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Space engineering

Electrical and electronic

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Foreword

This Standard is one of the series of ECSS Standards intended to be applied together for the management, engineering and product assurance in space projects and applications. ECSS is a cooperative effort of the European Space Agency, national space agencies and European industry associations for the purpose of developing and maintaining common standards. Requirements in this Standard are defined in terms of what shall be accomplished, rather than in terms of how to organize and perform the necessary work. This allows existing organizational structures and methods to be applied where they are effective, and for the structures and methods to evolve as necessary without rewriting the standards.

This Standard has been prepared by the ECSS-E-ST-20 Working Group, reviewed by the ECSS Executive Secretariat and approved by the ECSS Technical Authority.

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Change log

ECSS-E-20A 4 October 1999	First issue
ECSS-E-20B	Never issued
ECSS-E-ST-20C 31 July 2008	Second issue The following is a summary of changes between ECSS-E-20A and the current issue: • Generic modifications: o Modifications to comply with the ECSS drafting rules. In particular, the standard has been reorganised such every requirement is individually identified. o For clauses 4, 5 and 7, verification tables have been created. These tables specify how and when to verify the requirements, and where to document it. o The lists of abbreviated terms, terms and definitions have been up-dated according to the document modifications. o For all clauses, minor modifications to ensure consistency with other ECSS standards have been done. • Clauses 4 and 5 modifications; o Some requirements have been reworded for clarity. These modifications concern mainly power electronics designs (control, protections, failure propagation, redundancies, and commands) and methods of verification (tests, analysis, review of design). o A few generic requirements, not specific to electric and electronics, were deleted because they were already part of another ECSS standard. o New generic and relevant requirements related to bus protections were included. o The parts dedicated to battery and solar arrays have been re-examined: new requirements are now clearly expressing the parameters to consider for solar array power calculations. • Clause 6, covering EMC general requirements, has been reviewed, simplified and harmonised with ECSS-ST-20-07C (Electromagnetic compatibility) and ECSS-ST-20-06C (Spacecraft charging). • Clause 7 concerning Antennas, RF breakdown, and Passive Inter-modulation has been reorganised: the Passive Inter-modulation part has been completely re-written. • Clause 8 (optical systems) has been removed.

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1 Scope

This Standard establishes the basic rules and general principles applicable to the electrical, electronic, electromagnetic, microwave and engineering processes. It specifies the tasks of these engineering processes and the basic performance and design requirements in each discipline.

It defines the terminology for the activities within these areas.

It defines the specific requirements for electrical subsystems and payloads, deriving from the system engineering requirements laid out in ECSS-E-ST-10 "Space engineering – System engineering general requirements".

This standard may be tailored for the specific characteristic and constrains of a space project in conformance with ECSS-S-ST-00.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this ECSS Standard. For dated references, subsequent amendments to, or revision of any of these publications do not apply, However, parties to agreements based on this ECSS Standard are encouraged to investigate the possibility of applying the more recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-S-ST-00-01	ECSS system – Glossary of terms
ECSS-E-ST-10	Space engineering – System engineering general requirements
ECSS-E-ST-20-01	Space engineering – Multipaction design and test
ECSS-E-ST-20-06	Space engineering – Spacecraft charging
ECSS-E-ST-20-07	Space engineering – Electromagnetic compatibility
ECSS-E-ST-20-08	Space engineering - Photovoltaic assemblies and components
ECSS-E-ST-33-11	Space engineering – Explosive systems and devices
ECSS-E-ST-50-05	Space engineering – Radio frequency and modulation
ECSS-Q-ST-30-11	Space product assurance – Derating – EEE components
IEC 60479:1994	Effects of current on human beings and livestock
IEEE 145-1993	Antenna terms

3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.

3.2 Terms specific to the present standard

3.2.1 antenna farm

ensemble of all antennas accommodated on the spacecraft and provides for all the transmission and reception of RF signals

3.2.2 antenna port

abstraction of the physical connection among the antenna and its feeding lines, realised by means of connectors or waveguide flanges

3.2.3 antenna RF chain

sequence of microwave components (ortho-mode transducers, polarisers, transformers as well as filters) inserted between an antenna input port or a BFN output port and a corresponding individual radiating element

3.2.4 antenna support structure

part of an antenna having no electrical function, which can however impact its electrical performances of the antenna, either directly (due to scattering) or indirectly (e.g. due to induced thermo-elastic deformations)

3.2.5 array antenna

antenna composed by a number of, possibly different, elements that radiate RF signals directly into free space operating in combination, i.e. such that all or a part of them radiate the same signals

3.2.6 array-fed reflector antenna

antenna composed by a (feed) array, which can include or not a beam forming network, and one or more optical elements (reflectors and lenses)

3.2.7 beam forming network (BFN)

wave-guiding structure composed a chain of microwave components and devices (lines, phase shifters, couplers, loads) aimed at distributing the RF power injected at the input ports to a number of output ports; in a transmitting antenna the RF power injected from the transmitter is routed to the radiating elements, in a receiving antenna the RF power coming from the radiating elements is routed to the antenna ports connected to the receiver

3.2.8 conducted emission (CE)

desired or undesired electromagnetic energy that is propagated along a conductor

3.2.9 critical pressure

pressure at which corona or partial discharge can occur in an equipment

3.2.10 diffusivity

ability of a body to generate (incoherent) diffuse scattering due to (local) roughness, inhomogeneity or anysotropy when illuminated by RF waves

3.2.11 depth of discharge (DOD)

ampere–hour removed from an initially fully charged battery expressed as a percentage of the nominal nameplate capacity

3.2.12 double insulation

barrier between conductors or elements of an electronic circuit such that after any credible single failure, conductors or elements of an electronic circuit are still insulated from each other

3.2.13 electrical bonding

process of connecting conductive parts to each other so that a low impedance path is established for grounding and shielding purposes

3.2.14 electromagnetic compatibility (EMC)

ability of equipment or a system to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment

3.2.15 electromagnetic compatibility control

set of techniques to effectively regulate the electromagnetic interference environment or susceptibility of individual space system components or both

NOTE They include, among others, the design, placement of components, shielding, and employment of rejection filters.

3.2.16 electromagnetic interference (EMI)

undesired electrical phenomenon that is created by, or adversely affects any device whose normal functioning is predicated upon the utilization of electrical phenomena

NOTE It is characterized by the manifestation of degradation of the performance of an equipment, transmission channel, or system caused by an electromagnetic disturbance.

3.2.17 electromagnetic interference safety margin (EMISM)

ratio between the susceptibility threshold and the interference present on a critical test point

3.2.18 emission

electromagnetic energy propagated by radiation or conduction

3.2.19 essential function

function without which the operator cannot recover the spacecraft (following any conceivable on-board or ground-based failure), the spacecraft cannot be commanded, the spacecraft permanently loses attitude and orbit control, the spacecraft consumables (e.g. fuel and energy) are depleted to such an extent that more than 10% of its lifetime is affected, or the safety of the crew is threatened

3.2.20 foldback current limiter (FCL)

non latching current-limiting function where the current limit will decrease with the output voltage

NOTE This function is used for power distribution and protection typically for essential loads.

3.2.21 fully regulated bus

bus providing power during sunlight and eclipse periods with a regulated voltage

3.2.22 grounding

process of establishing intentional electrical conductive paths between an electrical circuit reference or a conductive part and equipment chassis or space vehicle structure

NOTE grounding is typically performed for safety, functionality, signal integrity, EMI control or charge bleeding purpose.

3.2.23 high Priority telecommand (HPC)

command originated from ground and issued by the telecommand decoder for essential spacecraft functions without main on board software intervention

3.2.24 high voltage

AC or DC voltage at which partial discharges, corona, arcing or high electrical fields can occur

3.2.25 lens antenna

antenna composed by a number of RF lenses and reflecting surfaces illuminated by a primary source, the feed

3.2.26 latching current limiter (LCL)

latching current-limiting function used for power distribution, switching and protection

3.2.27 lightning indirect effects

electrical transients induced by lightning in electrical circuits due to coupling of electromagnetic fields

3.2.28 major reconfiguration function

function used to recover from system failures of criticality 1, 2 or 3

NOTE Criticality categories are defined in ECSS-Q-ST-30 and ECSS-Q-ST-40.

3.2.29 nominal nameplate capacity

capacity stated by the manufacturer of an energy storage cell or battery

NOTE It is given in ampere-hours. It is not necessarily equal to any measurable capacity.

3.2.30 non essential loads

loads related to units which do not implement essential functions for the spacecraft

3.2.31 passive intermodulation products (PIM)

spurious signals generated by non-linear current-voltage characteristics in materials and junctions exposed to sufficiently RF high power carried by guided or radiated fields and currents, possibly triggered by (microscopic) mechanical movement

3.2.32 photovoltaic assembly (PVA)

power generating network comprising the interconnected solar cell assemblies (strings and sections), the shunt and blocking diodes, the busbars and wiring collection panels, the string, section and panel wiring, the wing transfer harness, connectors, bleed resistors and thermistors

3.2.33 primary cell or battery

battery or cell that is designed to be discharged once and never to be recharged

3.2.34 radiofrequency (RF)

frequency band used for electromagnetic waves transmission

3.2.35 radiated emission (RE)

radiation and induction field components in space

3.2.36 recharge ratio (k)

ampere–hours charged divided by the ampere–hours previously discharged, starting and finishing at the same state of charge

NOTE It is also known as the k factor.

3.2.37 reflector antenna

antenna composed by a number of reflecting surfaces, RF reflectors, illuminated by a primary source, the feed

3.2.38 RF chain

sequence of microwave components inserted between the RF power amplifier and the antenna input port

3.2.39 RF lens

plastic, composite or metallic (e.g. waveguide-array lenses) structure acting on transmitted RF waves to control the antenna pattern

3.2.40 RF reflector

metallic or composite structure, possibly metallised or with printed or embedded metallic elements, acting on reflected RF waves to control the antenna pattern

NOTE Frequency and polarisation surfaces as well as other fully reflecting or partially reflecting and transmitting structures, also having non-uniform or anisotropic scattering behaviour, are considered reflectors

3.2.41 secondary cell or battery

battery or cell that is designed to be charged and discharged multiple times.

3.2.42 solar cell assembly (SCA)

solar cell together with interconnector, coverglass and if used, also a by-pass diode

3.2.43 susceptibility

malfunction, degradation of performance, or deviation from specified indications, beyond the tolerances indicated in the individual equipment or subsystem specification in response to other than intended stimuli

3.2.44 susceptibility threshold

interference level at a test point which just causes malfunction in the equipment, subsystem, or system

3.2.45 vacuum

environment with a pressure of 10 Pa or below

3.3 Abbreviated terms

For the purpose of this Standard, the abbreviated terms from ECSS-S-ST-00-01 and the following apply:

Abbreviation	Meaning
A	analysis
AC	alternative current
AR	acceptance review
BFN	beam forming network
BOL	beginning–of–life
CDR	critical design review
DC	direct current
DDF	design definition file
DJF	design justification file
DOD	depth of discharge
DRB	Delivery review board
DRD	document requirement definition
DRL	document requirement list
EED	electro-explosive device
EGSE	electrical ground support equipment
EIDP	end item data-package
EMC	electromagnetic compatibility
EMEVP	electromagnetic effects verification plan
EMEVR	electromagnetic effects verification report
EMI	electromagnetic interference
EOL	end of life
EPS	electrical power system
ESA	European space agency
ESD	electrostatic discharge
FCL	fold-back current limiter
FDIR	failure detection isolation and recovery
FMECA	failure mode effect and criticality analysis
GDIR	general design and interface requirement
INS	inspection
ICD	interface control document
I–V	current–voltage
LCL	latching current limiter
MPPT	maximum power point tracker

Abbreviation	Meaning
MRB	manufacturing review board
PCB	printed circuit board
PDR	preliminary design review
PIM	passive inter-modulation product
PVA	photovoltaic assembly
QTR	qualification test report
RF	radio frequency
ROD	review of design
SAD	solar array drive
SCA	solar cells assembly
SEE	single event effects
SEU	single event upsets
SRR	system requirement review
T	test
TRB	test review board
TRR	test readiness review
TM&TC	telemetry/telecommand
UV	ultraviolet
VCD	verification control document

4
General requirements

4.1 Interface requirements

4.1.1 Overview

ECSS-E-ST-10 specifies that interfaces external or internal to a system are adequately specified and verified. The following requirements address this issue and are processed in phase B, C and D of a project (see ECSS-E-ST-10).

4.1.2 Signals interfaces

a. Interface engineering shall ensure that the characteristics on both sides of each interface are compatible, including source and load impedances, the effects of the interconnecting harness and the grounding network between both sides comprising: common mode impedance conducted and radiated susceptibility and emission.

b. In order to minimize the number of interface types, standard interface circuitry shall be defined to be applied throughout a project.

c. Except for direct commands to relay coils, circuits receiving high level telecommands for direct execution of a major reconfiguration function or other critical function shall include noise discrimination filtering such that spurious commands of nominal peak–to–peak amplitude and of less than 10 % of the nominal command duration at a repetition period of 40 % of the nominal command duration are ignored.

d. The application of the nominal signals or a faulty signal (as defined in the general design and interface requirements document) to an un-powered interface shall not cause damage to that interface.

NOTE In case verification by analysis is not conclusive a complementary verification by test is necessary.

e. An undetermined status at the interfaces of a powered unit shall not cause damage to an un-powered interface.

NOTE 1 Undetermined status includes: non-nominal operating modes, permanent and non permanent failure modes, powered and un-powered interfaces.

NOTE 2 In case verification by analysis is not conclusive a complementary verification by test is necessary.

f. Signal interfaces shall withstand without damage positive or negative nominal voltages that are accessible on the same connector (from the unit itself, from the interfaced units or from EGSE).

NOTE In case verification by analysis is not conclusive a complementary verification by test is necessary.

NOTE Any circuit intended to receive a signal should include noise discrimination filtering compatible with EMC susceptibility recommendations defined in ECSS-E-ST-20-07, Annex A.

4.1.3 Commands

a. Every command (intended to be sent to the spacecraft) shall be assessed for criticality at equipment level, and confirmed at subsystem/system level.

NOTE The criticality of a command is measured as its impact on the mission in case of inadvertent function (erroneous transmission), incorrect function (aborted transmission) or loss of function. The definition of criticalities can be found in ECSS-Q-ST-30 and ECSS–Q-ST-40.

b. All executable commands shall be explicitly acknowledged by telemetry.

c. High Priority telecommand decoding and generation shall be independent from the main on-board processor and its software.

NOTE That implies the high level command decoder, command generator and their power supply to be entirely implemented in a dedicated module in a secure and independent way.

d. With the exception of pyrotechnic commands, the function of an executable command shall

1. not change throughout a mission, and

2. not depend on the history of previous commands.

e. For commands of category 1 and 2 criticality, at least two separate commands for execution: an arm/safe or enable/disable followed by an execute command shall be used.

NOTE For criticality categories, see ECSS-Q-ST-30 or ECSS-Q-ST-40.

f. The functionality shall be provided to repeat the transmission of all the executable commands without degradation of the function or a change of its status.

g. In case of critical commands of category 1 and 2, at least two physically independent electrical barriers, including associated control circuits, are mandatory for arming and executing the command.

NOTE 1 For criticality categories, see ECSS-Q-ST-30 or ECSS-Q-ST-40.

NOTE 2 Mechanical barriers can be considered.

NOTE 3 Physically independent electrical barriers and associated control circuits are the ones not sharing any hardware function and without risk of reciprocal failure propagation.

h. Processor and simple logic circuits shall not be able to issue category 1 and 2 critical commands without a ground commanded arm/safe or enable/ disable command.

NOTE To avoid inadvertent activation of processes enabled/disabled by category 1 or 2 critical commands during ground operations and in low earth orbit phases, it is necessary to foresee safety barriers (arm/safe commands) to inhibit the execution of such critical commands. Such safety barriers might be spacecraft skin connections (to be established or broken just before flight) or connections/disconnection plugs to be activated by launcher stages release (in flight). The activation/deactivation of such barriers has to be independent from on board processor.

i. Any on–board processing which issues commands to reconfigure subsystems or payloads shall be overridable and potentially inhibited by ground command.

NOTE For criticality categories, see ECSS-Q-ST-30 or ECSS-Q-ST-40.

j. No commands shall be issued unless the transmitter power supply voltages of the function to be commanded are in the operational nominal range.

4.1.4 Telemetry

a. Telemetry data devoted to the spacecraft subsystem and payloads monitoring shall allow

1. the retracing of the overall configuration at least up to all reconfigurable elements.

2. the location of any failure able to impact the mission performances and reliability at least up to all reconfigurable elements.

b. The operational status (On/Off, enabled/disabled, active/not-active) of each element of any telemetry acquisition chain should be provided to the on-board computer in order to determine without ambiguity the validity of the telemetry data at the end of the overall chain.

c. Main bus load currents shall be monitored by telemetry, to enable, together with the bus voltage telemetry, a complete monitoring of a main bus power load.

d. Telemetry shall be implemented to monitor the evolution of the power-energy resources and the source temperatures during the mission.

4.2 Design

4.2.1 Failure containment and redundancy

a. A single failure shall not propagate outside a single reconfigurable element.

b. Redundant functions shall be routed separately.

c. Provision 4.2.1b should be met via redundant harness and physically separated connectors.

d. Redundant functions shall be physically separated with no risk of failure propagation by thermal or other coupling and as a minimum, contained within a different package to avoid failure propagation.

NOTE E.g. within hybrid and integrated circuit.

e. For redundant functions implemented on the same PCB, a physical separation shall be provided, with no risk of thermal or other failure propagation.

NOTE Example of physical separation are by a minimum distance, insulation, or cut-out.

f. For redundant functions implemented on the same PCB, any deviation of the physical separation specified in 4.2.1e shall be tracked in the Critical item List.

g. For hybrids, redundant and protection functions shall be located in a different cavity.

h. In case a cold redundant function is simultaneously activated together with the nominal one, by a deliberate or wrong command or due to a fault, this shall not induce permanent degradation of either of the two functions or loss of the mission before FDIR action.

NOTE E.g. thermal and EMC functions.

i. In case verification of 4.2.1h by analysis is not conclusive a complementary verification by test shall be performed.

j. Any active equipment dissipating more than 20 W in nominal or failure condition shall include a temperature monitoring capability (individual heaters excluded).

k. In case of signal cross-strapping, no single failure of either interface circuit shall propagate to the other one.

l. In the case of hot redundant essential functions, either latching protection shall not be used, or it shall have an autonomous periodic reset.

m. Override of critical on-board autonomous functions shall be implemented only if a safety interlock is implemented which prevents the activation of the override feature on both main and redundant functions.

n. Any protection latch, which does not have autonomous reset capability, shall be at least re-settable from ground command.

o. Any protection of an essential function shall not share with the essential function itself the same hybrid cavity or component or integrated circuit nor utilize common references or auxiliary supply.

p. Essential functions shall not rely on other functions which are centrally generated.

NOTE 1 E.g. on synchronization and auxiliary supply.

NOTE 2 That implies the capability of any equipment performing an essential function of operating independently of any external synchronization and auxiliary power supply.

q. For essential functions supplied by an FCL, lock-up phenomenon requiring recovery via the removal of external power shall be prevented.

r. All units to be powered during launch shall be designed for operation with critical pressure.

s. A venting analysis shall be performed for all units not designed to operate under critical pressure and not powered during launch, to determine when they can safely be turned-on.

t. Any on-board autonomous function, the failure of which can result in malfunctions of category 1 and 2 criticality, shall have override capability.

NOTE Examples of override are:

- a simple inhibition or isolation (e.g. cold or hot redundant chain[s] exists)
- an H/W reset (e.g. in case of SEU)
- an inhibition + by-pass (e.g. a stepper motor control loop by-passed by a direct step by step command as back-up)

u. Any on-board autonomous protection override, leading to hazardous situation for the mission (category 1 and 2 criticality), shall not be implemented.

NOTE E.g. an LCL function for instance protecting the main power Bus against a short circuit at Bus user level or Main Bus over-voltage protection.

v. SEE shall not activate protection circuits of essential functions.

NOTE Mitigation techniques can be implemented to avoid such phenomena: filtering, majority voting, etc

w. The spacecraft electrical system shall be single point failure free (or double point failure free for manned mission), regardless of any occurrence of non destructive SEEs.

NOTE A non destructive SEE is not a failure.

4.2.2 Data processing

4.2.2.1 Overview

All operational and mission specific data are processed for acquisition, algorithm application, transmission, storage. On board time is managed by data handling subsystem, in line with the mission requirements. Data processing includes the man machine, interface if any. The data processing system includes all hardware and software elements used for that purpose (e.g. microprocessor and its instruction set, interface means, data busses and remote terminals).

4.2.2.2 Provisions

a. Margins shall be defined at project SRR, applied and kept under configuration control throughout the whole project.

b. The margin for available memory size and load factors of processors should be

 1. for new developments, 50 % as a minimum at PDR for new on board software parts;

 2. 25 % at launch.

c. The margin on the throughput of on-board communication networks should be

 1. for new developments, 50 % as a minimum at PDR on the average throughput;

 2. such that real time overflow is avoided.

d. In the absence of specific mission requirements the following applies: After error correction, reset or data corruption of main functions at equipment level should be kept to a rate of occurrence less or equal to 10^{-4} per day for worst case conditions of environment.

e. For programmable logic devices, the available margin of unused blocks and margin with respect to clock frequency and propagation time should be, for new developments, 50 % as a minimum at PDR.

4.2.3 Electrical connectors

a. A connector carrying source power or external test connectors on units shall have no contact areas exposed to possible short circuit during mating and de-mating process.

 NOTE They generally are female type connectors.

b. All external test connectors on a unit shall be covered for flight.

c. The test connector covers should be metallic or metallized and grounded to structure.

d. The use of a connector saver for ground testing shall not alter the performance of the equipment.

e. It shall be ensured that erroneous mating is avoided by connector keying or marking.

NOTE The requirement is met either by harness routing, or by using keyed connectors, or adequate positioning of connectors, or connectors of different type or size, or connector marking.

f. If the equipment has several connectors, visibility and clearance around each of them shall be such as to enable mating or de-mating without disturbing others already in place or necessitating custom–made tooling.

NOTE A usual practice is the insertion of a breakout box for trouble shooting.

g. For supplies and signals of pyrotechnics and non-explosive single shot device drivers. different connectors should be used for different classes of electrical functions.

h. When 4.2.3g is not met, power, signals, and telemetry shall be separated in the connector by a set of unused pin locations.

i. Spare contacts or sockets shall be available on each connector.

j. For new developments, when the connection is not aligned to a defined standard, 10% spare contacts at unit PDR and at least 5 % at CDR shall be achieved with in any case a minimum of two spare contacts available at CDR.

k. In the absence of grounding provision at connector shell level, at least one contact per connector shall be connected to the unit structure as provision for potential additional grounding at subsystem or system level.

l. Provision shall be taken to avoid arcing or short circuits in connectors.

NOTE For example: unused pins, placed between positive and return lines; specific connector design.

m. The following shall be performed for any connector the loss of which can lead to the loss of the mission:

1. Document the connector in the single point failure list
2. Verify its integrity up to the highest spacecraft integration level

n. The accidental de-mating of connectors (where it is a realistic case) or any internal connector failure shall not lead to catastrophic consequences.

o. Battery and solar array power shall be distributed by multiple contacts on both positive and return lines.

4.2.4 Testing

a. Test-stimulus points shall be accessible without the need of modifying the electrical configuration of an item of equipment.

b. Test-stimulus points shall be protected for flight operation.

c. For the purpose of meeting requirement 4.2.4a and 4.2.4b, dedicated test connectors should be used.

d. The functionality shall be provided to test the redundant function of a closed unit.

e. Test points on equipment shall be protected against damage up to the maximum fault voltage present on the connector either coming from the equipment or the EGSE.

f. Test points on equipment shall be such that unintentional connection of these points to ground does not damage the equipment.

g. The redundancy of parts and functions, which failure can lead to the loss of the mission or human injury, shall be verified by test simulating the failure event.

h. Stimuli points on equipment and payload shall not provoke unwanted operation.

i. The protection of functions, which failure can lead to the loss of the mission or human injury, shall be verified by test simulating the failure event.

j. The test of a protection function or a redundant function shall present no risk of stress or failure propagation due to the injection of stimuli.

k. Hot redundant functions and protection functions shall be tested up to the highest possible level of integration of the unit.

l. Hot redundant functions and protection functions that cannot be tested beyond unit level shall be identified in the critical item list.

m. Redundant functions and protection functions within a unit shall be verified by test at unit level.

NOTE Tests can be performed at open unit or closed unit levels.

n. Redundant units within a system shall be verified by test at system level.

o. Protection functions within a unit protecting other units shall be verified by test at system level.

4.2.5 Mechanical: Wired electrical connections

a. Wired electrical connections shall contain stress relief.

NOTE The objective is to avoid excessive mechanical loads on wires.

4.2.6 Dependability

a. Each item shall be directly interchangeable in form, fit, and function with other equipment of the same part number and of the same qualification status.

b. The uniformity of the performance characteristics and dimensions of the units shall enable equipment interchange without unforeseen adjustments and recalibration.

c. When components operating in a single event are used, 4 times the quantity to be used for flight units shall be procured as one lot: 25 % for the lot acceptance test, 25 % for flight use, 25 % for spares and 25 % for a confirmation test near to the launch date.

NOTE Example of such components are fuses.

d. The number of components to be procured shall be defined to ensure, as a minimum, the quantity needed for flight and flight spares, plus the number of components to be tested at incoming reception and components to be tested just before launch in case of alert or failure.

4.3 Verification

4.3.1 Provisions

a. The requirements of this Clause 4 shall be verified by the verification methods, at the reviews, and recorded in the documentation as specified in Table 4-1.

NOTE For verification, see also ECSS-E-ST-10-02.

4.3.2 Documentation

a. The design report, PSA, WCA, FMECA, thermal analysis, radiation analysis, EMC analysis for electrical design, supported by the detailed circuit diagrams, shall be included in the DJF.

NOTE The DJF contain all descriptions and analyses meant to verify that the design meets the requirements. For the DJF, see ECSS-E-ST-10.

b. Failure modes of all components used in a unit shall be defined.

c. FMECA shall be performed and based on the failure modes previously defined at component level.

Table 4-1: Verification of electrical general requirements

Requirement	At the following verification points	Verification methods
	SRR: System requirements review PDR: Preliminary design review CDR: Critical design review TRR: Test readiness review TRB: Test review board DRB: Delivery review board AR: Acceptance review X: Preliminary formal verification point	RoD: Review of design T: Test A: Analysis INS: Inspection NOTES: RoD includes review of documentation
4.1.2a	SRR	RoD, A, T
4.1.2b	SRR	RoD
4.1.2c	SRR	RoD, A
4.1.2d	PDR	A, T
4.1.2e	PDR	RoD, A, T
4.1.2f	PDR	RoD, A, T
NOTE	PDR	RoD, A
4.1.3a	SRR	RoD, A
4.1.3b	SRR	RoD, T
4.1.3c	PDR, CDR	RoD
4.1.3d	PDR, CDR	RoD
4.1.3e	PDR, CDR	RoD
4.1.3f	PDR, CDR	RoD, A, T
4.1.3g	PDR, CDR	RoD
4.1.3h	PDR, CDR	RoD
4.1.3i	PDR, CDR	RoD, T
4.1.3j	PDR, CDR	RoD, A, T
4.1.4a	PDR, CDR	RoD, A
4.1.4b	PDR	RoD, A, T
4.1.4c	PDR	RoD, A, T
4.1.4d	PDR, CDR	RoD, A
4.2.1a	PDR	A
4.2.1b	PDR	RoD
4.2.1c	PDR	RoD
4.2.1d	PDR	RoD. A
4.2.1e and 4.2.1f	PDR	RoD, A
4.2.1g	PDR	RoD

Requirement	At the following verification points	Verification methods
4.2.1h	PDR	RoD, A
4.2.1i	PDR	RoD, T
4.2.1j	PDR	RoD, A
4.2.1k	PDR	RoD, A
4.2.1l	PDR	RoD
4.2.1m	PDR	RoD, A, T
4.2.1n	PDR	RoD, A, T
4.2.1o	PDR	RoD
4.2.1p	PDR	RoD
4.2.1q	PDR	A, T
4.2.1r	PDR	A, T
4.2.1s	PDR	A
4.2.1t	PDR	RoD, A, T
4.2.1u	PDR	RoD, A
4.2.1v	PDR, CDR	RoD, A
4.2.1w	PDR	RoD, A
4.2.2.2a	SRR	RoD
4.2.2.2b	PDR	RoD, A
4.2.2.2c	PDR	RoD, A
4.2.2.2d	PDR	RoD, A
4.2.2.2e	PDR	RoD, A
4.2.3a	PDR	RoD, INS
4.2.3b	AR	INS
4.2.3c	AR	RoD
4.2.3d	CDR	RoD, A
4.2.3e	CDR	RoD, INS
4.2.3f	CDR	RoD, INS
4.2.3g and 4.2.3h	PDR	RoD
4.2.3i	PDR	RoD
4.2.3j	PDR	RoD
4.2.3k	PDR	RoD
4.2.3l	PDR	RoD, A
4.2.3m	PDR	RoD, INS
4.2.3n	PDR	RoD, A

Requirement	At the following verification points	Verification methods
4.2.3o	PDR	RoD
4.2.4a and 4.2.4b	PDR	RoD, INS
4.2.4c	PDR	RoD
4.2.4d	PDR	RoD
4.2.4e and 4.2.4f	PDR	RoD, A
4.2.4g	CDR	A, T
4.2.4h	PDR	RoD, A or T
4.2.4i	CDR	A, T
4.2.4j	PDR	RoD, A
4.2.4k and 4.2.4l	PDR	RoD, T
4.2.4m	PDR	RoD, T
4.2.4n	PDR, AR	RoD, T
4.2.4o	PDR	RoD, T
4.2.5a	PDR	RoD, INS
4.2.6a	CDR	RoD
4.2.6b	CDR	RoD
4.2.6c	PDR	INS
4.2.6d	PDR	INS
4.3.2b	SRR	RoD
4.3.2c	PDR	A

5 Electrical power

5.1 Functional description

Electrical power is used by all active spacecraft systems and equipment for their operation. Electrical power engineering includes power generation, energy storage, conditioning, line protection and distribution as well as high voltage engineering.

5.2 Power subsystem and budgets

5.2.1 General

a. Budgets and margins shall be established during Project phase B, and reviewed in all subsequent phases of the project.

5.2.2 Provisions

5.2.2.1 Power subsystem

a. The power subsystem of a spacecraft shall be able to generate, store, condition, distribute and monitor the electrical power used by the spacecraft throughout all mission phases in the presence of all environments actually encountered.

5.2.2.2 Engineering process

a. An analysis of power demand versus power available shall be performed, including peak power, in the platform and the payloads for all phases of the mission.

b. An analysis of the energy demand versus energy available shall be performed in all phases of the missions, including inrush power demands, eclipses, solar aspect angle and depointing.

c. A power budget shall be established based on the peak power values and an energy budget based on the average power values for all mission phases.

d. A plan shall be established for the maintenance and periodical review of the budget established in requirement 5.2.2.2c during all project phases.

NOTE These budgets take into account:

- spacecraft–sun distance,
- sun and eclipse durations,
- solar aspect angle,
- pointing accuracy,
- environmental temperature and degradation effects,
- reliability and safety aspects,
- any one failure in the system (two failures for manned mission) not counting solar array string and battery cell failure,
- Failure detection, isolation and recovery scenarios.

e. A system margin of not less than 5 % at AR on available power and energy shall be included in the budget, available (as a minimum) with the solar array string losses as defined by the customer with the minimum of one string lost and one battery cell failed during all the designed life of the power system including all spacecraft modes of operation.

f. When using a MPPT, the reduction of transferred power due to the differences in IV curves of the different strings and panels shall be included in the power and energy budgets, leading to multiple local Maximum Power Points and mismatches.

5.3 Failure containment and redundancy

a. Any protection function of a power converter or regulator preventing failure propagation shall:

1. not be implemented in the same hybrid cavity or integrated circuit, and
2. not utilize common references.

b. It shall not be possible to inhibit a protection feature which can lead to the loss of the main primary power bus in case of a single failure at spacecraft level.

c. In flight operation, the power system shall be able to start up from any of its power sources irrespective of the status of the other power source even after a failure (or after a double failure for manned mission).

d. The supplier shall submit for customer approval the list of single failure cases (or double failure cases for manned missions) against which the requirement 5.3c shall be fulfilled.

5.4 Electrical power interfaces

a. The electrical power interface between the solar array(s) and the power control units and between batteries and power control units shall

1. be defined, and

2. result in the specification of the input impedance seen by the power conditioning units.

b. The power interfaces with the power subsystem shall be specified.

NOTE E.g. umbilical and EGSE.

c. The availability of the specified solar array power up to the power conditioning shall be verified by a representative end-to-end test at spacecraft level and correlated analysis.

d. The solar array interface voltage shall be defined at the solar array harness connector interface.

e. The solar array interface voltage shall include voltage losses within the electrical circuitry of the solar array, including at least blocking diodes, wiring resistance and losses associated with harness interconnections in operational conditions.

5.5 Energy generation

5.5.1 Solar cell, coverglass, SCA and PVA qualification

For the qualification of solar cells, protection diodes, coverglass, SCA and PVA, see ECSS-E-ST-20-08.

5.5.2 Solar array specification and design

a. The solar array shall be designed to meet the average power demand in each mission phase (including battery recharge power) during operational life with the string loss tolerance defined by the customer.

NOTE 1 The solar array is designed to be single-failure tolerant at string level.

NOTE 2 In order to meet the solar array reliability requirements, the impact of other loss factors may lead to the addition of other spare strings.

b. In case of a sunlight-regulated bus, provisions shall be made for recovery from lock–up.

c. The solar array design shall satisfy the power requirements established by the spacecraft manufacturer in the solar array specification, for each mission phase in worst-case conditions.

d. Provision shall be made against potential failure propagation in case of short-circuit failure of a solar array section and its connection to the power system.

e. The solar array design shall be such that charging phenomena do not degrade the performance of the solar array below the requirements specified in 5.5.2a and 5.5.2c.

NOTE Good practices in accordance with the present state of the art, are to:

- limit the differential voltage in between cells to 30 V in all conditions if the minimum accepted gap between adjacent non-directly connected cells is 0,5 mm;
- implement string blocking diodes;
- have a coverglass extending beyond the solar cell limits.

f. In case verification by analysis of 5.5.2e is not conclusive a complementary verification by test shall be performed.

g. In the flight configuration, electrical continuity of the solar array conductive panels to each other or to the spacecraft structure shall be avoided.

h. In the flight configuration, means to prevent differential voltage due to electrostatic charging between solar array structure and the spacecraft electrical ground reference shall be implemented.

i. In the flight configuration, bleeding resistors shall be implemented.

NOTE Bleeding resistors are used to control both electrostatic charging and power loss from the solar array section and dissipation in the resistor itself in case of a cell string to panel short (including de-rating).

j. At solar array level, one short between a solar cell string and a conductive panel structure shall not produce any solar array power loss.

k. At solar array level, in case of two shorts on the same panel, the power loss shall not be more than the power of two strings.

l. The PVA layout shall be designed to meet the solar array magnetic moment requirements.

m. The solar array shall be designed to survive the atomic oxygen orbit environment without performance degradation below specification.

n. In case verification by analysis of 5.5.2m is not conclusive a complementary verification by test shall be performed.

o. Provision shall be made to prevent failure due to power transients from the power sub-system or due to operation in shadow.

NOTE E.g. individual string blocking diodes.

p. Solar array shall be subdivided in sections.

q. Solar cells shall be protected against any deleterious reverse-bias conditions.

5.5.3 Solar array power computation

a. The solar spectrum for near-Earth and lunar missions, shall be in conformance with the "Sun simulator and calibration procedures" of ECSS-E-ST-20-08.

b. The model used for the computation of the IV curve of the solar cell shall be validated by test on the specific solar cell type for the mission.

c. I-V solar cells characteristics shall be computed in BOL and EOL conditions at maximum and minimum operating temperatures according to the mission profile.

d. The EOL solar cell IV curve shall be measured at the temperatures specified in 5.5.3c after irradiation with particles (electrons and protons) in conformance with the "Electron irradiation" test for "Bare solar cells" specified in ECSS-E-ST-20-08, and agreed with the customer.

e. The forward voltage of the string blocking diode (if present) shall be computed:

   1. using the worst-case voltage drop specified by the diode manufacturer,

   2. at the diode operating temperature corresponding to the operational string current for each mission phase in worst case conditions.

f. The BOL worst and best case power calculations shall include the parameters indicated in Table 5-1.

g. For recently developed solar cells and produced in large scale, the string current calculation shall include as a random parameter the increase of solar cell performance.

h. In addition with the parameters indicated in Table 5-1, the EOL worst and best case calculations shall include the parameters indicated in Table 5-2.

i. Shadowing and hot spot phenomena shall be analysed.

j. Leakage losses of bypass diodes shall be deducted from the power computation if they represent more than 0,1 % of the overall power to be provided.

k. Plume impingement effects shall be analysed.

Table 5-1: Parameters for BOL worst and best case power calculations

Parameter	Applicable to string	Type of loss/gain
Current Cell mismatch	Current	Random
Calibration error [a]	Current	Random
Cover glass gain / loss	Current	Direct
Blocking Diode Loss	Voltage	Direct
Harness Voltage Drop	Voltage	Direct
Pointing error due to disorientation and internal Solar Array error	Current	Direct
Orbital Losses & Sun Intensity [b]	Current & Voltage [c]	Direct
Shadow losses [d]	Current & Voltage	Direct
Temperature coefficient [e]	Current & Voltage	Direct
Temperature Gradient on String	Current & Voltage	Direct

[a] Typical value is ± 3%, including secondary working standard calibration and bare solar cell measurement accuracies,

[b] Orbital losses as; EQX/SS, altitude, inclination, albedo, solar array angle including the cosine law deviation

[c] E.g. High/Low Intensity interplanetary mission

[d] E.g. Voltage losses due to cells and solar cell shunt diodes

[e] For the average operational temperature on orbit ±5°C.

Table 5-2: Additional power parameters for EOL worst and best case calculations.

Parameter	Applicable to string	Type of loss/gain
UV degradation [a]	Current	Direct
Micrometeorites [b]	Current	Direct
”Loss of strings” tolerance	Current	Direct
Reliability of components and interconnection	Current & Voltage	Random
Degradation due to ESD Phenomena	Current & Voltage	Random
Solar array surface contamination	Current	Direct
Radiation [c]	Current & Voltage	Direct

[a] Typical value, 0,25 % loss per year in orbit.

[b] Depending of in-orbit available data for each type of cell.

[c] See ECSS-E-ST-10-04, clause 9.2.

5.5.4 Solar array drive mechanisms

a. The qualified de-rated current capability of slip ring contacts shall be greater than the best case BOL solar array section current in short circuit and use transient currents caused by the discharge of the solar array section capacitance.

b. The design of the insulation barriers between adjacent slip rings shall be such that no discharge phenomena can occur.

c. Where non-insulated conductors are used, arcing phenomena shall be prevented by design.

5.6 Electrochemical Energy Storage

5.6.1 Applicability

For the purpose of this clause, a battery is defined as a device that converts the chemical energy contained in its active materials into electric energy by means of electrochemical oxidation-reduction (redox) reaction.

It is made-up of one or more electrochemical cells, which can be grouped in modules permanently connected in series or parallel.

Clauses 5.6.2 to 5.6.5 apply to primary and secondary batteries where reference is not made to charge. Clause 5.6.5 defines additional safety requirements for all battery types.

Fuel cells and super capacitors are not addressed by the present standard.

5.6.2 Batteries

a. Batteries shall be designed to support the spacecraft through the launch sequence, including all anticipated contingencies and through all foreseen losses of solar energy during the mission, including those resulting from failures.

NOTE For example: depointing due to loss of pointing sensors, attitude control.

b. The ability of a battery to meet mission lifetime requirements specified by the spacecraft manufacturer in the battery specification, where not covered by qualification life testing or previous in flight experience, shall be justified by the ground test data or by dedicated tests under representative conditions.

c. Specific measures shall be taken in the battery design to keep under control the series inductance and the magnetic moment.

d. In case verification by analysis of 5.6.2c is not conclusive a complementary verification by test shall be performed.

e. Batteries having to tolerate a single fault shall be designed such that they can operate with one cell either failed shorted or open circuit.

f. In batteries having to tolerate a single fault and where the effects of a single cell failure are mitigated by the use of a cell bypass device, the following shall be met:

1. The probability of the bypass circuit untimely operation is lower than the probability of a failure of the cell.

2. If the bypass operation is not instantaneous, the power system design is able to operate without damage during the transient situation.

3. The maximum number of cells that can be bypassed after a failure or a wrong command is equal to the number of failures allowed by the specific mission design.

g. Transient currents, occurring when two or more separate strings of series-connected cells are connected together in parallel or when a cell fails short-circuit in a battery composed of parallel strings, shall not result in exceeding the peak cell current rating.

h. Procured battery cells shall be originating from the same production lot, with the same operational history

NOTE Cells making–up a battery are selected (matched) in accordance with the cell manufacturer's requirements. Sufficient extra matched spare cells are procured to allow for replacement of any cells damaged during integration of batteries. If cells are not individually replaceable, then appropriately matched cell groups/modules are available. It is good practice to specify the number of spare cells in the battery procurement documentation.

i. When individual batteries are discharged in parallel, imbalance between the battery cells shall not result in current and temperature exceeding the cell qualification limits.

j. Conducting cases of battery cells in a battery package shall be double-insulated from each other and from battery structure, with an insulation between any cell and the structure greater than 10 MΩ (measured at 500 V DC).

k. The battery design shall include the following provisions for interfacing with the ground support equipment during pre-launch operations:

— signal lines for monitoring battery voltage, battery temperature;

— capability to charge or discharge the battery;

— cell or cell group voltage monitoring protected by current limitation.

l. A logbook shall be maintained by the supplier for each flight battery starting with the first activation after battery assembly up to launch, describing chronologically all test sequences, summary of observations, identification of related computer–based records, malfunctions, and references to test procedures and storage conditions.

NOTE The logbook is used for the following purposes:

- to ensure compliance with storage, handling and operational requirements before launch (e.g. maximum time allowed at upper temperature limits, correct scheduling of maintenance activities);
- to allow verification of flight worthiness.
- special care has to be paid to external current discharge paths during integration phases.

m. Battery thermal design shall ensure that:

1. maximum and minimum qualification temperature of cell operation under intended cycling conditions are not exceeded;

2. maximum qualification temperature gradients between different parts of the same cell and between two cells in a battery are not exceeded.

n. The battery mechanical design shall ensure that cell stress and fatigue limits are not exceeded

5.6.3 Battery cell

a. Absolute maximum ratings of the cell, in term of voltage, charge and discharge current (continuous and peak), temperature, shall be defined.

b. The ability of a cell to meet mission lifetime requirements, where not covered by qualification life testing or previous in flight experience, shall be justified by the ground test data or by dedicated tests under representative conditions.

c. The ability of a cell to meet mission life time requirements may be verified by similarity with qualification life testing or previous in flight experience only in case of identical design and identical manufacturing processes.

d. For any intended cell operation under acceleration greater than 1 g, the supplier shall ensure that no effect upon both short term (e.g. capacity) performance and lifetime can prevent battery nominal operation.

e. In case verification by analysis of 5.6.3d is not conclusive a complementary verification by test shall be performed.

f. Any special in-flight measures to ensure that the batteries meet their performance requirements that impose operational constraints shall be identified at system level for implementation from the phase B (design phase) onwards.

NOTE E.g. in orbit reconditioning for Ni-Cd and Ni-H2, cell state of charge balancing for some lithium-ion technologies)

g. The battery supplier shall inform the customer of any change in design, materials or process from cells which have experienced life testing or flight.

5.6.4 Battery use and storage

a. The design of the spacecraft shall be such that cells and batteries can be removed and replaced at any time prior to launch without affecting the acceptance status of the rest of the spacecraft.

b. For the procurement of cells and batteries the manufacturer shall supply a user manual in conformance with Annex D.

c. Flight batteries should not be used for ground operations to prevent any possible damage and subsequent degradation of life performance.

d. If 5.6.4c is not met, the flight worthiness of the batteries shall be re-verified after these ground operations are completed, in time for a possible replacement.

NOTE Re-verification can be done e.g. by capacity measurements.

e. Any test equipment interfacing with the battery shall include an associated undervoltage, overvoltage, overcurrent and over-temperature activated insulation switch.

f. Any cell, which has experienced an electrical, mechanical, or thermal level outside the qualification range shall be flagged and tracked.

g. Any cell, which has experienced an electrical, mechanical, or thermal level outside the qualification range, should be forbidden for flight.

5.6.5 Battery safety

5.6.5.1 Overview

Almost all battery technologies used aboard spacecraft can be hazardous if not properly managed. Most are capable of delivering very high currents when shorted. When abused, cells can develop excessive internal pressure and eventually vent their contents, in extreme cases explosively. The electrolyte, cell reactants, and/or reaction products expelled can be corrosive (e.g. alkaline cells, lithium-SO_2, Lithium $SOCl_2$), flammable (e.g. lithium cell organic electrolytes) or toxic endangering any nearby personnel as well as neighbouring equipment. The principal cell failure modes, which can lead to these effects, are listed in 5.6.5.2b.

Detailed descriptions of the hazards associated with different battery chemistry are given in reference document: Crew vehicle battery safety requirements, JSC-20793 Rev B April 06.

The design rules in earlier clauses which aim at maximizing battery performance and cycle life also reduce the possibility that cells and batteries exhibit failure modes such as those listed above. However, in applying the safety rules of ECSS-Q-ST-40, some battery failure modes are critical or catastrophic. Further design or management provisions are implemented to achieve the required level of fault tolerance.

For safety requirements related to pressure vessels see ECSS-E-ST-32.

5.6.5.2 Provisions

a. All potential failure modes and their possible consequences to personnel and equipment shall be identified and reported in the battery safety and hazard report to be provided by the battery supplier.

NOTE The potential failure modes include the ones listed in 5.6.5.2b.

b. The design of the battery and associated monitoring and control electronics shall preclude the occurrence of any of the following:

1. Over-temperature (from battery thermal dissipation or environmental heating);
2. excessive currents (discharge or charge) including short–circuit (external or internal to the battery);
3. overcharging;
4. Attempt to charge in the case of primary cells;
5. over discharge (including cell reversal);
6. cell leakage (gases or electrolyte).

c. Where 5.6.5.2b is not met, the design shall mitigate the damaging effects of any such failure mode

NOTE E.g. by containment of cell leakage at battery level.

d. The failure of one or more cells within a battery due to imbalance in the state of charge, temperature or other parameter between cells should be prevented by the battery control electronics.

e. When the battery has non-insulated, exposed cell terminals, the battery should be delivered with a red insulation cover to be removed before spacecraft closure and for flight.

f. Provision should be made not to change the thermal balance of the battery during charge and discharge operations with the cover notified in 5.6.5.2e.

5.7 Power conditioning and control

5.7.1 Applicability

The requirements in 5.7.2 and 5.7.3 apply to power subsystems, those in 5.7.4 and 5.7.5 apply both to power subsystems and payloads, and those in 5.7.6 apply to payloads.

5.7.2 Spacecraft bus

a. No single point failure shall result in the loss of the power system capability to the extent that the minimum mission requirements, in any of its phases, cannot be fulfilled.

b. For manned missions, no double failure shall result in the loss of the power system capability to the extent that the minimum mission requirements, in any of its phases, cannot be fulfilled.

c. The following main control features of a power bus shall be completely independent from any control external to the electrical power system, even in case of failure:

1. Main Bus voltage regulation control for regulated Bus;
2. Battery discharge control;
3. Control of solar array power, when using Maximum Power Point Trackers (MPPT).

NOTE Main control features do not include parameter settings by the OBC.

d. The ultimate switching between main and redundant MPPT circuitry shall be implemented by hardware independent from any on board software.

e. No single point failure in the spacecraft, including for instance failure of wiring and connectors, shall open or short a main electrical power bus or violate the specified over voltage or under voltage limit requirements.

f. The design shall ensure that under all conditions during the required lifetime, including operation in eclipse with one battery cell failure and one solar array string failed, the main bus voltage remains within nominal tolerances.

g. For fully regulated buses, the nominal bus voltage value should be standardized according to the following:

1. 28 V for power up to 1.5 kW;
2. 50 V for power up to 8 kW;
3. 100 V and 120 V for higher power.

NOTE 1 Bus voltage types are standardized in order to maximize the reuse of equipments.

NOTE 2 The rationale for this requirement is the following:

It is in practice difficult to design output impedance below 10 milliohm without an unwanted effect of the intrinsic connections and components resistance. For the design of a bus with 10 milliohm output impedance such that a 50 % load modulation induces a 1 % voltage change maximum as per 5.7.2i.1 requirement:

$0,5\ P/U \times 0,01 < 0,01U$ which means $P < U^2/0,5$

Thus for $U = 28$ V, $P < 1,57$ kW
$U = 50$ V, $P < 5$ kW
$U = 100$ V, $P < 20$ kW

In practice, at 50 V for example, higher power has been used on telecom spacecraft buses, because the

1 % voltage change referred to a lower load change of 20 % to 30 % instead of 50 %.

h. A fully regulated bus shall keep its nominal value in steady state within ± 0,5 % of the bus voltage at the main regulation point.

i. With a fully regulated bus in nominal operation the bus voltage transients shall:

1. for load transients of up to 50 % of the nominal load not exceed 1 % of its nominal value.

2. for any source and load transients remain within 5 % of its nominal value.

j. Fuses should be avoided to maintain the quality of the bus.

NOTE The rationale for requirement 5.7.2h to 5.7.2j is the following:

In order to be advantageous over an unregulated scheme, a regulated bus ensures a good regulation quality at the regulation point, including when the various loads on the bus are changing. The regulated bus is designed to ensure that normal transients including interdomain are within 5% all included. Abnormal transients are more than twice the normal transients; the load is then designed to operate nominally in normal transients and sustain without damage abnormal transients.

k. In case of fuse blowing, the recovery from the fuse clearance shall not produce an overshoot of more than 10 % above the nominal bus value.

l. The model of the fuse and of the electrical network to be protected by the fuse, shall be validated by test with a representative set-up

m. A fully regulated bus shall have a nominal ripple voltage below 0,5 % peak-to-peak of the nominal bus voltage, measured at the regulation point with at least 1 MHz bandwidth.

n. A fully regulated bus shall have commutation voltage spikes in the time domain of less than 2 % peak-to-peak of the nominal bus voltage, measured at the regulation point with an analogue oscilloscope of 50 MHz minimum bandwidth or a digital oscilloscope offering equal or better performance.

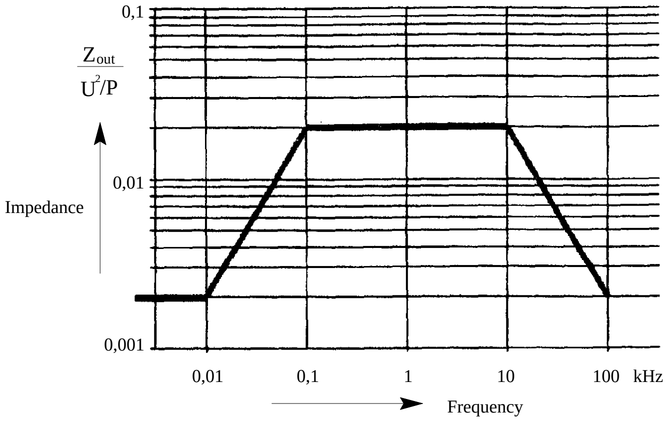
o. At the point of regulation, the impedance mask of a fully regulated bus, operating with one source shall be below the impedance mask shown in Figure 5-1.

NOTE 1 E.g. battery, solar array.

NOTE 2 Rationale for the impedance mask:

It translates requirement 5.7.2i.1 of 1 % voltage change for 50 % load change in a domain of regulation up to 10 kHz bandwidth. In DC the integrator in the control loop is designed to ensure no static error, in higher frequency, between

10 kHz and 100 kHz it is likely that the inductance effect of the components and connections are seen and the impedance rise not always making feasible to respect the ideal impedance mask.



U = Nominal regulated output voltage (Volt)
P = Power capability (Watt)

Figure 5-1: Output impedance mask (Ohm)

p. For unregulated buses, the following parameters shall be specified, analysed and tested:

1. maximum and minimum bus voltage guaranteed at payload level in all steady state and transients conditions;

2. maximum ripple in time domain, measured with at least 1 MHz bandwidth.

3. maximum spikes in the time domain superimposed on the bus voltage, measured with an analogue oscilloscope of 50 MHz minimum bandwidth or a digital oscilloscope offering equal or better performance.

4. impedance mask.

NOTE Rationale for the requirement: Also for an unregulated bus, it is important to identify the bus impedance mask to verify the compatibility between the power bus and the loads, as for instance the guaranteed voltage range at bus level including the effects of load variations.

q. During integration phase the power system shall be able to start up from any of its power sources irrespective of the connection of the other power source.

r. In the case of an unexpected battery disconnection during ground operation, the main power bus voltage shall remain below its maximum specified overvoltage requirement.

s. The design shall ensure that a short circuit to ground or to the return line of a solar array section does not result in a failure of category 1 and 2 criticality.

NOTE The definition of criticalities can be found in ECSS-Q-ST-30 or ECSS-Q-ST-40.

5.7.3 Battery Charge and Discharge Management

a. Battery chargers shall be designed to ensure charging of a battery discharged down to zero volts.

NOTE The possibility of recovery applies mainly to the capability of recharging the battery exposed to extreme discharge conditions (e.g. lithium ion technology).

b. The solar array power shall be capable to satisfy the recharge of the battery in any mission phase with the essential loads connected on the bus and one worst case load connected representing a failure, whichever is the more constraining.

NOTE This is to ensure recovery from loss of spacecraft attitude.

c. The minimum energy reserve in the battery shall be enough to guarantee the mission and a safe recovery of the spacecraft under all conditions.

NOTE Take into account that the charge rate plays a major role in the effectiveness of battery recharge.

d. The charging technique shall be designed to ensure that the batteries are never overcharged.

NOTE To avoid over (or under) charge when taper charging is employed, the voltage limit above which taper charging begins can be adjusted as a function of temperature, ageing or other parameters, depending on the battery technology. In some missions, required lifetime can only be obtained if the taper charge limit is lowered during periods of no or little battery use.

e. The charging technique shall ensure that the applied recharge ratio does not violate the manufacturer's requirements for the particular cell technology, operational temperature and cycle life.

f. The charging technique shall ensure that any lifetime related maximum cell voltage and temperature limits, as stated by the manufacturer for the adopted technology, are respected.

g. The battery charge current and end of charge control shall be autonomous and one fault tolerant (two failure tolerant for manned mission).

h. The ultimate over charging/discharging protection circuitry shall be implemented by hardware and independent from any on board software.

i. Battery charge and discharge management shall be such that a single failure does not impair the lifetime of the energy storage system with respect to minimum or maximum voltage as well as maximum charge or maximum discharge current.

NOTE Such failure tolerance can be implemented at cell, battery or subsystem level.

5.7.4 Bus under-voltage or over-voltage

a. For fuse protected busses the delay before non-essential loads disconnection in the event of a bus undervoltage of more than 10% below the minimum value shall be at least 50 ms.

NOTE Rationale for the requirement:

The bus overload can be due to a failure of a load. Disconnecting prematurely or attempting to disconnect prematurely this load can damage the relay in the presence of a high fusing current. Fuses blow within 20 ms (see requirement 5.8.1i), thus leaving 50 ms allows the fuse clearance which can restore the bus to its nominal value without performing a non-essential load shedding.

b. In the case of an unregulated bus (or battery supply), all non-essential loads shall be switched-off automatically in the event of reaching the battery energy level that is able to maintain all essential loads for a time guaranteeing safe recovery.

c. The ultimate non-essential load disconnection circuit shall be implemented as a full hard-wired chain from sensor to actuator.

d. The ultimate non-essential load disconnection circuit shall be one failure tolerant.

e. The spacecraft design shall be such that in the event of an under-voltage condition on the bus, no failure is induced in the power system or the loads during and when recovering from this under-voltage.

f. After recovery as mentioned in 5.7.4e the loads shall be as follows:

1. all essential loads be supplied nominally;
2. all non-essential loads be in a known configuration that cannot create damage to any part of the spacecraft.

5.7.5 Power converters and regulators

a. For converters and regulators of the power system (solar array regulators, battery chargers and dischargers) the phase margin shall be at least 60° and the gain margin 10 dB for worst case end–of–life conditions with representative loading.

b. The phase margin of converters and regulators not belonging to the spacecraft power system shall be at least 50° and the gain margin 10 dB for worst case end–of–life conditions with representative loading.

NOTE Rationale for this requirement:

The condition expressed in requirements 5.7.5a and 5.7.5b assumes that the converter has a monotonic decreasing transfer function for which the sufficient condition of the Nyquist criterion can be applied. It indirectly encourages the designer to make designs for which the verification of the stability is simple. A higher quality is used for converters driving the bus quality, and in particular 60° is selected to minimize the "overshoot" in the response.

c. The electrical zero–volt reference of isolated converters and regulators shall be isolated from the unit case by more than 10 kΩ per converter.

NOTE Rationale for this requirement:

The value of 10 kΩ is a compromise: to be very large in DC and low frequency to minimize ground loop currents and to be small for high frequencies above 5 MHz in order to minimize the volt-drop between references due to common mode currents.

d. The capacitance between the zero–volt reference of isolated converters and regulators and the unit case shall be less than 50 nF per converter.

NOTE Rationale for this requirement:

The value of 50 nF is a compromise such that for a given piece of equipment this value is sufficiently high to dominate all parasitic capacitances to unit case, and low enough such that if many equipments are connected to a bus, the sum of bypassing capacitors to unit case and thus to ground reference is not significantly biasing the insulation of the bus or bus return to ground.

e. If a switching converter is externally synchronized, it shall remain in nominal operation for any increase or decrease of synchronizing frequency, intermediate amplitude of synchronizing signal, phase jumps, or loss and recovery of the signal.

f. An analysis at unit level shall be performed to verify that no single failure generates an increase of conducted emission exceeding specified limit by more than 6 db.

g. If an increase of conducted emission exceeding specified limit by more than 6 db is identified from the unit level analysis of 5.7.5f, then a system level analysis shall be conducted to ensure that compatibility is maintained.

NOTE Rationale for this requirement:

6 dB is the margin usually taken between unit and subsystem when building up the EMC compatibility at system level. It means that failed

equipment uses that EMC margin but does not perturb further the system.

h. A switching converter shall be able to reach nominal operation when the nominal input voltage is applied with any slope that can be provided by the power source and its associated impedance, connected to the switching converter.

5.7.6 Payload interaction

a. Inrush, under-voltage and a representative set of failures agreed with the customer for the payload interaction with the main bus, shall be verified by test.

b. No load shall generate a spurious response that can damage itself or any other equipment during bus voltage variation, up or down, at any ramp rate, and over the full range from zero to maximum bus voltage.

c. All current limiting devices and automatic switch-off circuits shall be monitored by telemetry.

d. The failure of the monitoring function of 5.7.6c shall not cause the protection elements to fail.

5.8 Power distribution and protection

5.8.1 General

a. The primary power source shall be grounded to the spacecraft structure at the star reference point with a connection capable of sustaining the worst case fault current.

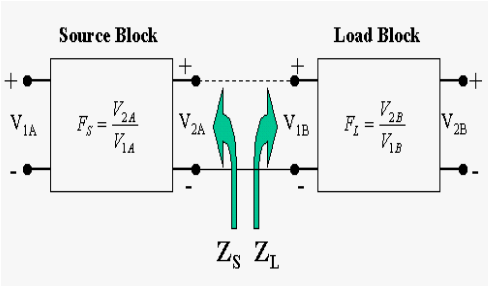
b. Whenever two or more blocks are connected in cascade, the stability of the cascade between each source block and load block shall be ensured by:

1. meeting the Nyquist criterion or,
2. demonstrating that |ZSource| << |ZLoad| by one decade

NOTE Rationale for this requirement (see Figure 5-2):

This requirement comes from lessons learnt on complex cascaded distribution systems, where beyond selective hierarchical protection aspects, also performance aspects (in case of e.g. load transients or start-up of a load downstream with other loads already connected on a common path upstream) must result in an overall stable situation.

The term "1+H_m" represents the loading effect caused by integrating the subsystems. H_m can be viewed as the system equivalent loop gain and the integrated system stability can be determined by applying the Nyquist criterion to H_m.



$$F_{SL} = \frac{F_S F_L}{1 + H_m}$$

$$H_m = \frac{Z_{Source}}{Z_{Load}}$$

Figure 5-2: Source Block cascaded with a Load Block

c. All non–protected sections of a main bus distribution system shall be protected as a minimum by double insulation (including harness, connector, wiring and PCB) up to the first protection device (fuse, current breaker or current limiter).

d. All load paths shall include protection circuitry on the source side.

NOTE The aim is to locate them as near as possible to the source.

e. No load shall be permanently disconnected from its power source as a consequence of an SEE.

f. If fuses are used to protect main bus distribution lines, they shall be accessible and replaceable without compromising equipment acceptance, up to and including the final integration of the stand-alone spacecraft.

g. Switching ON/OFF a load supplied from a fully regulated bus shall not generate a bus voltage transient exceeding +/-2 % of the nominal bus voltage.

NOTE Rationale for the requirement

This is to respect the quality of the regulated bus. Normal switching of a load, unlike fuse blowing, is not seen nor has the effect of an abnormal transient.

h. If fuses are used to protect main bus distribution lines, the design shall ensure that the power generation system can fuse them within less than 20 ms in case of load short circuit.

NOTE This to ensure compatibility with 5.7.4a.

i. Relays shall be protected such that the peak voltage across the contacts at switch-off does not exceed the de-rated voltage requirement of the relay in ECSS-Q-ST-30-11, for “Relays and switches”, or 1,1 times the switched voltage, which ever is the lowest.

j. Equipment connected to independent, redundant power buses shall ensure that:

1. for unmanned missions, no single failure causes the loss of more than one power bus;

2. for manned missions two failures do not cause the loss of more than one power bus .

k. The stability of current limiters shall be ensured for the actual loads characteristics, verified by analysis under worst case conditions, and tested under a set of cases agreed with the customer.

l. In case the distribution lines are protected by latching, or periodically reset current limiters, it shall be ensured by worst case analysis and test that the inrush energy demanded by the load in normal switch-on does not cause the trip-off of the latching protection with a margin of 20 %.

m. When indefinitely resetable current limiters are used instead of foldback current limiters, the periodicity of resets after a fault condition shall be such that:

1. no system EMC requirement is violated,

2. the thermal stress resulting from the failed load current does not compromise the limiter operation i.e. components remain within their de-ratings.

n. In case the distribution lines are protected by latching, foldback or periodically reset current limiters, it shall be verified by analysis or test that the transient current peaks at current limiter intervention are within the rated stress limits of the components used, for the worst case condition (minimum series impedance case).

o. When protection elements are in cascade the closest one upstream from the anomaly shall be the first to act.

p. When protections are used in cascade from a power source to a function to be supplied, the compatibility of these protections shall be analysed.

5.8.2 Harness

a. No piece of harness shall be used as a mechanical support.

b. With the exception of the solar array, routing of power lines shall be near ground.

c. With the exception of the solar array, power lines shall be such that each line is twisted with its return, when the structure is not used as a return.

NOTE The purpose of the requirements b and c is to minimize current loop area and harness inductance.

d. The power distribution shall be protected in such a way that no over-current in a distribution wire can propagate a thermal failure to another wire.

e. The harness inductance for a fully regulated bus, from the distribution node of the regulated bus to the load, shall be such that the break frequency is at least 5 000 Hz.

NOTE 1 That means that:

$L < R/2\pi f$

where:

L harness inductance in H

R harness resistance in Ω

f break frequency in Hz, i.e. $f = 5\,000$.

NOTE 2 Rationale for this requirement

This ties-up with the impedance mask requirement, because beyond the break frequency, the impedance is going to rise and one wants to keep the quality established on the regulation point with the impedance mask as best as possible and as far as possible to the loads.

f. Harness shall be tested up to connector brackets under 500 V DC between conductors, conductors and structure, conductors and shielding.

NOTE 500 V DC is selected in order to detect insulation defects potentially induced by air voltage breakdown.

g. The harness restraining systems on the structure shall not bring about any stress at connector level.

h. There shall be umbilical and test connectors to provide external electrical interfaces.

NOTE 1 E.g. with the launcher and with the EGSE.

NOTE 2 Functions provided include all those necessary for supporting AIT and launch site activities (e.g. monitor spacecraft operation, maintain synchronization between spacecraft, EGSE and real time simulators, put the spacecraft in a defined operation scenario like a quick upload of SW).

i. Electrical and Safe and arm plugs shall be provided for disabling on ground hazard functions.

NOTE For harness design and manufacturing guidelines and handbook, see RNC-CNES-Q-70-511 and NASA-STD-8739.4.

j. Cross strapping of redundant paths and circuits shall not be carried out in the harness.

5.9 Safety

a. The design of electrical systems and payloads shall include safety aspects as documented in IEC 60479:1994 “Effects of current on human beings and livestock”.

5.10 High voltage engineering

a. For non pressurised and non potted high voltage equipment, the applicable pressure range when this equipment is on shall be specified.

b. Non pressurised and non potted high voltage equipment shall be designed and manufactured to avoid discharge phenomena according to Pashen curves valid for its specified pressure range.

c. The field enhancement factors shall be ensured by the design.

NOTE This applies in particular to the routing of high voltage cables.

d. For potted circuits, the glass transition point of the potting material shall be outside the temperature range of qualification.

e. The design of high voltage equipment shall be such that worst case DC and AC field strengths are less than half of the values for which breakdown can occur.

5.11 Verification

5.11.1 Provisions

a. The requirements of this Clause 5 shall be verified by the verification methods, at the reviews, and recorded in the documentation as specified in Table 5-3.

NOTE For verification, see also ECSS-E-ST-10-02.

5.11.2 Documentation

a. The design report, PSA, WCA, FMECA, thermal Analysis, Radiation Analysis, EMC analysis for electrical design, supported by the detailed circuit diagrams, shall be included in the DJF

NOTE The DJF contain all descriptions and analyses meant to verify that the design meets the requirements. For the DJF, see ECSS-E-ST-10.

b. Failure modes of all components used in a unit shall be defined.

c. FMECA shall be performed and based on the failure modes previously defined at component level.

Table 5-3: General verification of electrical power requirements

Requirement	At the following verification points	Verification methods	Recorded in
	SRR: System requirements review PDR: Preliminary design review CDR: Critical design review TRR: Test readiness review TRB: Test review board DRB: Delivery review board AR: Acceptance review X: Preliminary formal verification point	RoD: Review of design T: Test A: Analysis INS: Inspection NOTES: RoD includes review of documentation	[1] Electrical ICD (including SAR ICD and Battery ICD). [2] Budget documents (e.g. Power, Energy, Processor, and memory budgets) [3] DDF or DJF [4] GDIR [5] Tests Reports [6] Specification [7] User manual
5.2.1a	PDR	RoD	[2]
5.2.2.1a	SRR	RoD, A, T	[3][5]
5.2.2.2a	PDR	RoD, A	[2][3]
5.2.2.2b	PDR	RoD, A	[2][3]
5.2.2.2c	PDR	RoD	[2]
5.2.2.2d	PDR	RoD	[3]
5.2.2.2e	PDR, AR	RoD, A	[2]
5.2.2.2f	PDR	RoD, A	[2][3]
5.3a	PDR	RoD	[3]
5.3b	PDR	RoD, A	[3]
5.3c	PDR	RoD, A	[3]
5.3d	PDR	RoD, A	[3]
5.4a	SRR	RoD	[1][4][6]
5.4b	PDR	RoD	[1][4][6]
5.4c	AR	A, T	[3][5]
5.4d	PDR	RoD	[1][4][6]
5.4e	PDR	A	[3]
5.5.2a	PDR	A	[2]
5.5.2b	PDR	A	[3]
5.5.2c	PDR	RoD, A, T	[3][5]
5.5.2d	PDR	RoD, A	[3]
5.5.2e	PDR	RoD, A	[3]
5.5.2f	PDR	T	[5]

	At the following verification points	Verification methods	Recorded in
5.5.2g, 5.5.2h and 5.5.2i	PDR	RoD, A, T	[3][5]
5.5.2j	PDR	RoD, A	[3]
5.5.2k	PDR	RoD, A	[3]
5.5.2l	PDR	RoD, A	[3]
5.5.2m	PDR	RoD, A	[3]
5.5.2n	PDR	T	[5]
5.5.2o	PDR	RoD, A	[3]
5.5.2p	PDR	RoD	[3]
5.5.2q	PDR	RoD, A, T	[3][5]
5.5.3a	PDR	INS	[6]
5.5.3b	PDR	A, T	[3][5]
5.5.3c	PDR	A	[2][3]
5.5.3d	CDR	T	[5]
5.5.3e	PDR	A	[3]
5.5.3f	PDR	RoD, A	[2][3]
5.5.3g	PDR	RoD, A	[2][3]
5.5.3h	PDR	A	[2][3]
5.5.3i	PDR	A	[2][3]
5.5.3j	PDR	A	[2][3]
5.5.3k	PDR	A	[2][3]
5.5.4a	PDR	RoD, A	[3]
5.5.4b	PDR	RoD, A	[3]
5.5.4c	PDR	RoD, A	[3]
5.6.2a	PDR	RoD, A	[1][2][3][6]
5.6.2b	PDR	RoD, A, T	[3][5]
5.6.2c	PDR	RoD, A	[3][6]
5.6.2d	PDR	T	[5]
5.6.2e	PDR	RoD, A	[3]
5.6.2f	PDR	RoD, A	[1][2][3]
5.6.2g	PDR	RoD, A	[3]
5.6.2h	PDR	RoD, INS	[3][6]
5.6.2i	PDR	RoD, A	[3]
5.6.2j	PDR	RoD, T	[3][5]
5.6.2k	PDR	RoD	[1][3]

	At the following verification points	Verification methods	Recorded in
5.6.2l	CDR	INS	[7]
5.6.2m	PDR	RoD, A, T	[3][5]
5.6.2n	PDR	RoD, A, T	[3][5]
5.6.3a	PDR	RoD, A	[3][7]
5.6.3b	PDR	RoD, A, T	[3]
5.6.3c	PDR	RoD, A	[3]
5.6.3d	PDR	A	[3]
5.6.3e	PDR	T	[5]
5.6.3f	PDR	RoD, A	[3][7]
5.6.3g	PDR	RoD, INS	[3]
5.6.4a	PDR	RoD, A	[3]
5.6.4b	PDR	RoD	[7]
5.6.4c	TRR	RoD	[3][6]
5.6.4d	TRR	RoD, T	[5]
5.6.4e	PDR	RoD, A, T	[3][5]
5.6.4f	CDR	RoD	[3]
5.6.4g	SRR	RoD	[3]
5.6.5.2a	PDR	A	[3]
5.6.5.2b	PDR	RoD, A	[3]
5.6.5.2c	PDR	RoD, A	[3]
5.6.5.2d	PDR	RoD, A	[3]
5.6.5.2e	PDR	RoD, INS	[1][3][7]
5.6.5.2f	PDR	RoD, A	[3]
5.7.2a	PDR	RoD, A	[2][3]
5.7.2b	PDR	RoD, A	[2][3]
5.7.2c	PDR	RoD, A	[3]
5.7.2d	PDR	RoD, A	[3]
5.7.2e	PDR	RoD, A	[3]
5.7.2f	PDR	RoD, A	[2][3]
5.7.2g	PDR	RoD	[2][3]
5.7.2h	PDR	RoD, A, T	[3][5]
5.7.2i	PDR	RoD, A, T	[3][5]
5.7.2j	PDR	RoD	[3]
5.7.2k	PDR	A	[3]

	At the following verification points	Verification methods	Recorded in
5.7.2l	PDR	RoD, A, T	[3][5]
5.7.2m	PDR	RoD, A, T	[3][5]
5.7.2n	PDR	RoD, A, T	[3][5]
5.7.2o	PDR	RoD, A, T	[3][5]
5.7.2p	PDR	RoD, A, T	[3][5][6]
5.7.2q	PDR	RoD, A, T	[3][5]
5.7.2r	PDR	RoD, A, T	[3][5]
5.7.2s	PDR	RoD, A	[3]
5.7.3a	PDR	RoD, A, T	[3][5]
5.7.3b	PDR	RoD, A	[3][2]
5.7.3c	PDR	RoD, A	[3][2]
5.7.3d	PDR	RoD, A	[3]
5.7.3e	PDR	RoD, A	[3]
5.7.3f	PDR	RoD, A	[3]
5.7.3g	PDR	RoD, A	[3]
5.7.3h	PDR	RoD, A	[3]
5.7.3i	PDR	RoD, A	[3]
5.7.4a	PDR	RoD, A, T	[3][5]
5.7.4b	PDR	RoD, A, T	[3][5]
5.7.4c	PDR	RoD, A	[3][6]
5.7.4d	PDR	RoD, A	[3][6]
5.7.4e	PDR	RoD, A	[3]
5.7.4f	PDR	RoD, A, T	[3][5]
5.7.5a	PDR	RoD, A, T	[3][5]
5.7.5b	PDR	RoD, A, T	[3][5]
5.7.5c	PDR	RoD, A, T	[3][5]
5.7.5d	PDR	RoD, A, T	[3][5]
5.7.5e	PDR	RoD, A, T	[3][5]
5.7.5f, 5.7.5g	PDR	A	[3]
5.7.5h	PDR	RoD, A, T	[3][4][5]
5.7.6a	PDR	RoD, A, T	[3][4][5]
5.7.6b	PDR	RoD, T	[3][5]
5.7.6c	PDR	RoD, T	[3][5]
5.7.6d	PDR	RoD, A	[3]

	At the following verification points	Verification methods	Recorded in
5.8.1a	PDR	RoD, A, INS	[3]
5.8.1b	PDR	RoD, A	[3]
5.8.1c	PDR	RoD, A, INS	[3]
5.8.1d	PDR	RoD, A	[3]
5.8.1e	PDR	RoD, A	[3]
5.8.1f	PDR	RoD, INS	[3]
5.8.1g	PDR	RoD, A, T	[3][5]
5.8.1h	PDR	RoD, A	[3]
5.8.1i	PDR	RoD, A	[3]
5.8.1j	PDR	RoD, A	[3]
5.8.1k	PDR	RoD, A, T	[3][5]
5.8.1l	PDR	RoD, A, T	[3][5]
5.8.1m	PDR	RoD, A, T	[3][5]
5.8.1n	PDR	RoD, A or T	[3][5]
5.8.1o	PDR	RoD, A, T	[3][5]
5.8.1p	PDR	A	[3]
5.8.2a	PDR	RoD, INS	[3]
5.8.2b	PDR	RoD, INS	[3]
5.8.2c	PDR	RoD, INS	[3]
5.8.2d	PDR	RoD, A	[3]
5.8.2e	PDR	RoD, A	[3]
5.8.2f	TRR	T	[5]
5.8.2g	PDR	RoD, INS	[3]
5.8.2h	PDR	RoD, INS	[3]
5.8.2i	PDR	RoD, INS	[3]
5.8.2j	PDR	RoD, INS	[3]
5.10a	SRR	RoD	[6]
5.10b	PDR	RoD, A	[3]
5.10c	PDR	RoD, A	[3]
5.10d	PDR	RoD, A	[3]
5.10e	PDR	RoD, A	[3]
5.11.2b	SRR	RoD	[3]
5.11.2c	PDR	A	[3]

6 Electromagnetic compatibility (EMC)

6.1 Overview

The objective of the following EMC requirements is to ensure that the space system is designed to achieve electromagnetic compatibility (EMC) between all equipment and subsystems within the space system and in the presence of its self–induced and external electromagnetic environment.

6.2 Policy

6.2.1 Overall EMC programme

a. The supplier shall establish an overall EMC programme.

NOTE 1 The EMC programme is an activity the purpose of which is to provide for spacecraft-level compatibility with the minimum impact to programme cost, schedule and operational capabilities. The role of the customer in the EMC programme is that of top-level oversight.

NOTE 2 The EMC programme is based on requirements of this standard, the statement of work, spacecraft specification, and other applicable contractual documents.

b. The EMC programme shall:

1. plan and verify that EMC technical criteria, mainly design and management controls are in place to achieve EMC;
2. plan and accomplish the verification of spacecraft–level EMC.

6.2.2 EMC control plan

a. As part of the EMC programme, an EMC control plan shall be written by the supplier for the PDR in conformance with the DRD in Annex A.

NOTE The Control plan initial release documents the procedures of the EMC programme including basic design guidelines, while subsequent routine updates document the programme progress.

b. The EMC control plan shall apply to every item of equipment and subsystem in the project.

6.2.3 Electromagnetic compatibility advisory board (EMCAB)

a. For such programmes where EMC has been identified during phase A as critical for mission performance, the EMC programme shall include an EMC Advisory Board (EMCAB).

b. The EMCAB shall:

1. Ensure the timely and effective execution of the EMC programme under the general project manager.

2. Respond to the problems related to EMC as they arise.

c. The supplier shall chair the EMCAB, with customer oversight.

NOTE 1 The EMCAB members are representatives of the Spacecraft Supplier and payload suppliers and users.

NOTE 2 EMCAB members can invite associate suppliers or independent experts.

NOTE 3 The EMCAB accomplishes its duties and document its activities mainly through the use of the system-level EMC documentation.

6.3 System level

6.3.1 Electromagnetic interference safety margin (EMISM)

6.3.1.1 Circuits categories

a. Functional criticality of circuits for all equipment/subsystem circuits shall be identified in accordance with the following categories:

1. Safety critical circuit - EMI problems that can result in loss of life or loss of space platform. This category comprises electro-explosive devices and their circuits.

2. Mission critical circuit - EMI problems that can results in injury, damage to space platform, mission abort or delay, or performance degradation which unacceptably reduces mission effectiveness.

3. Non critical circuit – Any problems that do not belong to categories 6.3.1.1a.1 and 6.3.1.1a.2.

6.3.1.2 Critical points

a. The list of points where the margin is demonstrated (critical points) shall be submitted to the customer for approval.

6.3.1.3 Margins

a. Electromagnetic interference safety margins shall be determined at critical points under all operating conditions.

b. The minimum margins shall be 20 dB for safety critical circuits, and 6 dB for mission critical circuits.

6.3.2 Inter-system EMC and EMC with environment

6.3.2.1 Overview

The objectives of the following requirements are to ensure that the space system operates without performance degradation in the electromagnetic environment due to external sources (natural sources and man-made sources, intentional or not).

6.3.2.2 EMC with the launch system

a. The electromagnetic environment seen by the spacecraft and the EMC requirements during the pre-launch and launch phases shall be according to those described in the applicable launchers user's manuals.

NOTE Specific EMC requirements during the pre-launch and launch phase are described in an Interface Control document established on a contractual basis between the launching company and the customer.

6.3.2.3 Protected frequency bands

a. For protection of radiometric and communication bands, requirements on “Emissions” of “Transmitted signals” in ECSS-E-ST-50-05, shall apply.

6.3.2.4 Lightning

a. The space system shall be protected against both direct and indirect effects of lightning such that the mission is without degradation of performances after exposure to the lightning environment.

6.3.3 Hazards of electromagnetic radiation

a. The space system shall be designed so that humans, fuels, explosive systems, and electronically actuated thrusters are not exposed to hazards of electromagnetic radiation present in the entire electromagnetic environment, including interference sources from possible external transmitters.

6.3.4 Spacecraft charging protection program

6.3.4.1 Applicability

a. A spacecraft charging protection programme shall be produced by the supplier for the PDR, and submitted to the customer for approval, for all the space systems encountering a space charging environment i.e.

1. Earth orbits above 8 000 km;
2. Earth orbits above 40 degrees latitude;
3. Jupiter encounters closer than 15 Rj (Jupiter radii), and
4. other planets (plasma and dust charging), as specified by the customer.

6.3.4.2 General

a. The spacecraft charging protection programme shall include the preparation and maintenance of an analysis plan, and the preparation and maintenance of a test plan.

NOTE The objective of the programme is to ensure that the space vehicle is capable of operating in the specified space plasma charging environment and its energetic electron content without degradation of the specified space vehicle capability and reliability and without changes in operational modes, location, or orientation.

b. The performance shall be accomplished without the intervention of external control such as commands from a ground station.

c. The spacecraft charging protection programme shall include:

1. surface electrostatic charging,
2. threat from internal electrostatic charging of dielectric materials and isolated conducting items, due to the penetration of energetic electrons as defined in the environmental specification.

NOTE ECSS-E-ST-20-06 is intended to provide clear and consistent requirements to the application of measures to assess and mitigate hazardous effects arising from spacecraft charging and other environmental effects on a spacecraft's electrical behaviour.

6.3.4.3 Performance

a. The space vehicle electrical subsystem and system may undergo an outage during an arc discharge if operation and performance returns to specified levels within

1. a telemetry main frame period after onset of the discharge, or
2. within some other period defined by the customer.

b. A command to the space vehicle from an external source such as a ground station need not be executed if an arc discharge occurs during transmission of the command.

c. Provision shall be made such that an unintended action does not result.

d. Provision shall be made such that the space vehicle is capable of receiving and executing subsequent commands, and

e. Provision shall be made such that the space vehicle meets specified performances within the time period defined in clause 6.3.4.3a.

6.3.5 Intrasystem EMC

a. The space system shall operate without performance degradation in the electromagnetic environment due to on-board sources (intentional or not).

6.3.6 Radio frequency compatibility

a. The spacecraft shall be RF compatible with all antenna-connected equipments and subsystems, the compatibility criteria being based on the mission performance and operability requirements.

b. When an inter-system interface is required, each system shall be RF compatible with all antenna-connected equipments and subsystems, the compatibility criteria being based on the mission performance and operability requirements.

c. The RF compatibility analysis, if used instead of test, shall include the effects of inter-modulation products.

6.3.7 Spacecraft DC magnetic field emission

6.3.7.1 Overview

DC magnetic emissions have impacts on two main areas, magnetic sensors of payloads and the attitude control system (ACS). Other specific components are susceptible (ultra-stable crystal oscillators, plasma monitors, high-permeability magnetic shields).

6.3.7.2 Spacecraft with susceptible payload

a. In case the payload involves equipments sensitive to DC H-Field, the maximum acceptable DC magnetic field at their location from the rest of the spacecraft shall be specified by the customer because of the mission performance requirements.

NOTE It is the role of the EMCAB to translate the customer's DC magnetic field requirements, specified at the sensitive payload location, into subsystem and equipment magnetic requirements (magnetic field or magnetic moment limits, test methods).

6.3.7.3 Attitude control subsystem

a. On the basis of the attitude control requirements, the supplier shall derive magnetic requirements for the spacecraft so as to limit transient, diurnal and secular torques.

b. If magnetometers are used as part of the Spacecraft Attitude Control Subsystem, the maximum acceptable DC magnetic field at their location from the rest of the spacecraft shall be specified by the supplier because of the attitude control subsystem requirements and submitted to the customer approval.

6.3.8 Design provisions for EMC control

6.3.8.1 Electrical bonding

a. The electrical bonding shall be in conformance with the "Electrical bonding requirements" specified in ECSS-E-ST-20-07.

6.3.8.2 Grounding

a. A controlled ground reference concept, including the definition of circuit and unit categories shall be specified and agreed with the customer for the spacecraft prior to initial release of the EMC control plan.

6.3.8.3 Wiring

a. Classification of cables, and cables shield shall be in conformance with the requirements for "Wiring" specified in ECSS-E-ST-20-07.

6.3.9 Detailed design requirements

a. The EMC system design shall be performed in conformance with the "Detailed system requirements" specified in ECSS-E-ST-20-07.

6.4 Verification

6.4.1 Verification plan and report

a. The verification plan shall be accomplished by the supplier in the frame of the EMC programme.

b. The verification plan shall be documented in the electromagnetic effects verification plan (EMEVP) in conformance with the DRDs in Annex B.

c. An electromagnetic effects verification report (EMEVR) in conformance with the DRD in Annex C shall be prepared by the supplier.

6.4.2 Safety margin demonstration for critical or EED circuit

a. Safety margins for critical or EED circuit shall be demonstrated at system–level.

b. If the demonstration of safety margins is done by test, the spacecraft suite of equipment and subsystems shall be operated in a manner simulating actual operations, agreed with the customer.

6.4.3 Detailed verification requirements

a. EMC verification shall be performed in conformance with the requirements on "Verification" in specified in ECSS-E-ST-20-07.

7 Radio frequency systems

7.1 Functional description

Radio frequency (RF) systems include transmitters, receivers, antennas and their associated transmission lines (waveguides) including connectors, operating typically in the range from 30 MHz to 300 GHz. The transmitted or received signals can be narrowband or wideband, often with complex modulation and sometimes with multiple carriers. Transmitters and receivers require high mutual insulation and antennas can interact strongly with the spacecraft.

For achieving the RF performance requirements, the following parameters are considered by the engineering process:

- antenna field of view and polarization;
- link or radiometric budget;
- spatial and spectral resolution;
- signal to noise ratio;
- frequency plan.

For achieving the performances requirement, the following parameters are considered by the RF design and development:

- transmitter power;
- receiver sensitivity;
- active and passive intermodulation products;
- multipaction;
- corona
- spectral purity;
- VSWR;
- frequency stability;
- reflection and diffraction effects on antenna performance;
- mutual coupling between antennas;
- insulation between transmitter and receiver;
- EIRP.

7.2 Antennas

7.2.1 General

7.2.1.1 Overview

As specified in ECSS-E-ST-10, budgets and margins are established and requested during Project phase B, and reviewed in all subsequent phases of the project.

7.2.1.2 Provisions

7.2.1.2.1 Definition of terms in the documentation

a. All antenna terms used in all documentation (DDF, DJF, Test Report, Test Procedures, ICD and EIDP) shall follow the definitions found in IEEE 145:1993 "Antenna Terms".

7.2.1.2.2 Engineering process

a. The following engineering process shall be applied:

1. Perform an analysis of the mission requirements for RF signal transmission and reception for all systems and payload for all phases of the mission.
2. Perform electrical, mechanical and thermal computer assessments to identify feasibility and performance margin for the whole antenna farm
3. Establish performance budgets, including losses, simulation/measurement error and technology maturity margins for the whole antenna farm.
4. Establish prediction, measurement and operational error/accuracy budgets for the whole antenna farm.

   NOTE E.g. Pointing, excitation, phase centre.

5. Establish a plan for the maintenance and periodical review of the budgets established in requirement 7.2.1.2.2a.3 and 7.2.1.2.2a.4 during all project phases.

7.2.1.3 Failure containment and redundancy

a. Antennas are in general single point failure elements; therefore their failure rates shall be agreed with the customer, specified and demonstrated.

   NOTE To improve the failure rate, special precautions in the redundancy architecture are commonly taken to cover the failures of active elements.

7.2.2 Antenna structure

7.2.2.1 General

a. The antenna category (7.2.2.2), composing elements (7.2.2.4), used technologies (7.2.2.4) and the performance parameters (7.2.2.5) shall be established at the beginning of the project phase B.

7.2.2.2 Categories

7.2.2.2.1 TT&C and data transmission

a. The antenna radiation pattern shall be characterised including the scattering effects of all surrounding structures.

NOTE TT&C and data transmission antennas are in general compact antennas (individual radiating elements - 7.2.2.3.1) with broad radiation patterns and a single beam. In some cases (e.g. deep space missions), more complex antennas falling into one of the other categories are used.

b. If a number of TT&C antennas operate simultaneously, the combined radiation pattern shall be used in the performance evaluation.

7.2.2.2.2 Reflector/Lens antennas

a. The reflection and transmission properties (losses, depolarisation and diffusivity) of the reflecting or transmitting elements shall be quantified and their impact on antenna performances assessed.

NOTE Reflector/Lens antennas are constituted by one or more radiating elements (7.2.2.3.1), possibly including an antenna RF chain (7.2.2.3.5), one or more (partially) reflecting or transmitting elements (reflectors - 7.2.2.3.2, lenses - 7.2.2.3.3) and an antenna support structure (in one or more portions- 7.2.2.3.6). If several radiating elements are present, also a Beam Forming Network can be present to distribute the RF signal (7.2.2.3.4).

b. The effects of antenna support structures shall be quantified and the impact on antenna performances assessed.

c. Deformations of reflector antennas, which parts are physically attached to different portions of the spacecraft platform, shall be quantified and their impact on antenna performance assessed.

NOTE For large reflector antennas that use hold-down and release, deployment mechanisms as well as pointing devices, ECSS-E-ST-33-11 can be applied.

7.2.2.2.3 Array antennas

a. The effect of the radiation of individual array element on the others shall be quantified and the impact on antenna performances assessed.

NOTE Array antennas are constituted by a number of radiating elements (7.2.2.3.1), possibly including an antenna RF chain (7.2.2.3.5) and arranged in a more or less regular layout. The RF signals are routed to/from each element through a wave-guiding network generally known as Beam Forming Network (7.2.2.3.4). An antenna support structure can also be present 7.2.2.3.6.

b. The effects of antenna support structures on the main RF wave propagation path shall be quantified and the impact on performance assessed.

c. Deformations of array antennas, which parts are physically attached to different portions of the spacecraft platform, shall be quantified ant their impact on antenna performance assessed.

NOTE For large array antennas that use hold-down and release, deployment mechanisms as well as pointing devices, ECSS-E-ST-33-11 can be applied.

7.2.2.2.4 Array-fed reflector antennas

a. For array-fed reflector antennas clauses 7.2.2.2.2 (Reflector/Lens antennas) and 7.2.2.2.3 (Array antennas) shall apply.

7.2.2.3 Elements

7.2.2.3.1 Radiating elements

a. The isolated performances of radiating elements shall be characterised as part of the performance prediction of the whole antenna, at least up to the end of Phase B.

NOTE Individual radiating elements are a key element to the overall antenna performances. They can be completed by a chain of RF components (see antenna RF chain 7.2.2.3.5), to ensure a suitable RF interface.

b. Whenever an antenna RF chain is attached to the radiating element its impact on the radiating element performances shall be assessed.

c. Deviations from the nominal geometry of the radiating element shall be quantified and their impact on antenna performances assessed.

NOTE Typical deviations are due to manufacturing errors, thermo-elastic effects and modification of the material characteristic in the orbit environment, moisture release in composites.

d. It shall be demonstrated that the scattering of the radiation pattern of individual radiating elements does not affect the accuracy of all radiated performance measurement.

e. Thermal dissipation of RF power shall be quantified and the impact on antenna performances assessed.

f. Whenever a radiating element is used to route high power levels,

1. The applicable pressure range and gas properties shall be specified.

2. The design and manufacturing shall be performed to avoid discharge phenomena according to Paschen curves valid for its specified pressure range and gas properties.

NOTE See clause 7.3 for further details.

g. All metallic parts in a radiating element shall be connected to the equipment DC ground to avoid electrostatic discharge (ESD).

7.2.2.3.2 RF Reflectors

a. Reflective properties (losses, depolarisation, and diffusivity) of the materials and composites used shall be quantified and their impact on antenna performances assessed.

b. The reflective and transmissive properties (losses, depolarisation, diffusivity) of the materials and composites used for polarisation and frequency selective reflectors shall be quantified and their impact on antenna performances assessed.

c. Deviations from the nominal geometry of the reflector shall be quantified and their impact on antenna performances assessed.

NOTE 1 Reflectors can require hold-down and release, deployment as well as pointing devices. ECSS-E-ST-33-11 and ECSS-Q-ST-70 are relevant and applicable in this case.

NOTE 2 Typical deviations are due to manufacturing errors, thermo-elastic effects and modification of the material characteristic in the orbit environment, moisture release in composites.

7.2.2.3.3 RF Lenses

a. Reflective and transmissive properties (losses, depolarisation, and diffusivity) of the materials and/or composites used for the lenses shall be quantified and their impact on antenna performances assessed.

b. Deviations from the nominal geometry of the lens shall be quantified and their impact on antenna performances assessed.

NOTE Typical deviations are due to manufacturing errors, thermo-elastic effects and modification of the material characteristic in the orbit environment, moisture release in composites.

c. Measures to drain accumulated electric charges from all non conductive parts shall be implemented to avoid electrostatic discharge (ESD).

d. Any metallic parts shall be connected to the equipment DC ground to avoid electrostatic discharge (ESD).

7.2.2.3.4 RF Beam Forming Network

a. The circuit characteristics of the RF BFN shall be independently quantified and their impact on antenna performances assessed at least up to CDR.

b. Deviations from the nominal geometry of the RF BFN shall be quantified and their impact on antenna performances assessed.

NOTE Typical deviations are due to manufacturing errors, thermo-elastic effects and modification of the material characteristic in the orbit environment, moisture release in composites.

c. In all RF BFN structures having a central conductor (ideally insulated), the thermal power generated by Joule effect on the conductor itself shall be quantified and its impact on antenna performances assessed.

d. For RF BFN, the applicable pressure range and gas properties shall be specified.

e. For RF BFN, the design and manufacturing shall be performed to avoid discharge phenomena according to Paschen curves valid for its specified pressure range and gas properties.

NOTE See clause 7.3 for further details.

7.2.2.3.5 Antenna RF chain

a. The circuit characteristics of the antenna RF chain shall be independently quantified and their impact on antenna performances assessed at least up to CDR.

b. The cumulative effects of wave propagation discontinuities along the whole antenna RF chain, including the radiating elements attached to it, shall be quantified and the impact on antenna performances assessed.

c. For antenna RF chain the applicable pressure range and gas properties shall be specified.

d. For antenna RF chain the design and manufacturing shall be performed to avoid discharge phenomena according to Pashen curves valid for its specified pressure range and gas properties.

NOTE See clause 7.3 for further details.

7.2.2.3.6 Antenna support structures

a. The possible scattering effects of the support structures shall be quantified and their impact on the antenna performances assessed.

b. Deviations from the nominal geometry of the supporting structure shall be quantified and their impact on antenna performances assessed.

NOTE Typical deviations are due to manufacturing errors, thermo-elastic effects and modification of the material characteristic in the orbit environment, moisture release in composites.

7.2.2.4 Technologies

7.2.2.4.1 Metal based

a. The level of passive inter-modulation products generated by the antenna shall be quantified and their impact on antenna performances assessed.

NOTE 1 See clause 7.4 for further details.

NOTE 2 Ferro-magnetic materials and metal-to-metal junctions are the most common non-linear elements in antennas.

b. The impact of thermally-induced effects on the generation of passive intermodulation products shall be quantified and the impact on antenna performances assessed.

NOTE A typical example of thermally induced effects triggering the generation of PIM is the sudden releases of stresses in metal-to-metal joints due to temperature variations.

c. Thermally induced changes of dimension and shape in all metallic antenna parts shall be quantified and their impact on antenna performances assessed.

7.2.2.4.2 Composite based

a. The impact of surface characteristics and finish on antenna performances shall be assessed.

NOTE 1 In particular this is essential for the RF conductive surfaces of the component.

NOTE 2 Electrical conductivity and depolarisation properties are the most typical parameters affected.

b. Thermally induced changes of dimension and shape in all composite and combined metal-composite antenna parts shall be quantified and their impact on antenna performances assessed.

c. Measures to drain accumulated electric charges from composite parts shall be implemented to avoid electrostatic discharge (ESD).

7.2.2.4.3 Plastic based

a. The dielectric losses of plastic component in the RF power path shall be quantified and their impact on antenna performances assessed.

NOTE Components made from homogeneous plastic are usually limited to small parts (e.g. spacers or washers).

b. Thermally induced changes of dimension and shape in all plastic and combined metal-plastic antenna parts shall be quantified and their impact on antenna performances assessed.

c. Measures to drain accumulated electric charges from all plastic parts shall be implemented to avoid electrostatic discharge (ESD).

7.2.2.5 Performance parameters

a. The characterisation of antenna performances shall cover the following parameters.

1. Coverage or Beam shape;
2. Directivity;
3. Electrical boresight or Beam pointing;
4. Gain or Beam efficiency;
5. Input impedance mismatch factor;
6. Radiation pattern;
7. Sense of polarization;
8. Side lobe level;
9. Polarisation purity or Axial ratio;
10. Group delay;
11. Noise temperature, for receive antennas;
12. Phase centre position;
13. Variations with frequency, angle (where applicable) and aging of all above parameters.

7.2.3 Antenna interfaces

7.2.3.1 Guided-wave interfaces

a. Connectors or waveguide flanges at the antenna ports shall be demonstrated to have the specified power handling capabilities and impedance mismatch factors.

NOTE Antenna RF ports are realised using a wave-guiding structure (coaxial cable or waveguide, in most instances). Connectors or flanges are used to realise the physical interface.

b. It shall be demonstrated that the generation of passive inter-modulation products that can occur at the antenna ports is below the specified limits agreed with the customer.

c. For antenna ports the applicable pressure range and gas properties shall be specified.

d. For antenna ports the design and manufacturing shall be performed to avoid discharge phenomena according to Pashen curves valid for its specified pressure range and gas properties.

NOTE See clauses 7.3 and 7.4 for further details.

7.2.3.2 Radiative interfaces

a. Electromagnetic interactions among the antenna and the surrounding spacecraft structure and appendages shall be quantified starting from Phase B, as a minimum, and their impact on antenna performances assessed.

NOTE The field radiated or received by the antenna interacts with the surrounding environment. Interactions with the spacecraft structure and appendages usually have a direct impact on the antenna performances.

b. For all high-power applications, the risk of generation of passive intermodulation products by the surrounding spacecraft structure and appendages shall be assessed starting from Phase B, as a minimum, and the impact on antenna performances assessed.

7.2.4 Antennas Verification

a. The requirements of this clause 7.2 shall be verified by the verification methods, at the reviews, and recorded in the documents as specified in Table 7-1.

NOTE For verification, see also ECSS-E-ST-10-02.

Table 7-1: Antennas verification requirements

Requirement	Verification method	At review	Recorded in
	RoD: Review of design T: Test A: Analysis NOTES: RoD includes review of documentation	PDR: Preliminary design review CDR: Critical design review QTR: Qualification test report AR: Acceptance review	[1] Antenna ICD [2] EIDP [3] DDF or DJF [4] Tests Reports [5] Antenna specification
7.2.1.1	RoD	PDR	[3]
7.2.1.2.1a	RoD	Maintained through all reviews	[3]
7.2.1.2.2a.1	RoD	Maintained through all reviews	[3]
7.2.1.2.2a.2	RoD	PDR	[3]
7.2.1.2.2a.3	RoD, A	PDR, CDR	[3]
7.2.1.2.2a.4	RoD, A	PDR, CDR	[3]
7.2.1.2.2a.5	RoD, A	PDR, CDR	[3]
7.2.1.3a	A	PDR	[3]
	T	CDR	[4]
7.2.2.1a	RoD	PDR, CDR	[3]

Requirement	Verification method	At review	Recorded in
7.2.2.2.1a	A,T	PDR, CDR	[3], [4]
7.2.2.2.1b	A, T	PDR, CDR	[3], [4]
7.2.2.2.2a	A, T	PDR, CDR	[3], [4]
7.2.2.2.2b	A, T	PDR, CDR	[3], [4]
7.2.2.2.2c	A, T	PDR, CDR	[3], [4]
7.2.2.2.3a	A, T	PDR, CDR	[3], [4]
7.2.2.2.3b	A, T	PDR, CDR	[3], [4]
7.2.2.2.3c	A, T	PDR, CDR	[3], [4]
7.2.2.2.4a	RoD	PDR	[3]
7.2.2.3.1a	A, T	PDR	[3]
7.2.2.3.1b	A, T	PDR, CDR	[3], [4]
7.2.2.3.1c	A, T	PDR, CDR	[3], [4]
7.2.2.3.1d	A	PDR, CDR	[3], [4]
7.2.2.3.1e	A, T	PDR, CDR, QTR, AR	[3], [4]
7.2.2.3.1f	A, T	PDR, CDR, QTR, AR	[3], [4]
7.2.2.3.1g	RoD, T	PDR, CDR, QTR, AR	[1], [4]
7.2.2.3.2a	A, T	PDR, CDR	[3], [4]
7.2.2.3.2b	A, T	PDR, CDR	[3], [4]
7.2.2.3.2c	A	PDR, CDR	[3], [4]
7.2.2.3.3a	A, T	PDR, CDR	[3], [4]
7.2.2.3.3b	A	PDR, CDR	[3]
7.2.2.3.3c	RoD, T	PDR, CDR, QTR, AR	[3], [4], [1]
7.2.2.3.3d	RoD, T	PDR, CDR, QTR, AR	[3], [4], [1]
7.2.2.3.4a	A, T	PDR, CDR	[3], [4]
7.2.2.3.4b	A	PDR, CDR	[3]
7.2.2.3.4c	A	PDR, CDR	[3]
7.2.2.3.4d	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.3.4e	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.3.5a	A, T	PDR, CDR	[3], [4]
7.2.2.3.5b	A, T	PDR, CDR	[3], [4]
7.2.2.3.5c	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.3.5d	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.3.6a	A, T	PDR, CDR	[3], [4]
7.2.2.3.6b	A, T	PDR, CDR	[3], [4]
7.2.2.4.1a	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]

Requirement	Verification method	At review	Recorded in
7.2.2.4.1b	A, T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.4.1c	A	PDR, CDR	[3]
7.2.2.4.2a	A	PDR, CDR	[3]
7.2.2.4.2b	A	PDR, CDR	[3]
7.2.2.4.2c	T, RoD	PDR, CDR, QTR,AR	[3], [4], [2]
7.2.2.4.3a	A, T	PDR, CDR	[3], [4]
7.2.2.4.3b	A	PDR, CDR	[3]
7.2.2.4.3c	T, RoD	PDR, CDR, QTR, AR	[3], [4], [2]
7.2.2.5a	RoD	PDR, CDR, QTR, AR	[3], [4]
7.2.3.1a	A, T, RoD	PDR, CDR	[3], [4], [2]
7.2.3.1b	A, T, RoD	PDR, CDR, QTR,AR	[3], [4], [2]
7.2.3.2a	A, T	PDR, CDR	[3], [4]
7.2.3.2b	A	PDR	[3]

7.3 RF Power

7.3.1 Overview

The objective of the following RF breakdown requirements is to ensure that the space system operates at maximum power levels without any risk of Multipaction, RF power handling limitation and Corona (also called "gas discharge").

- Multipaction requirements are described in ECSS-E-ST-20-01.
- RF power handling requirements are described in clause 7.3.2.
- Corona (or Gas Discharge) requirements are described in clause 7.3.3 and apply for:
  - — vented RF components during launch and pressurisation due to out-gassing of the spacecraft or re-entry, and
  - — pressurized RF components.

7.3.2 RF Power handling (thermal)

7.3.2.1 General requirements

a. All the components and equipments of the RF chain shall be able to stand the maximum specified operating RF power during its application in space with:

   1. no degradation of the component,

2. no degradation of the RF signal including radiative losses, and

3. with their thermal levels not exceeding those corresponding to the maximum available RF power at the maximum qualification temperature.

7.3.2.2 Design and Verification

a. Each element of the RF chain shall be designed and verified to withstand the maximum specified operating RF power levels plus safety margins agreed with the customer in the development phase at the maximum qualification temperature.

7.3.3 Corona or Gas Discharge

7.3.3.1 General requirements

a. All the components and equipments of the RF chain shall be free of any risk of Gas discharge (Corona) at the maximum specified operating RF power over the full pressure range during:

1. the depressurization of the RF components and equipments at launch environmental conditions,

2. the pressurization due to out-gassing of the spacecraft in orbit,

3. ground testing at ambient pressure, and

4. the pressurization of the spacecraft during planetary re-entry phases at the mission environmental conditions.

b. For those components and equipments which design does not allow operating them over the full pressure range the following action shall be taken:

1. specify the applicable pressure range and gas properties,

2. ensure that the design and manufacturing is such to avoid discharge phenomena according to Pashen curves valid for its specified pressure range and gas properties.

7.3.3.2 Design and Verification

a. RF components and equipments of the RF chain shall be designed and verified to withstand the maximum specified operating RF power levels plus safety margins agreed with the customer in the development phase.

7.3.4 Qualification for power handling and gas discharge

a. The following criteria shall be met for qualification for power handling and gas discharge:

1. the RF component and equipment has no physical degradation,

2. the RF component and equipment has no degradation of the RF performance during and after the test.

7.4 Passive intermodulation

7.4.1 Overview

Passive intermodulation products are generated when two or more RF transmit signals illuminate or passing through a non-linear passive RF component. The RF frequencies of the passive intermodulation products are derived as for any other generation of intermodulation products, when two or more RF signals are present simultaneously. However, the power levels of the passive intermodulation products depend on the materials used, manufacturing tolerances and processes, assemble techniques, and oxidation of surfaces. Thus, they are hardly predictable implying that verification by test is mandatory for those intermodulation products that can adversely impact the mission or cause interference in third party protected frequency bands.

7.4.2 General requirements

a. The acceptance level of interference caused by passive intermodulation products shall be agreed with the customer in the development phase.

b. All the components of the RF chain shall be designed and manufactured to guarantee that the passive intermodulation products derived from the transmit carriers do not cause interference with any of the spacecraft receive bands or third party protected frequency bands during the operating temperature cycles.

7.4.3 Identification of potentially critical intermodulation products

a. All operating conditions shall be identified in which two or more transmit RF signals simultaneously illuminate or passed through a passive RF component, equipment or both.

b. For each of the conditions identified in 7.4.3a, the frequencies, number of carriers and power levels of these carriers shall be determined.

c. An analysis shall be performed to establish all the passive intermodulation products falling within any of the spacecraft receive bands or third party protected frequency bands, for all combinations of frequency carriers up to the intermodulation order of 100.

7.4.4 Verification

a. Testing at the lowest intermodulation order as identified in 7.4.3c shall be performed to ensure that the amplitudes of the passive intermodulation products are below the specified interference level.

b. Passive Intermodulation tests shall be carried out on the flight hardware in the same configuration as it is during operational use.

c. The test frequencies, number of carriers and power levels of these carriers shall be those as identified in 7.4.3b.

d. Qualification testing shall be carried out

1. on RF non radiative passive components, or equipments, or systems, over the full qualification temperature range,

2. on RF radiative components, equipments or systems over a temperature range to be agreed with the customer, range which can be limited to ambient temperature.

e. Acceptance testing shall be carried out on flight components, equipments or systems over an acceptance temperature range to be agreed with the customer, range which can be limited to ambient temperature.

7.4.5 Qualification for passive intermodulation

a. The amplitude of each passive intermodulation product falling within any of the spacecraft receive bands or third party protected frequency bands shall be lower than the level specified in 7.4.2a.

7.5 Verification

The requirements of the clauses 7.3 and 7.4 shall be verified by the verification methods, at the reviews, and recorded in the documentation as specified in Table 7-2.

Table 7-2: Power handling and Passive intermodulation table of verification

Requirement	At the following verification points	Verification methods	Recorded in
	SRR: System requirements review PDR: Preliminary design review CDR: Critical design review TRR: Test readiness review TRB: Test review board DRB: Delivery review board AR: Acceptance review X: Preliminary formal verification point	RoD: Review of design T: Test A: Analysis INS: Inspection NOTES: RoD includes review of documentation	[1] DDF or DJJF [2] Tests Reports
7.3.2.1a.1	TRB	INS	[2]
7.3.2.1a.2	TRB	T	[2]
7.3.2.1a.3	TRB	T	[2]
7.3.2.2a	PDR, CDR, TRB	A, T	[1], [2]
7.3.3.1a.1	PDR, CDR, TRB	A, T	[1], [2]
7.3.3.1a.2	PDR, CDR, TRB	A, T	[1], [2]
7.3.3.1a.3	PDR, CDR, TRB	T	[2]
7.3.3.1a.4	PDR, CDR, TRB	A, T	[1], [2]
7.3.3.1b.1	SRR	RoD	[1]
7.3.3.1b.2	PDR, CDR	RoD	[1]
7.3.3.2a	PDR, CDR, TRR, TRB	A, RoD, T	[1], [2]
7.3.4a.1	TRB	INS	[2]
7.3.4a.2	TRB	T	[2]
7.4.2a	SRR, PDR, CDR	RoD	[1]
7.4.2b	SRR, PDR, CDR	RoD, A, INS	[1]
7.4.3a	PDR, CDR, TRR	A, RoD	[1], [2]
7.4.3b	PDR, CDR, TRR	A, RoD,	[1], [2]
7.4.3c	PDR, CDR, TRR	A, RoD,	[1], [2]
7.4.4a	TRR, TRB	T	[2]
7.4.4b	TRR, TRB	T	[2]
7.4.4c	TRR, TRB	T	[2]
7.4.4d	TRR, TRB	T	[2]
7.4.5a	TRR, TRB	T	[2]

Annex A (normative) EMC control plan - DRD

A.1 DRD identification

A.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-20, requirement 6.2.2a.

A.1.2 Purpose and objective

The EMC control plan defines the approach, methods, procedures, resources and organization to design, produce and verify a product to operate within its specified electromagnetic environment and performance characteristics.

It provides the instruction for conducting all activities related to the management, the design requirements and the verification of the electromagnetic compatibility of all items of equipment and subsystems of a project.

A.2 Expected response

A.2.1 Scope and content

a. The EMC control plan shall contain a description of the purpose, objective, content and the reason of prompting its preparation.

b. The EMC control plan shall list the applicable and reference documents to support the generation of the document.

c. The EMC control plan shall include any additional definition, abbreviation or symbol used.

d. The EMC control plan shall list the EMC requirements to be verified, covering at least the following areas:

1. The EMC programme management:

   (a) responsibilities of customer and supplier at all levels, lines and protocols of communication, control of design changes;

   (b) planning of the EMC control program: facilities and personnel required for successful implementation of the

EMC control program; methods and procedures of accomplishing EMC design reviews and coordination;

(c) programme schedules: Integration of EMC program schedule and milestones within the program development master schedule.

2. System level performance and design requirements:

(a) definition of electromagnetic and related environments;

(b) definition of critical circuits;

(c) allocation of design responses at system and subsystem and equipment levels;

(d) antenna–to–antenna interference reduction analysis and technique;

(e) magnetic moment upper limit required for AOCS;

(f) magnetic cleanliness control plan (spacecraft with specific payloads);

(g) magnetic budget;

(h) establishment of a controlled grounding scheme;

(i) assessment of possible fault currents;

(j) wiring (including shielding and shield termination and categorization) practises;

(k) electrical bonding;

(l) material properties, effects of corrosion prevention and similar concerns on bonding and general EMC issues;

(m) design criteria for alleviating effects of spacecraft charging and other electrification issues.

3. Subsystem and equipment EMI performance requirements and verification:

(a) allocated EMI performance at the equipment level, including tailored equipment level requirements. The control plan shall be the vehicle for tailoring limits and test methods;

- Conducted emission on power leads in the frequency domain
- Inrush current on power leads
- Common mode conducted emission on power and signal leads
- Conducted emission on antenna ports
- DC magnetic field emission
- Radiated magnetic field emission in the low frequency range (scientific spacecraft)
- Radiated electric field emission in the low frequency range (scientific spacecraft)

- Radiated emission of RF electric field
- Conducted susceptibility on power leads in differential mode
- Conducted susceptibility on power and signal leads in common mode
- Conducted susceptibility to transients on power leads
- Radiated susceptibility to low frequency magnetic fields
- Radiated susceptibility to RF electric fields
- Susceptibility to electrostatic discharges

(b) test results from subsystem and equipment level EMI tests shall be summarized. Any specification non–compliances judged to be acceptable shall be described in detail and the justifying rationale presented.

4. Electro–Explosive Devices (EED):

(a) appropriate requirements (ECSS-E-ST-33-11 and ECSS-E-ST-20-07);

(b) design techniques;

(c) verification.

5. EMC analysis:

(a) predictions of intra–system EMI and EMC based on expected or actual equipment and subsystem EMI characteristics;

(b) design of solutions for predicted or actual interference situations;

6. Spacecraft level EMC verification, including outline of system–level EMC test plan, including rationale for selection of critical circuits for safety margin demonstration and instrumentation techniques for both critical and EED circuit sensitisation.

A.2.2 Special remarks

None.

Annex B (normative) Electromagnetic effects verification plan (EMEVP) - DRD

B.1 DRD identification

B.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-20, requirement 6.4.1b.

B.1.2 Purpose and objective

The electromagnetic effects verification plan (EMEVP) defines the approach, methods, procedures to verify electromagnetic effects.

The EMEVP provides the instruction for conducting all activities required to verify that the effects of the electromagnetic environment are compatible with the requirements of the project.

B.2 Expected response

B.2.1 Scope and content

a. The EMEVP shall contain a description of the purpose, objective, content and the reason of prompting its preparation.

b. The EMEVP shall list the applicable and reference documents to support the generation of the document.

c. The EMEVP shall include any additional definition, abbreviation or symbol used.

d. The EMEVP shall list the requirements of the plan, including:

   1. methods to be used to select critical circuits, used to monitor conformance to degradation criteria and safety margins, including the definition of the method of selection;

   2. procedures used for developing failure criteria and limits;

3. test conditions and procedures for all electronic and electrical equipment installed in or associated with spacecraft and sequence for operations during tests, including switching;

4. specific tolerance for particular measurement;

   NOTE See also B.2.1e.and f.

5. implementation and application of test procedures, including modes of operation and monitoring points for each subsystem or equipment;

6. use of approved results from laboratory interference tests on subsystems and equipment;

7. methods and procedures for data readout and analysis;

8. means of verifying design adequacy of spacecraft electrification;

9. means of simulating and testing electro–explosive subsystems and devices (EEDs);

10. verifying electrical power quality, and methods for monitoring DC and AC power busses;

11. test locations and descriptions of arrangements for simulating operational performance in cases where actual operation is impractical;

12. configuration of equipment and subsystems modes of operation to ensure victim equipment and subsystems are tested in most sensitive modes, while culprit equipment and subsystems are tested in noisiest mode(s);

13. details concerning frequency ranges, channels, and combinations to be specifically tested such as image frequencies, intermediate frequencies, local oscillator, transmitter fundamental and harmonically related frequencies, and including subsystem susceptibility frequencies identified during laboratory testing;

14. to precise parallel or series injection for conducted susceptibility test;

15. personnel to perform the test, including customer and supplier personnel at all levels, and quality representatives;

16. list of all test equipment to use, including a description of unique EMC instrumentation for stimulating and measuring electrical, electronic, and mechanical outputs of equipment and subsystems to be monitored during the test programme;

17. description of cables attached to the equipment under test;

18. definition of the line impedance stabilization network (values of internal components);

19. need for calibration and check of the measurement setup;

20. antennas to use for RF emission and susceptibility tests;

21. Method of switching ON for inrush current testing.

e. An intra–system compatibility culprit/victim test matrix shall be included in the EMEVP, showing all combinations of individual equipment/subsystems to be tested in order to verify overall intra–system compatibility;

f. The description of the Step–by–step test procedures for operation of all matrix equipment shall be included in the EMEVP to support test execution.

B.2.2 Special remarks

None.

Annex C (normative) Electromagnetic effects verification report (EMEVR) - DRD

C.1 DRD identification

C.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-20, requirement 6.4.1c.

C.1.2 Purpose and objective

The electromagnetic effects verification report (EMEVR) provides reporting of all activities in relation with the verification of the effects of the electromagnetic environment.

The document is prepared for each project, based on the electromagnetic effects verification plan.

It then applies to every item of equipment and subsystem in the project.

C.2 Expected response

C.2.1 Scope and content

a. The EMEVR shall contain a description of the purpose, objective, content and the reason of prompting its preparation.

b. The EMEVR shall list the applicable and reference documents to support the generation of the document.

c. The EMEVR shall include any additional definition, abbreviation or symbol used.

d. The EMEVR shall include:

1. identification of specific objectives, including applicable requirements and EMEVP references;

2. description of test article (e.g. configuration and drawings and photographs);

3. description of any fixes or configuration changes to article resulting from verification failures;
4. description of changes to cables attached to the equipment under test with respect to the EMEVP
5. summary of results including an executive summary stating degree of conformance to requirements;
6. description of any deviations from test facilities, analysis techniques or tools, and inspection aids in EMEVP;
7. description of any deviations from step–by–step procedures in EMEVP;
8. test set–up diagrams/photographs as appropriate;
9. list of test equipment, including calibration information;
10. recorded data or logs, including instrument readings, correction factors, and reduced results; methods of data reduction .
11. If value of data has been compromised due to test conditions, the reason and impact on results;
12. description of ambient and other test conditions.

C.2.2 Special remarks

None.

Annex D (normative) Battery user manual - DRD

D.1 DRD identification

D.1.1 Requirement identification and source document

This DRD is called from ECSS-E-ST-20, requirement 5.6.4b.

D.1.2 Purpose and objective

The battery user manual is a document generated by the manufacturer, that can be used by the customer for the procurement of cells and batteries.

D.2 Expected response

D.2.1 Scope and content

a. The battery user manual shall contain the following information:

1. maximum ground storage life (where applicable before and after activation);
2. maximum period of non–use without special "wake–up" cycling;
3. range of battery temperatures and maximum durations during pre–launch and operational phases;
4. battery maintenance procedures during integration and pre–launch phases including case of launch delay;
5. storage procedure, range of storage temperature, cell discharge requirements before storage;
6. humidity and packaging constraints for storage;
7. maximum and minimum state of charge to be maintained during storage, requirements on individual shorting of cells, details of any trickle charge or periodic maintenance (e.g. minimum voltage checks and top-up charge to a maximum voltage in case a minimum cell voltage is reached)
8. reactivation procedure after storage;

9. handling and cell connecting procedures and precautions;
10. cell and battery safety related information;
11. transportation requirements.

D.2.2 Special remarks

None.

Bibliography

ECSS-S-ST-00	ECSS system – Description, implementation and general requirements
ECSS-E-ST-10-02	Space engineering – Verification
ECSS-E-ST-10-04	Space engineering – Space environment
ECSS-E-ST-32	Space engineering – Structural general requirements
ECSS-Q-ST-30	Space product assurance – Dependability
ECSS-Q-ST-40	Space product assurance – Safety
ECSS-Q-ST-70	Space product assurance – Materials, mechanical parts and processes
NASA-STD-8739.4	Crimping, interconnecting cables, harnesses, and wiring
RNC-CNES-Q-70-511	Spécification de conception et de contrôle des interconnexions filaires
JSC-20793 Rev B April 06	Crew vehicle battery safety requirements