



BSI Standards Publication

Space engineering - Electrical and electronic

National foreword

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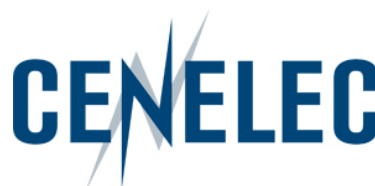
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European Foreword

This document (EN 16603-20:2020) has been prepared by Technical Committee CEN-CENELEC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-20:2020) originates from ECSS-E-ST-20C Rev.1.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by March 2021, and conflicting national standards shall be withdrawn at the latest by March 2021.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN [and/or CENELEC] shall not be held responsible for identifying any or all such patent rights.

This document has been prepared under a standardization request given to CEN by the European Commission and the European Free Trade Association.

This document has been developed to cover specifically space systems and has therefore precedence over any EN covering the same scope but with a wider domain of applicability (e.g. : aerospace).

According to the CEN-CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, Former Yugoslav Republic of Macedonia, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and the United Kingdom.

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 constraints of a space project in conformance with ECSS-S-ST-00.

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.

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16603-10	ECSS-E-ST-10	Space engineering – System engineering general requirements
EN 16603-20-06	ECSS-E-ST-20-06	Space engineering – Spacecraft charging
EN 16603-20-07	ECSS-E-ST-20-07	Space engineering – Electromagnetic compatibility
EN 16603-20-08	ECSS-E-ST-20-08	Space engineering - Photovoltaic assemblies and components
EN 16603-20-20	ECSS-E-ST-20-20	Space engineering - Electrical design and interface requirements for power supply
EN 16603-33-11	ECSS-E-ST-33-11	Space engineering – Explosive systems and devices
EN 16603-50-05	ECSS-E-ST-50-05	Space engineering – Radio frequency and modulation
EN 16603-50-14	ECSS-E-ST-50-14	Space engineering – Spacecraft discrete interfaces
EN 16602-30-11	ECSS-Q-ST-30-11	Space product assurance – Derating – EEE components
EN 16602-40	ECSS-Q-ST-40	Space product assurance – Safety
	IEEE 145-1993	Antenna terms
	Impedance Specifications for Stable DC Distributed Power Systems, EEE transactions on power electronics, Vol. 17, no. 2, March 2002	Impedance Specifications for Stable DC Distributed Power Systems, X. Feng, J. Liu, F.C. Lee, IEEE Transactions on power electronics, Vol. 17, no. 2, March 2002

Terms, definitions and abbreviated terms

3.1 Terms from other standards

- a. For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply.
- b. For the purpose of this Standard, the following terms and definitions from ECSS-E-ST-20-20 apply:
 - 1. latching current limiter (LCL)
 - 2. retriggerable latching current limiter (RLCL)

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 inserted between an antenna input port or a BFN output port and a corresponding individual radiating element

NOTE Examples of microwave components are: ortho-mode transducers, polarisers, transformers as well as filters.

3.2.4 antenna support structure

part of an antenna having no electrical function, which can however impact its electrical performances, either directly due to scattering or indirectly

NOTE Example of indirect effect is 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, 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 like reflectors and lenses

3.2.7 battery bus

primary power bus directly connected to the battery

NOTE Battery bus is sometimes called unregulated bus (although the battery charge is regulated).

3.2.8 beam forming network (BFN)

wave-guiding structure composed a chain of microwave components and devices 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

NOTE Examples of microwave components and devices are lines, phase shifters, couplers, loads.

3.2.9 conducted emission (CE)

desired or undesired electromagnetic energy that is propagated along a conductor

3.2.10 critical pressure

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

3.2.11 diffusivity

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

3.2.12 depth of discharge (DOD)

ampere-hour removed from a battery expressed as a percentage of the nameplate capacity

3.2.13 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

3.2.14 electrical bonding

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

3.2.15 electromagnetic compatibility (EMC)

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

3.2.16 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.

3.2.17 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 element caused by an electromagnetic disturbance.

3.2.18 electromagnetic interference safety margin (EMISM)

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

3.2.19 emission

electromagnetic energy propagated by radiation or conduction

3.2.20 energy balance

situation in which the spacecraft energy budget is positive when elaborated over a considered period of time

NOTE 1 Energy budget is generation minus consumption and losses.

NOTE 2 The considered period of time can be one orbit, several orbits or any relevant mission period.

3.2.21 energy reserve

energy that remains available from the energy storage assembly at the worst-case, most depleted, point of nominal operations

NOTE It is important that the energy reserve is sufficient to permit reaching a safe operating mode upon occurrence of an anomaly

3.2.22 essential function

function without which the spacecraft cannot be recovered following any conceivable on-board or ground-based failure

NOTE Examples of unrecoverable spacecraft is when spacecraft cannot be commanded, or permanently losses attitude and control, or the energy balance is no longer ensured, or the spacecraft consumables (e.g. hydrazine or Xenon) are depleted to such an extent that more than 10% of its lifetime is affected, or the safety of the crew is threatened.

3.2.23 faulty signal

signal generated by a circuit, appearing at its interface to another circuit, going out of its nominal range because of a failure

3.2.24 foldback current limiter (FCL)

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

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

3.2.25 fully regulated bus

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

3.2.26 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.

3.2.27 high Priority telecommand (HPC)

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

3.2.28 high voltage

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

3.2.29 lens antenna

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

3.2.30 lightning indirect effects

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

3.2.31 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.

3.2.32 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.

3.2.33 non essential loads

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

3.2.34 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

3.2.35 photovoltaic assembly (PVA)

power generating network comprising the interconnected solar cell assemblies, 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

3.2.36 primary cell or battery

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

3.2.37 primary power bus

spacecraft electrical node closest to the power sources where power is controlled and made available to the user equipment

3.2.38 radiofrequency (RF)

frequency band used for electromagnetic waves transmission

3.2.39 radiated emission (RE)

radiation and induction field components in space

3.2.40 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.

3.2.41 reflector antenna

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

3.2.42 RF chain

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

3.2.43 RF lens

plastic, composite or metallic structure acting on transmitted RF waves to control the antenna pattern

NOTE Example of metallic structures are waveguide array lenses.

3.2.44 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

3.2.45 secondary cell or battery

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

3.2.46 solar aspect angle (SAA)

angle between the normal to a solar panel and the sun vector

3.2.47 solar cell assembly (SCA)

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

3.2.48 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

3.2.49 susceptibility threshold

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

3.2.50 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	alternating current
AR	acceptance review
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
EMCAB	EMC Advisory Board
EMEVP	electromagnetic effects verification plan
EMEVR	electromagnetic effects verification report
EMI	electromagnetic interference
EOL	end of life
EPS	electrical power subsystem
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
INS	inspection
ICD	interface control document
I-V	current-voltage
LCL	latching current limiter
MPPT	maximum power point tracker
MRB	manufacturing review board

Abbreviation	Meaning
OBC	on-board computer
PCB	printed circuit board
PDR	preliminary design review
PVA	photovoltaic assembly
QTR	qualification test report
RF	radio frequency
RLCL	retriggerable latching current limiter
ROD	review of design
PSA	Part stress analysis
SAA	solar aspect angle
SADM	solar array drive mechanism
SCA	solar cells assembly
SEE	single event effects
SEU	single event upsets
SPF	single point failure
SRR	system requirement review
T	test
TRB	test review board
TRR	test readiness review
TM&TC	telemetry/telecommand
UV	ultraviolet
VCD	verification control document
WCA	worst case analysis

3.4 Nomenclature

The following nomenclature applies throughout this document:

- a. The word “shall” is used in this Standard to express requirements. All the requirements are expressed with the word “shall”.
- b. The word “should” is used in this Standard to express recommendations. All the recommendations are expressed with the word “should”.

NOTE It is expected that, during tailoring, recommendations in this document are either converted into requirements or tailored out.

- c. The words “may” and “need not” are used in this Standard to express positive and negative permissions, respectively. All the positive

permissions are expressed with the word “may”. All the negative permissions are expressed with the words “need not”.

- d. The word “can” is used in this Standard to express capabilities or possibilities, and therefore, if not accompanied by one of the previous words, it implies descriptive text.

NOTE In ECSS “may” and “can” have completely different meanings: “may” is normative (permission), and “can” is descriptive.

- e. The present and past tenses are used in this Standard to express statements of fact, and therefore they imply descriptive text.

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. Reconfiguration, high level or high priority command lines shall be immune to spurious activation.
- d. The application of the nominal signals or a faulty signal to an un-powered interface shall not cause damage to that interface.

NOTE This requirement covers all types of interfaces.
Standard interfaces are covered in clauses 4.2.4.3 and 4.2.4.4 of ECSS-E-ST-50-14.

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

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

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

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 For failure case, refer to requirement 4.2.1a.

- 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, shall be implemented 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 valid command shall be issued until the transmitter power supply is within operational voltage range and ready to transmit the command.

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. Primary bus load currents shall be monitored by telemetry, to enable, together with the bus voltage telemetry, a complete monitoring of a primary 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. Failure propagation shall meet the following conditions:
 - 1. A single hardware failure does not propagate to neighbouring components circuits or interfaces in an undetermined way.
 - 2. Failure propagation is verified by analysis.

3. Mechanical, thermal or electrical propagation of single hardware failures does not impair the corresponding protection or redundancy implemented at equipment or system level.
4. Single hardware failure does not propagate to equipment or functions under different contractual responsibility than the item where the failure takes place.

NOTE 1 4.2.1a.4 is normally covered by specification of fault emission and tolerance conditions.

NOTE 2 Component assembly (e.g. single cavity hybrid) and integrated circuits, especially if they contain redundancy or protection, require special attention."

- b. Redundant signal or power lines should be segregated via physically separated connectors and harnesses.
- c. Routing of redundant power or signal lines within common harness or connector shall be justified by analysis showing that inside the electrical unit and at external connector interface level there is no potential single failure leading to affect both nominal and redundant lines or to generate electrical or electromagnetic interference between both.

NOTE 1 Typical analysis for demonstrating compliance is provided within FMEA and EMC coupling analysis.

NOTE 2 Potential single failure includes short-circuit cases."

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

- 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. <<deleted>>

- j. Any active equipment, excluding heaters, dissipating more than 20 W in nominal or failure condition shall include a temperature monitoring available to the system.

- 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, latching protection shall not be used unless it has an autonomous periodic reset.
- m. Disabling critical on-board autonomous functions shall be allowed only if an interlock mechanism is implemented, which prevents the disabling of both main and redundant functions at the same time.

NOTE Critical functions refers to functions which prevent the satellite from being recovered when both main and redundant are switched off, e.g. RF receiver or command decoder.

- 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 component or integrated circuit nor utilize common references or auxiliary supply.
- p. Essential functions shall not be lost upon a single failure of other functions which are centrally powered or controlled.

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

NOTE 2 That can imply the capability of an equipment performing an essential function of operating independently of any external synchronization and auxiliary power supply if these are not SPF free.

- 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 failure tolerant for unmanned mission and double failure tolerant for manned mission.
- x. Occurrence of a non-destructive SEE after a failure shall not lead to the loss of the mission.

NOTE Accordingly, a non-destructive SEE cannot derail a reconfiguration process after first hardware 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. For technical budgets and margin policy the requirements of ECSS-E-ST-10 clause 5.4.1.2 shall be applied.
- 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 and spacecraft skin connectors shall be covered for flight.

NOTE Umbilical connectors (detached during launch) are not part of skin connectors (detached or connected before launch).

- 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.

NOTE RF savers are known to introduce extra insertion losses, in the range of 0,1 dB.

- 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 should 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. Except when pin allocation is imposed by a standard specification, spare contacts or sockets should 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 and document its integrity up to the highest spacecraft integration level, to avoid accidental demating.
- n. <<deleted>>
- 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. <<deleted>>
- 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.

NOTE It is expected that the design of the EGSE incorporates protections limiting the fault voltage emission to a level acceptable by the unit.
- 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. Circuits meant for on-ground testing or unused circuits shall not create or be sensitive to the noise expected during operation.

NOTE For example spacecraft stimuli, unit test points, unused operational amplifiers or comparators.

- 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. <<deleted>>
- l. Hot redundant functions and protection functions that cannot be tested beyond unit level shall be identified in the critical item list.
- m. All redundant functions and protection functions shall be tested, up to the highest possible level of integration of the unit.
- 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 or at unit level with representative interfaces.

NOTE 1 This is the case e.g. of a battery discharge regulator switching OFF autonomously at low input voltage to protect a Li-ion battery against irreversible damage to overdischarge.

NOTE 2 In the case of the LCL in power distribution, the limitation of current at turn-on is considered representative for validation of the protection 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 Miscellaneous

- 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 electrical performance characteristics of the units shall enable equipment interchange provided a minimum set of adjustments and recalibration as described in the unit user's manual.
- 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 should be verified by the verification methods and at the verification points listed in Table 8-3.

NOTE 1 Table 8-3 can be used as a starting point for the definition of the verification methods.

NOTE 2 For more details on the verification strategy see also ECSS-E-ST-10-02 in particular the requirements 5.2.1c, d and e.

- b. In case verification by analysis of an electrical part or circuit is not possible by lack of data, complementary verification by test shall be performed.

NOTE Electrical part or circuit encompasses in particular to EEE components, solar cell or solar array, battery cell or battery assembly.

4.3.2 Documentation

- a. The design report, PSA, WCA, FMECA, thermal analysis, radiation analysis, EMC analysis and the detailed circuit diagrams including component values, shall be part of the Design Definition and Justification Files.
- 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.
- d. The Design Definition and Justification Files shall be delivered by the supplier to the customer at the agreed verification points in compliance with Table 8-3.

Table 4-1: <<deleted, merged with new Table 8-3>>

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.

NOTE For passivation, refer to ECSS-U-AS-10.

5.2.2.2 Engineering process

- a. An analysis of power demand versus power available shall be performed, including average peak power, 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 and also failure mode affecting the power system.

NOTE Failure modes can result in transient or permanent overconsumption.

- 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,
- shadowing,
- 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, that are provisioned for achieving reliability of these item, but including transient or permanent overconsumption of a load,
- 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 actually using a MPPT, it shall be ensured that the transferred power is at least the required power, independent of the solar array operating conditions or environment.

NOTE The factors affecting the transferred power include in particular the following ones:

- Consideration of possible multiple local maximum power points,
- Different illumination (e.g. resulting from different SAA) for different SA sections,
- Temperature dispersion,
- Shadowing,
- Dispersion of the SA string I/V curves,
- Tracking accuracy and response time of MPPT control,
- Dynamic stability of MPPT control loop,

- Power conversion efficiency of MPPT converters.

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 integrated circuit, and
 2. not utilize common references.
- b. It shall not be possible to inhibit a protection feature if such an inhibition can lead to the loss of the main primary power bus in case of a single failure at spacecraft level.
- c. In flight operation, if primary power bus shutdown happens, the system, including the power subsystem, shall be able to restart.

NOTE 1 Startup is possible as soon as sufficient power is available for a sufficient time from any source of the primary power bus, without considering failure for unmanned mission, or after single failure for manned mission.

NOTE 2 This requirement can imply that the battery is sufficiently recharged before its energy starts to be provided, for example to recover spacecraft attitude.

- d. <<deleted>>

5.4 Electrical power interfaces

- a. The electrical power interface internal or external to the power subsystem shall be specified, including source and load impedance.

NOTE Main examples of internal power interface are battery to conditioning electronics, SA to conditioning electronics. Main examples of external power interface are primary power conditioning electronics to loads, EGSE to and from primary power conditioning electronics, umbilical to and from primary power conditioning electronics. Docked modules on board of spacecraft, like orbiter or rover, are concerned as well.

- b. <<deleted>>
- c. The availability of the specified solar array power up to the power conditioning electronics shall be verified as follows:
 1. on solar array level, availability of the specified solar array power up to and including the solar array connector by means of flasher tests, supported by correlated analysis,

2. on spacecraft level, full steady-state solar array power conditioning capability from solar array connector to power conditioning electronics, including solar array drive mechanism if any and harness, using solar array simulator,
 3. and finally, on spacecraft level, correct electrical connection of the solar array to the power conditioning unit by means of a flood test, that is by illumination of the solar array with a portable continuous lamp, checking if the generated voltage and current are detected at power conditioning side.
- d. The solar array interface voltage shall be defined at the solar array 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 Power 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 specified to provide the requested power and ensure the energy balance in each mission phase during operational life including any string loss tolerance defined by the customer, spacecraft charging effects and worst case conditions.

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 can lead to the addition of other spare strings.

NOTE 3 The computation of the energy balance is a typical task for the large system integrator based on defined power points expressed as a specification to the SA manufacturer.

- b. <<deleted>>
- c. <<deleted>>
- d. Provision shall be made against potential failure propagation in case of short-circuit failure of a solar array section or short circuit of its connection to the power subsystem.

NOTE In particular short-circuit of solar array interface (for example during ground operations) can lead to short-circuit of the main bus or the battery if no protections (e.g. blocking diodes in conditioning electronics) are implemented.

- e. The solar array design shall be such that charging phenomena do not degrade the performance of the solar array below the ones specified in 5.5.2a and 5.5.2c and meeting the requirements specified in clauses 7.1 and 7.2 of ECSS-E-ST-20-06.

NOTE Good practices in accordance with the present state of the art (maximum current of 0,6 A) are to:

- limit the differential voltage in between cells to 30 V (this relates to a factor of 2,3 margin with respect to Table 7-1 from ECSS-E-ST-20-06) 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. For voltages in between cells higher than 30V, ESD testing shall be performed in line with ECSS-E-ST-20-06 demonstrating a minimum safety margin of 2,3 for the voltage.

NOTE This means no sustained arcing for voltages being 2,3 times V_{max} (with V_{max} being the maximum possible voltage between two adjacent cells of different strings at the minimum gap distance that can occur and at the highest currents that can occur).

- g. In the flight configuration, solar array conductive panels and spacecraft structure shall be insulated from each other, disregarding the bleed resistor.

NOTE 1 Examples of such structural parts of the SA panel are hold-down mechanisms, yokes, hinges and CCL (Closed Cable Loop).

NOTE 2 Typical value of insulation is in the order of 100 M Ω , and typical bleed resistor is in between 2 k Ω to 20 k Ω .

- 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. <<deleted>>
- n. <<deleted>>
- o. Provision shall be made to prevent failure due to operation in shadow.
- p. Solar array shall be designed in sections according to the redundancy principle specified at system level.
 - NOTE 1 The number of sections can be equal to one or to the number of strings, depending on the redundancy principle.
 - NOTE 2 Sectioning the SA can alleviate failure mitigation constraints (see requirement 5.8.1c).
- q. Solar cells shall be protected against any deleterious reverse-bias conditions.

5.5.3 Solar array power computation

- a. Computation of solar array power shall be based on measurements at cell level performed in accordance with the requirements of clause 10 of ECSS-E-ST-20-08.
- b. The model used for the computation of the I(V) curve of the solar cell shall be validated by test on the specific solar cell type for the mission in conditions representative of the expected domain of operation.
 - NOTE Representative conditions are, for example, illumination, temperature or SAA.
- 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 I(V) curve shall be derived from measurements performed at the temperatures specified in 5.5.3c after irradiation with particles in conformance with the "Electron irradiation" and "Proton irradiation" tests for "Bare solar cells" specified in ECSS-E-ST-20-08 clause 7, and agreed with the customer.
 - NOTE The irradiated particles can either electrons or protons. The irradiation particles can be electrons or protons, chosen in order to facilitate the calculation of degradation, ideally

using the particle type that dominates the degradation during the mission.

- 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 best case calculations, the string current shall account for the difference between the specified current and the average production value.
- 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 $\pm 3\%$, 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 $\pm 5^{\circ}\text{C}$.		

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 wires, connector pins and slip ring contacts shall be greater than the best case BOL solar array section current in short circuit and include the effects of transient currents caused by the discharge of the solar array section capacitance.
- b. The design of the insulation barriers between adjacent wires, connector pins and 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. The battery shall be specified to ensure the energy balance in each mission phase during operational life, including contingency modes resulting from a single failure for unmanned missions and two failures for manned missions.
- b. <<deleted>>
- c. Specific measures shall be taken in the battery design to keep under control the series inductance and the magnetic moment.
- d. <<deleted>>
- 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 subsystem 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 in short-circuit within a battery composed of parallel strings, shall not result in exceeding the peak cell current rating.
- h. Battery supplier shall:
1. specify cell to cell performance variations so that mission requirements can be met,
 2. provide methodology and validation of cell performance variations for any spare or flight models.

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 batteries are discharged in parallel, this discharge shall not result in current and temperature exceeding the cell qualification limits.

NOTE This requirement is essentially applicable to primary Lithium batteries that have a positive voltage vs temperature coefficient.

- j. Conducting cases of battery cells in a battery package shall be double-insulated from each other.
- k. Provisions for interfacing the battery with the ground support equipment during pre-launch operations shall be made.

NOTE Such provisions can include:

- signal lines for monitoring battery voltage,
- signal lines for monitoring battery temperature,
- capability to charge the battery,
- capability to discharge the battery.

- 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 and spacecraft thermal design shall ensure together 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. <<deleted>>
- o. Conductive cases of battery cells shall be double insulated from spacecraft structure, with an insulation between any cell and the spacecraft structure greater than 10 M Ω , measured at 500 V DC.

5.6.3 Battery cell

- a. Absolute maximum ratings of the cell, in term of temperature, voltage, charge and discharge current in continuous and peak condition, 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. <<deleted>>
- f. <<deleted>>
- 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.