteristics which will be interfering element during testing, the polarization of the test antenna shall be matched with that of the interfering antenna. In the test chamber during attenuation, the polarization of the test piece may be different from that of the test antenna. Thus, to improve the quality of test, both polarizations (horizontal and vertical) shall be used.

A3. 3. 15 Immunity to signal line magnetic field conduction

Immunity to signal line magnetic field conduction shall be conducted by arranging the line applied with transient voltage parallel with the cable of the test piece. Typical test method shall be shown in Figure A3. 3. 15.

A3. 3. 16 Antenna terminal out-of-band immunity

The verification method largely differs depending on the receiver to be tested. For the qualification of the conventional superheterodyne receiver, the test methods specified in CS03, CS04 and CS05 in MIL-STD-461C shall serve as a guideline. (CS103, CS104, CS105 in MIL-STD-461E)

A3. 4. 1 Immunity test equipment

It is desirable to verify before testing that the EMI equipment used for measurement in the immunity test can measure 6 dB below the application standard limit.

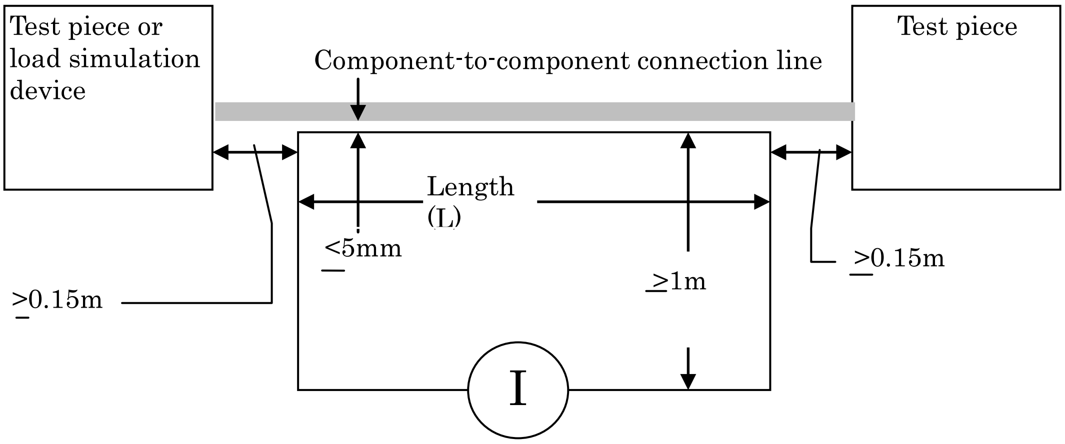


Figure A3. 3. 15 Signal line magnetic field conduction immunity test method