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Space engineering

Photovoltaic assemblies and components

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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.

The formulation of this Standard takes into account the existing ISO 9000 family of documents.

This Standard has been prepared by the ECSS-E-20-08 Working Group, reviewed by the ECSS Engineering Panel and approved by the ECSS Steering Board.

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Introduction

The qualification, procurement, storage and delivery of space solar arrays are defined in the dedicated solar array specification, where requirements for the solar array electrical layout, structure and mechanism are specified.

This Standard outlines the requirements for the qualification, procurement, storage and delivery of the main assemblies and components of the space solar array electrical layout: photovoltaic assemblies, solar cell assemblies, bare solar cells and coverglasses. This Standard does not outline the requirements for the qualification, procurement, storage and delivery of the solar array structure and mechanism.

The general requirements are covered in the main part of this Standard (Clauses 5 to 8). Annex B to Annex E specify the contents of the source control drawing of photovoltaic and solar cell assemblies, bare solar cells and coverglasses and include the inspection data, physical and electrical characteristics, other ratings and acceptance and qualification specific requirements, which can be different for each space project.

This Standard is divided into four specific subjects, each one corresponding to each assembly or component. Clause 5 defines requirements for photovoltaic assemblies, Clause 6 for solar cell assemblies, Clause 7 for bare solar cells, and Clause 8 for coverglasses.

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1 Scope

This Standard specifies the general requirements for the qualification, procurement, storage and delivery of photovoltaic assemblies, solar cell assemblies, bare solar cells and coverglasses suitable for space applications.

This Standard primarily applies to qualification approval for photovoltaic assemblies, solar cell assemblies, bare solar cells and coverglasses, and to the procurement of these items.

This Standard does not apply to qualification of the solar array structure and solar array mechanisms.

When reviewed from the perspective of a specific project context, the requirements defined in this Standard should be tailored to match the genuine requirements of a particular profile and circumstances of a project.

NOTE Tailoring is a process by which individual requirements of specifications, standards and related documents are evaluated, and made applicable to a specific project by selection, and in some exceptional cases, modification of existing or addition of new requirements.
[ECSS-M-00-02A, Clause 3]

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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 revisions 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 most recent editions of the normative documents indicated below. For undated references, the latest edition of the publication referred to applies.

ECSS-P-001	Glossary of terms
ECSS-E-20	Space engineering — Electrical and electronic
ISO 14644-1:1999	Cleanrooms and associated controlled environments — Part 1: Classification of air cleanliness
MIL-E-12397	Eraser, rubber pumice for testing coated optical elements
ASTM D1193-99	Standard specification for reagent water

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Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ECSS-P-001, ECSS-E-20 and the following apply.

3.1.1 General

3.1.1.1
bubbles
gaseous inclusion in the cell, coverglass or coverglass adhesive

3.1.1.2
chip
local absence of material along the edges and corners of a complete component and which extend through the thickness of the component

3.1.1.3
crack
fissure in the component with no separated portion from the remainder

NOTE Cracks can propagate from the edge of the material (edge cracks) or terminate at both ends within the material (surface cracks).

3.1.1.4
delamination
physical separation between two material layers, which are joined in design

3.1.1.5
discolouration
local variation of solar cell anti-reflection coating colour due to the influence of the structure orientation of the cell layer immediately below or the variation of the anti-reflection coating layer thickness

3.1.1.6
dig
cavities in the surface of a component caused by impact with a pointed object or by crushing a material into the surface

3.1.1.7
inclusion

volume contained within the component that is devoid of the substrate material

3.1.1.8
in-process testing

tests performed during the manufacturing of a component or assembly in order to identify, in advance, defects or low performances

3.1.1.9
nick

local absence of material on the surface of a complete component which does not extend through the thickness of the component

3.1.1.10
procurement lot

set of shipment lots of solar cells assemblies, bare solar cells and coverglasses, manufactured with the same processes and materials, on the same manufacturing line, that fill the same purchase order

3.1.1.11
scratch

linear marking of the component that represents a volume devoid of the substrate material emanating from a single face of the component and not penetrating through the whole thickness of the substrate at any point

3.1.1.12
shipment lot

solar cell assemblies, bare solar cells and coverglasses manufactured with the same processes and materials on the same manufacturing line delivered to the customer as a part of a purchase order

3.1.1.13
spatter

small bits of solid coating material imbedded on or in the coating or substrate

3.1.1.14
voids

absence of deposited materials

EXAMPLE Absence of cell contact material or anti-reflection coating.

3.1.2 Terms and definitions for photovoltaic assemblies

3.1.2.1
photovoltaic assembly

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

3.1.2.2
qualification coupon

non-flight representative test sample of flight panels, built with flight processes and containing representative materials and components to be used in the manufacture of flight panels

3.1.2.3
slicing
procedure to evenly distribute the total number of thermal cycles over temperature domains which are compatible with the temperature excursion on an orbit level rather than on the overall mission temperature envelope

NOTE Normally used for LEO missions.

3.1.3 Terms and definitions for solar cell assemblies

3.1.3.1
deformed interconnector
interconnector whose initial conformed shape is modified

3.1.3.2
interconnected cell
solar cell with interconnector without coverglass

3.1.3.3
solar cell assembly
solar cell together with interconnector, coverglass and, if used, by-pass diode

3.1.3.4
tearing interconnector
interconnector physically separated from the cell due to a failure of the welding or soldering joint

3.1.4 Terms and definitions for bare solar cells

3.1.4.1
bare solar cell
photovoltaic component capable to delivering electrical power when illuminated with light

3.1.4.2
component bare solar cell
specially manufactured solar cell, with only one active junction and the same spectral response as one sub cell of a multi-junction solar cell

3.1.4.3
contact vacuum evaporation batch
bare solar cells manufactured in the same contact vacuum evaporation run

3.1.4.4
drops
excess of metalization material on the solar cell contacts

3.1.4.5
hairline crack
fissure in the bare solar cell located in the photovoltaic active area

3.1.4.6
solar cell anti-reflection coating
single or multi-layer coating which reduces the reflection coefficient of the incident solar radiation

3.1.4.7
uncoated area
area of the solar cell where the bare solar cell is exposed and is devoid of coatings

3.1.4.8
worm shaped bulge
protuberance of contact material shaped in linear irregular paths or single dots where the contact material is locally delaminated from the immediate lower layer

3.1.5 Terms and definitions for coverglasses

3.1.5.1
coating
dielectric or conductive material applied to the glass substrate by vacuum deposition

NOTE Coatings applied to the external face of the coverglass is termed the "front surface coating". Coatings applied to the internal face of the glass substrate to be bonded to the solar cell is termed the "rear surface coating". Commonly used coatings include:

- single-layer anti-reflection coating,
- multi-layer anti-reflection coating,
- ultraviolet reflector,
- infrared reflector, and
- conductive coating.

3.1.5.2
conductive coating
transparent coating used to prevent the exposed surface from charging and consequently protecting the solar cell from the effect of electrostatic discharge

NOTE The coverglass usually comprises a suitable glass substrate and one or more of a combination of the coatings given in the note in 3.1.5.1.

3.1.5.3
coverglass
glass substrate and coatings applied to its surfaces

3.1.5.4
coverglass coating lot
collection of glass substrates subjected to the same coating run or runs (for coverglasses which have more than one coating)

3.1.5.5
infrared reflector
multi-layer dielectric coating which has a high reflectance coefficient in the infrared portion of the solar spectrum

NOTE The infrared reflector is used to reflect light that is not usefully converted to electrical energy by the solar cell thus reducing the operating temperature and increasing the efficiency of the SCA.

3.1.5.6
mark
stain
area which under inspection conditions can clearly be defined as not being optically homogeneous with the bulk material, and that cannot be categorized as an inclusion, scratch, crack, chip, dig, void or coating delamination

3.1.5.7
multi-layer anti-reflection coating
multiple layer coating which has the effect of increasing the transmission coefficient of the coverglass

3.1.5.8
single layer anti-reflection coating
simplest form of coating comprising a single layer of low index dielectric material which minimizes the reflection coefficient of the incident solar radiation thus increasing the transmission coefficient of the coverglass

NOTE The single layer of low index dielectrical material is usually done of MgF_2.

3.1.5.9
ultraviolet reflector
multi-layer dielectric coating which has a high reflectance coefficient in the UV portion of the solar spectrum

NOTE The ultraviolet reflector is used to protect the underlying adhesive and to reflect light that is not usefully converted to electrical energy by the solar cell thus reducing the operating temperature of the solar cell and increasing the efficiency of the SCA.

3.1.5.10
uncoated area
area of the coverglass where the bare coverglass substrate is exposed and is devoid of coatings

3.2 Abbreviated terms

The following abbreviated terms are defined and used within this Standard:

Abbreviation	Meaning
ADP	acceptance data package
AOCS	altitude and orbit control system
AM0	air mass 0 (zero)
APTC	ambient pressure thermal cycling
AR	anti-reflection
ARC	anti-reflection coating
ATOX	atomic oxygen
BOL	beginning-of-life
BSC	bare solar cell
BSR	back surface reflector
CIC	connector integrated cell (us designation of sca)
CIDL	configuration item data list
CVCM	collected volatile condensable material
CVG	coverglass
DCR	documentation change request
DJF	design justification file
DRB	delivery review board
DVG	direct voltage gradient
EIDP	end item data package
EMC	electromagnetic compatibility

EOL	end-of-life
ESD	electrostatic discharge
FMECA	failure modes, effects and criticality analysis
GaAs	gallium arsenide
GEO	geostationary orbit
IC	interconnected cell
$\mathbf{I_{mp}}$	maximum power current
$\mathbf{I_{op}}$	current at operational voltage
IRR	infrared reflector
$\mathbf{I_{sc}}$	short-circuit current
IVG	inverted voltage gradient
LEO	low Earth orbit
LVDT	linear voltage displacement transducer
MLAR	multi-layer anti-reflection coating
NCR	nonconformance report
NRB	nonconformance review board
OSTC	on station thermal cycling
PCDU	power control and distribution unit
PID	process identification document
$\mathbf{P_{max}}$	maximum power
PMCF	product manufacturing and control file
PMP	parts, materials and processes
PTH	power transfer harness
PVA	photovoltaic assemblies
r.m.s.	root mean square
RAMS	reliability, availability, maintainability and safety
RML	recovered mass loss
S.C.	solar constant
S.C. (AM0)	solar constant at air mass 0
SCA	solar cell assembly
SCD	source control drawing
SLAR	single layer anti-reflection coating
SWS	secondary working standard
TAT	type approval test
TML	total mass loss
UVR	ultraviolet reflector
$\mathbf{V_{mp}}$	maximum power voltage
$\mathbf{V_{oc}}$	open-circuit voltage
$\mathbf{V_{op}}$	operational voltage
$\mathbf{V_{test}}$	test voltage
WM0	world radiation centre standard solar spectrum at air mass 0 conditions

4 Overview

4.1 Objective and organization

The objectives of this Standard are:

- To define the rules for the flow of technical requirements from a project solar array specification down to component level in order to guarantee that lower level components and sub-assemblies are qualified according to specifications.
- To define the set of requirements from component level up to photovoltaic assemblies (PVA) to enable a generic qualification for each level of assembly for about 90 % of the solar array applications within a certain range; for example, deployable solar arrays for GEO or LEO.

This subclause describes the organization of the requirements and how they are applied.

The philosophy behind this Standard is that the qualification of a specific level of assembly is based on the use of qualified components and sub-assemblies at lower levels. The specification hierarchy that photovoltaic assemblies and their components form part of is illustrated in Figure 1.

This Standard defines the requirements for qualification at each level from components up to and including PVA on coupons. Coupons are built according to PVA specification with the objective of demonstrating that the design and manufacturing processes are ready for use on a flight application.

Full qualification for an application is only achieved after successful qualification of the PVA and its components in the solar array configuration, comprising amongst others final configuration sine vibration testing, acoustic noise testing, thermal cycling and wing deployment testing.

NOTE This Standard does not cover the concentration technology, and specially the requirements related to the optical components of a concentrator (e.g. reflector and lens) and their verification (e.g. collimated light source).

Project requirements are introduced via the source control drawing (SCD). This is the reference list for physical characteristics, performance requirements and environmental conditions.

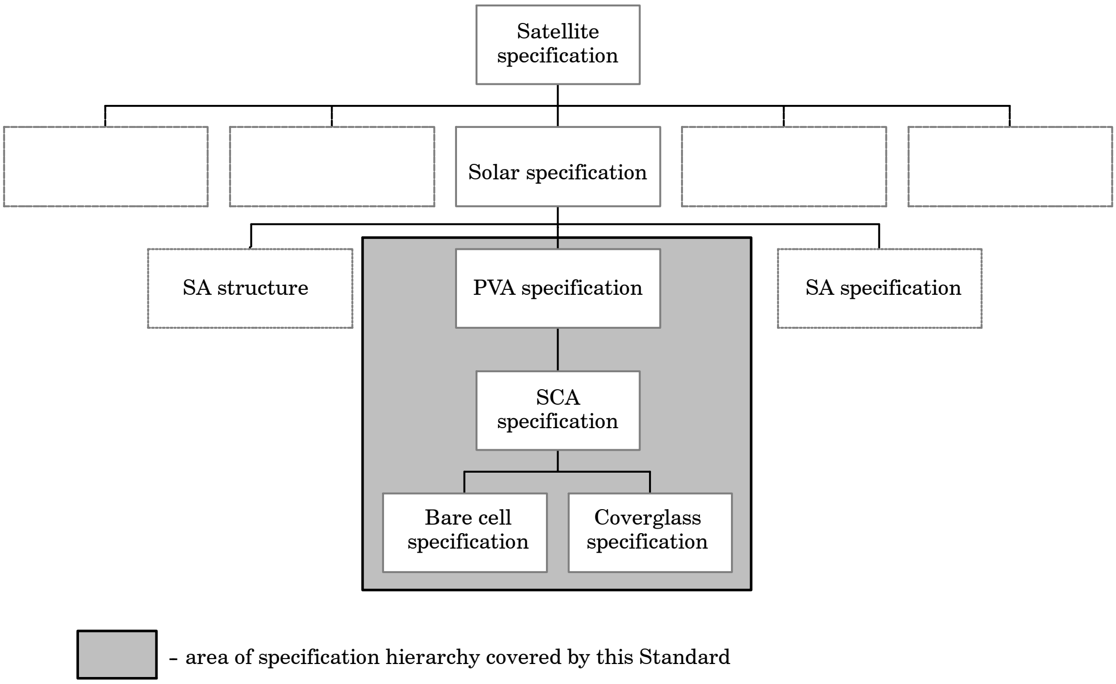

Figure 1: Specification hierarchy

4.2 Interfaces with other areas

In the specification hierarchy (Figure 1) only the components and assembly levels that are usually dedicated to solar arrays are shown. At every integration step, additional materials and components, not mentioned in the specification hierarchy, are used such as:

- adhesives,
- solder,
- interconnectors and busbars,
- diodes,
- resistors,
- thermistors,
- connectors, and
- wires.

Requirements for these materials and components can be found in their procurement specifications, and in EEE component specifications, which are reviewed as part of the qualification process.

NOTE For EEE component specifications, see the ECSS-Q-60 series of standards.

The qualification of the use of these items is a pre-requisite for the qualification of the assembly they are part of (for example, coverglass adhesive at the SCA level and busbars at the PVA coupon level).

Solar array design, power subsystem interface and mission specific related topics such as grounding, electromagnetic compatibility, magnetic moment, spacecraft related geometrical loss factors and end-of-life performance prediction related topics, including loss factors, are not addressed in this Standard.

Specific design measures to support the solar array in order to satisfy the requirements of this Standard, such as grounding spots and blocking diodes, are however, taken into account.

Specific environmental conditions which can be a limitation in the qualification for general use, are not addressed in this Standard as these aspects are usually the subject of a project dedicated qualification (for example, the chemical contents in local ambient air).

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5
Photovoltaic assemblies

5.1 General

5.1.1 Description

The photovoltaic assembly (PVA) comprises the electrical parts to satisfy the requirements of the solar array specification.

This Clause applies to solar arrays using a planar design without concentration and based on crystalline solar cells.

NOTE In case of concentration, this Clause applies to the PVA without the optics, provided that the electrical performance tests are adapted to the light incidence and intensity imposed by the optics.

Usually, a PVA consists of parallel connected strings. A string is the smallest operational component at the PVA level. A string consists of a series interconnected solar cells connected to the spacecraft bus. These strings are supported by a solar array panel substrate or frame.

The parts comprising a PVA usually include:

- interconnected SCAs,
- bleed resistors,
- wiring,
- panel connectors,
- diodes (blocking and shunt),
- thermal sensors,
- telemetry indicator wiring, and
- grounding.

5.1.2 Purpose and objective

In this Clause the design limits, including margins, and the responsibilities for PVA manufacturing are defined and include the:

- design requirements (refer to 5.3);
- mechanical and electrical interface;
- manufacturing requirements for PVA (refer to 5.4);

- qualification requirements for PVA (refer to 5.5.1);
- acceptance requirements for PVA (refer to 5.5.2).

The values specified for the SCA level are provided by the solar assembly supplier and confirmed during the SCA qualification tests (refer to 6.4).

In order to design and verify a solar array, data for the following parameters at the SCA level or lower are used:

- characteristics of the SCA (V_{oc}, I_{sc}, V_{mp} and I_{mp});
- spectral response;
- reference calibration standard;
- relative damage coefficient and electron-proton equivalence;
- temperature coefficients as a function of radiation fluences;
- reverse characteristics versus temperature;
- UV and Sun spectrum characteristics (reflectivity);
- capacitance versus temperature;
- optical properties (hemispherical emissivity, and solar absorptance, and cover gain or loss);
- behaviour with regard to specific mission environments:
  - ATOX sensitivity,
  - thruster erosion sensitivity,
  - micro-meteoroids and debris sensitivity;
- loss factors for interconnecting the cells into a string.

5.1.3 Conditions and method of test

a. In addition to the requirements of this Standard, the conditions and methods of testing shall conform to the following:

   1. The photovoltaic assembly source control drawing (SCD-PVA).

      NOTE 1 The PVA specification consists of two parts, the generic specification (this Standard) and the SCD.

      NOTE 2 For the preparation of the SCD-PVA, refer to Annex B.

   2. The solar cell assembly source control drawing (SCD-SCA).

      NOTE For the preparation of the SCD-SCA, refer to Annex C.

b. The SCD-PVA shall be prepared by the supplier and provided to the customer for reviewing and agreement.

c. Any deviation from in-process, acceptance and qualification test procedures shall be justified in the SCD-PVA.

d. Deviations from this Standard applicable to the SCD-PVA shall:

   1. be agreed between the customer and the supplier;
   2. include alternative requirements equivalent to those of this Standard;
   3. not affect the reliability and performances of the photovoltaic assemblies;
   4. be only those specified in c.

5.2 Test and storage

5.2.1 Test environment

a. The atmospheric conditions during all inspection, test operations and storage should be as follows:

1. Pressure: (1 013,25 ± 33) hPa.
2. Temperature: (23 ± 5) °C.
3. Average relative humidity: 40 % - 60 %.
4. Airborne particle count: Class 8 ISO 14644-1.

NOTE A pressure of (1 013,25 ± 33) hPa is equivalent to (760 ± 25) mmHg.

b. All test environments for all tests shall be recorded in the end item data package (EIDP).

NOTE 1 For EIDP, refer to 5.6.

NOTE 2 Semiconductor devices (i.e. diodes) can short-circuit if no special precautions are taken during long storage periods under certain atmospheric conditions. This is because chlorine content, in combination with illumination, can produce metal contact migrations on these semiconductor devices.

5.2.2 Test tolerances and accuracies

a. The accuracy of the instruments and test equipment used to control or measure test parameters should be one order of magnitude higher than the tolerance on the variable to be measured.

NOTE Examples of where this cannot be achieved include measurements of electrical performance and temperatures.

b. All instrumentation used for qualification and acceptance tests shall:

1. be calibrated using a procedure approved by the customer, and
2. be within the specified calibration period at the time of test.

c. Instrumentation whose calibration period runs out during the planned test time shall not be used.

d. The maximum test temperature tolerances for thermal testing at fixed temperatures shall be as given in Table 1.

Table 1: Test tolerances on temperature

Temperature range (°C)	Minimum temperature (°C)	Maximum temperature (°C)
From –55 to +180	-3 / +0	-0 / +3
Below -55	-4 / +0	-0 / +4
Above +180	-4 / +0	-0 / +4

e. The tolerance for relative humidity shall be ± 10 %.

f. The accuracy of mass measurements shall be better than ±1 % or 0,01 g, whichever is higher.

g. The test condition tolerances shall be applied to the nominal test values specified.

h. The accuracy of the electrical performance test on PVA level shall be better than or equal to the calibration loss factor taken into account in the power analysis.

5.3 Photovoltaic assembly design

5.3.1 General

The objective of this Standard at the PVA level is to specify the requirements for the detailed design, performance, performance analysis, qualification, manufacture, testing, and preparation for delivery of the panel equipped with PVA. The inputs for these requirements are the mission specification, the ground test programme and the spacecraft design.

5.3.2 Parameters related to parts, materials and processes (PMP)

5.3.2.1 Outgassing

a. Flight hardware shall be constructed from space qualified materials having the following properties:

1. A recovered mass loss (RML) of 1 % or less.

   NOTE See ECSS-Q-70-02.

2. A collected volatile condensable material (CVCM) of 0,1 % or less when heated in a vacuum to 125 °C and collected at 25 °C.

b. The PMP list shall include the RML and CVCM values for all materials used.

5.3.2.2 Toxicity

a. Any material used in the construction of the PVA that is dangerous to the health of the personnel shall be identified.

b. Preventive handling measures shall be taken in accordance with a standard approved by the customer.

5.3.2.3 Flammability

Any flammable materials used in the construction of the PVA shall be identified.

5.3.2.4 Corrosion

a. The supplier and customer shall agree on the measures to be taken to prevent corrosion during storage or in normal operational service.

b. Standard atmospheric conditions may be assumed for general applications in the spacecraft, over a period of time that is agreed between the supplier and customer.

c. To avoid electrolytic corrosion, a process, approved by the customer, shall be used.

5.3.2.5 Magnetism

a. Permanent magnetic materials shall be avoided when specified by the mission.

b. Non-magnetic materials should be used.

5.3.2.6 Erosion

PVA materials shall be capable of tolerating a defined erosion level resulting from spacecraft operation (e.g. thruster plumes) without degradation in the nominal performance of the PVA, as specified in the solar array specification.

5.3.3 Network design

5.3.3.1 Cell integration

a. The solar cells shall be structured such that the PVA is capable of withstanding all phases of ground handling, transportation, qualification testing and acceptance testing, launch and orbit operations.

b. The capability for replacement of cracked, broken or damaged SCAs shall be included in the design.

c. Repair shall be feasible in horizontal and vertical panel positions.

5.3.3.2 Stringing

a. The solar cells shall be electrically interconnected such that the functional performance conforms to requirements during all phases of the mission.

b. If blocking diodes are applied in the design at the panel level, the positive end of the strings shall be connected to the panel connector by a blocking diode.

c. To enable performance measurement at the lowest level of assembly at the coupon level, strings should not be connected into sections in parallel.

d. Coupon layout shall be as defined in a overall assembly drawing as part of the SCD-PVA.

5.3.3.3 Cell interspacing

The cell interspacing shall be compatible, as a minimum, with the following mission requirements:

a. thermal expansion and contraction within the mission temperature extremes;

b. panel geometry;

c. ESD requirements;

d. network design.

5.3.3.4 Sectioning

a. Sections shall not be included at the coupon level.

b. To test the technique of interconnecting strings, the negative ends of individual strings may be connected in a way that is representative for flight panels.

5.3.3.5 Reverse bias protection

The solar cells that are potentially subject to reverse bias shall be protected by shunt diodes unless the solar cells are insensitive to the effects of reverse bias.

NOTE Types of reverse bias include:

- AOCS failure shadowing,
- self shadowing, and
- power management.

5.3.3.6 Insulation

The following items shall be electrically insulated from each other:

a. Any solar cell circuits to substrate (the grounding reference of the coupon).

b. Solar cell circuits to solar cell circuits (if not connected at the negative ends).

c. Thermal sensor to the solar cell circuits and to the substrate (the grounding reference of the coupon).

d. Conductive coverglass grounding network to solar cell circuits.

5.3.3.7 Derating

For the derating requirements of components, see ECSS-Q-60-11.

5.3.3.8 Redundancy

For redundancy requirements, see ECSS-Q-30.

For failure modes requirements, see ECSS-Q-30-02.

5.3.3.9 Fault tolerance

a. A FMECA shall be performed, including:

1. equipment, and
2. redundant parts and internally redundant units.

NOTE For FMECA, see ECSS-Q-30-02.

b. No single fault shall result in the following:

1. The loss of integrity of an internally redundant unit.
2. The propagation of the fault causing permanent damage or loss of use to another unit.

NOTE Integral redundancy is defined as "separation of the implementation of the design so that no single fault can cause the loss of both nominal and redundant functions".

c. No failure shall be propagated from one solar array wiring group to another.

5.3.3.10 Add-on mass

For the add-on mass, refer to the SCD-PVA.

5.3.3.11 Fatigue resistance

The effects of fatigue shall be taken into account in the design of the PVA.

5.3.3.12 Adherence to substrate

a. The adherence of the SCAs to the substrate shall be measured.

b. Requirements applying to adherence are as follows:

1. The SCAs shall stay attached to the panel and conform to all requirements during the test campaign and all the phases of the mission.
2. The adherence shall be such that the SCAs integrated on the substrate can be repaired, removed and replaced.
3. The thermal conductance to the substrate shall be such that the specified solar cell temperature can be maintained.

5.3.3.13 Electrostatic discharge (ESD)

a. The solar array design should be such that it can survive the charging environment and operating conditions defined by the mission.

b. Statement a. above shall be either demonstrated by analysis or by testing.

NOTE During and after launch, the spacecraft is surrounded by a low density plasma of high energy electrons and protons. On insulated surfaces of the spacecraft, the electrons build up a charge which discharges when breakdown of the insulating materials is reached.

5.3.3.14 Adhesion thickness

a. The thickness boundaries, including manufacturing and repair tolerances, shall be defined by means of analysis or test.

b. The boundary requirements on minimum and maximum thickness, as specified in a. above, shall be guaranteed by a controlled application process demonstrated on separate samples.

5.3.3.15 Atomic Oxygen (ATOX)

a. In cases where the solar array is exposed to an ATOX environment, the general performance of the PVA shall not degrade below the value stated in the SCD-PVA.

b. The ATOX resistivity shall be determined by analysis or test.

5.3.3.16 Electromagnetic compatibility (EMC)

The PVA shall be designed to meet the specific EMC requirements stated in the SCD-PVA.

5.3.3.17 Reparability

The capability of repairing, removing and replacing items down to component level (such as single SCAs, diodes, thermal sensors, wires and connectors) shall be provided.

5.4 PVA manufacturing

5.4.1 Process validation

The manufacturing and integration processes shall be validated taking into consideration the project specific design configurations and engineering design requirements.

5.4.2 Defect acceptability

The acceptability of defects at the PVA level shall be:

a. agreed with the customer;

b. defined in a production control document;

c. validated by qualification testing.

5.4.3 In-process testing

5.4.3.1 General

The in-process tests are performed during the manufacturing of the PVA to detect deviations and defects as early as possible. This subclause 5.4.3 lists the test to be performed during the manufacturing of the PVA.

5.4.3.2 Mass measurement

To determine the add-on mass of the PVA, the mass of the coupon substrate shall be measured before the coupon is equipped with the PVA parts and be in accordance with SCD-PVA.

5.4.3.3 Wet insulation test

a. A wet insulation test shall be performed by the supplier to prove the integrity of the bare coupon insulation layer, as follows:

   1. Apply a voltage which corresponds to the breakthrough value for short term exposure of the applied insulation material (E_{spec} V/µm) times the minimum guaranteed thickness.

   EXAMPLE For E_{spec}= 20 V/µm and a (50 ± 10) µm insulation layer, a test voltage of 800 V applies.

2. For the wet insulation test, use ethyl, isopropyl alcohol, or otherwise an equivalent fluid agreed with the customer, as contact fluid during the measurements.
3. Perform the test after verification of the continuity of coupon substrate.

b. The acceptance criteria shall be an insulation larger than 100 MΩ.

c. In case of a failure, a standard repair shall be performed.

d. No more than the maximum number of repairs stated in the SCD-PVA shall be performed in the same coupon.

5.4.3.4 Adherence to substrate

The adherence of the SCAs to the substrate shall be verified on separate samples with representative mechanical cells by means of a pull test or a lapshear test and shall conform to the minimum value of the flatwise tensile strength given in the SCD-PVA.

5.4.3.5 Visual inspection

a. A visual inspection shall be made after stringing.

NOTE This is to determine, as early as possible, defects in the rear sides of solar cells and, when feasible, the front sides.

b. The visual inspection procedure and criteria shall be agreed with the customer and be described in the SCD-PVA.

5.4.3.6 Continuity check

a. The continuity of all strings shall be checked after stringing, in order to detect defects not detected during the visual inspection.

b. Continuity of harness, wires and diodes shall be checked, and measured after final assembly.

c. The maximum values of resistance shall be given in the SCD-PVA.

5.4.4 Identification

For requirements on the identification and traceability of parts and materials, see 6.1.8, 7.1.3 and 8.2.3 for SCAs, bare cells and coverglass, respectively. For other components see ECSS-Q-60.

5.4.5 Recording

All processes and process variables related to PVA manufacturing shall be recorded during manufacturing.

5.5 PVA tests

5.5.1 Qualification tests

5.5.1.1 Purpose

Qualification tests are performed to check and qualify the design requirements.

5.5.1.2 Process

a. All qualification tests shall be in accordance with 5.1.3.

b. Qualification tests shall be preceded by the acceptance tests as listed in 5.5.2, in order to be representative of the life of flight hardware.

c. All results of the qualification test shall be reported in a qualification test report.

d. Qualification margins shall not exceed component and material specifications unless agreed between supplier and customer

e. The following environmental test shall be performed for qualification of PVAs on solar panels:
   1. Fatigue thermal cycling test on a dedicated thermal cycling coupon.
   2. Humidity tests on one of the following:
      (a) the coupons dedicated to the fatigue thermal cycling test, or
      (b) the coupon dedicated to the humidity test.
   3. UV test or equivalent test on a dedicated UV coupon.
   4. Four-point bending test on a dedicated mechanical test coupon.

f. In cases where the same coupon is used for the fatigue thermal cycling test and the humidity test, as specified in e.2.(a) the humidity test sequence shall precede the fatigue thermal cycling test sequence.

g. The following environmental tests should be performed for qualification of PVAs on solar panels:
   1. ESD test on a dedicated ESD coupon;
   2. ATOX on material and dedicated coupons;
   3. erosion on materials, due to thruster plume.

h. If g. is not satisfied, a justification shall be provided.

i. Except as specified in f., each type of test shall be performed on a dedicated qualification coupon built specifically for the test.

j. The qualification coupon need not be the same size as the flight panels, but shall contain a representative number of components to enable reliable verification of flight panel processes and materials.

k. The processes used to build the qualification coupon shall be documented in a parts, materials and process (PMP) list to ensure that the flight panels are built with identical processes, materials and configurations.

l. Each qualification coupon shall be flight representative.

   NOTE The tests to be performed for each qualification are listed in Table 2 and described in subclauses 5.5.2 and 5.5.3.

Table 2: Qualification test plan for PVA

Check	Fatigue thermal cycling	Humidity test	UV test	Four-point bending test	ESD test	ATOX
Full visual inspection (5.5.3.2)	1, 6, 9, 14	1, 5	1, 9	1, 5,8	1, 4	1, 5
Electrical health check and performance (5.5.3.3 and 5.5.3.4)	2, 7, 10, 15	2, 6	2, 6	2, 6,9	2, 5	2, 6
Capacitance (5.5.3.5)	3, (11), 16					
X-ray photo (5.5.3.10)	4, (12), 17					
Reflectance (5.5.3.8)		3, 7	3, 7			3, 7
Glass transmission (5.5.3.9)			4, 8			
Thermal vacuum cycling (5.5.3.12)	5, 13					
Substrate integrity (5.5.3.11)	18					
Fatigue thermal cycling (5.5.1.3)	8					
Humidity (5.5.1.4)		4				
UV exposure (5.5.1.5)			5			
Four-point bending (5.5.1.6)				4,7		
ESD test (5.5.1.7)					3	
ATOX (5.5.1.8)						4
Thermal cycling (5.5.1.6.4.e.3.)				3		
NOTE The numbers in each column indicate the sequence in which the checks are performed for each test.						

5.5.1.3 Fatigue thermal cycling test

5.5.1.3.1 Purpose

The purpose of the thermal cycling test is to demonstrate the life fatigue compatibility of all components and processes in an assembly.

5.5.1.3.2 General

a. The test conditions, specifically the thermal gradients through the stack thickness, shall be representative of the distribution predicted in space so that the components are not over-stressed or under-stressed beyond specified limits.

b. The temperature extremes of the thermal cycling shall be extended or a dedicated structural test shall be performed in cases where analysis demonstrates that the structural loading results in a greater stress than the thermal cycling.

5.5.1.3.3 Qualification coupon

The following requirements apply to the qualification coupon:

a. The coupon shall be defined by means of a representative drawing, document or matrix in the SCD-PVA.

b. Critical areas of the solar array shall be included on the qualification coupon.

EXAMPLE The substrate represents a worst-case stress part of the flight panels.

c. The qualification coupon shall be manufactured using the same qualified materials and processes as the flight panel, and any deviation shall be identified by the PVA supplier.

d. The qualification coupon shall contain only one PVA technology.

e. The number of (non-cell) components shall correspond to the number in a flight configuration of the unit they belong to (for example, blocking diodes: one per string, shunt diodes: one per shunt interval, bleed resistors: 2 per panel), but with a minimum of two.

f. If space is available, additional components may be included to be tested as separate items.

g. For every type of solar cell configuration (N-end tab, P-end tab or middle cell) one piece shall be repaired on the coupon after the acceptance test (only visual inspection and electrical health check), unless configurations are identical, in which case at least two cells shall be repaired.

h. The production of the test coupons shall be representative of the full processing of the flight hardware.

i. At least at two locations, two thermocouples per location shall be placed on each qualification coupon for temperature monitoring.

j. The coupon subjected to the fatigue thermal cycling test need not follow the acceptance test sequence.

k. Dedicated electrical test points shall be included in the electrical design of the PVA coupon such that the capacitance of single strings can be measured.

5.5.1.3.4 Test

a. The number of cycles and temperature deltas may be determined using one of the following criteria:

   1. The number of cycles is four times the number of cycles that occur during the mission with 0 °C temperature delta (upper-lower design temperature limit).

   2. The number of cycles is equal to 1,5 times the number of cycles occurring during the mission with a temperature delta of 10 °C at both extremes (upper-lower qualification temperature limit).

b. For GEO and LEO applications, the following cycling profiles are used:

   1. For a GEO mission, all the fatigue cycles shall be identical.

   2. For a LEO mission:

      (a) A temperature profile shall be used which envelopes the variation of temperature extremes during the mission.

      (b) The total profile should be divided into a number of equally shaped sub-profiles, where the number of sub-profiles are:

         * equal to the number of years of the mission, and

         * with extreme cycle temperatures derived from the slicing of the temperature profile of the hole mission.

c. The number of cycles and temperature limits of a. and b. above shall be stated in the SCD-PVA.

d. Monitoring of the insulation between the solar cell circuit and the substrate shall:

   1. be performed in accordance with 5.5.3.3.3, and

   2. take place during the cycles with the maximum temperature limits and for a minimum of two cycles.

e. Monitoring of the continuity of the solar cell circuits shall:
   1. be performed in accordance with 5.5.3.3.2, and
   2. take place during cycles with the maximum temperature limits and for a minimum of two cycles.

f. Insulation and continuity shall not be measured simultaneously.

g. For multi-junction components, during the hot cycles, the coupon shall either be illuminated at AM0 under load, or dark forward biased, in order to verify the stability of the components during the mission.

5.5.1.3.5 Pass-fail criteria

a. On completion the test,
   1. there shall be electrical continuity (no open circuit), and
   2. the power output of the test coupon and the insulation shall be within the limits stated in the SCD-PVA.

   NOTE The power output loss is the same as the thermal cycling loss factor taking into account the power output analysis.

b. Pre-test and post-test measurements of a. shall be made with the same test set-up (as this is a comparison measurement).

5.5.1.4 Humidity

5.5.1.4.1 Purpose

The purpose of the humidity test is to demonstrate the endurance of assembled PVA components in a real-life environment against standard environmental conditions using accelerated tests.

5.5.1.4.2 General

If there are requirements on specific environmental conditions, such as chemical vapours, they shall be stated in the SCD-PVA.

5.5.1.4.3 Coupon

a. The coupon shall be manufactured using the same qualified materials and processes as the flight panels.

b. The production of the test coupons shall be representative of the full processing of the flight hardware.

5.5.1.4.4 Test

a. The coupon shall be exposed to a humidity of (90 ± 5) % at (60 ± 5) °C over a period of 30 days.

b. In the case of solar cells with aluminium content window layers, the test specified in a. shall be extended to simulate on-ground expected duration and humidity and temperature conditions.

5.5.1.4.5 Pass-fail criteria

a. On completion of the test, the power output of the test coupon shall not have degraded more than the limit given in the SCD-PVA.

b. Pre-test and post-test measurements of a. shall be made with the same test set-up (as this is a comparison measurement).

5.5.1.5 UV test

5.5.1.5.1 Purpose

The purpose of the UV test is to demonstrate the resistivity of the PVA components and assemblies in their application (i.e. including PVA manufacturing processes) against the UV environment.

5.5.1.5.2 General

The UV test need not be performed if analysis demonstrates that the PVA components, materials and processes are not affected by the UV environment.

5.5.1.5.3 Coupon

a. The UV coupon shall be manufactured using the same qualified materials and processes as the flight panels.

b. The number of solar cells shall be eight or more.

c. The production of the test coupons shall be representative of the full processing of the flight hardware.

d. Provisions shall be made such that the the performance of solar cells can be individually characterized.

5.5.1.5.4 Test

a. The integrated intensity of the photons shall be measured with a Sun-blind photo-diode.

b. For photons with a wavelength between 200 nm to 400 nm the integrated intensity at the end of test shall be as follows:

   1. equal to (100 - 150) Sun-hours or 1 % of the mission life, whichever is the longer period;

   2. have a UV irradiation acceleration factor of less than 10 Suns as stated in the SCD-PVA.

c. The test shall be performed in a vacuum (i.e. pressure less than 10^{-3} Pa).

d. The temperature of the UV coupon shall be the nominal operational temperature ±5 °C (refer to SCD-PVA).

e. Control samples should be included the UV chamber in order to identify potential contaminations occurring during the test.

5.5.1.5.5 Pass-fail criteria

The coupon shall not significantly degrade more than 60 % of the UV loss factor taken into account for the EOL power analysis.

5.5.1.6 Four-point bending test

5.5.1.6.1 Purpose

The purpose of this test is to demonstrate that mechanical and tension stress do not exceed the limits specified for the thermal conditions corresponding to the design dimensioning case.

5.5.1.6.2 General

a. The four-point bending test may be used as a substitute for quasi-static shock tests at the panel and wing assembly level.

b. The maximum bending to be tested shall be calculated with an algorithm or equivalent finite element method analysis technique to be stated in the SCD-PVA.

   NOTE Maximum bending, during a mission, occurs in the following environments:

- launch,
- handling, and
- attitude control system movement.

5.5.1.6.3 Coupon

a. The four-point bending test coupon shall be manufactured using the same qualified materials and processes as the flight panels.

b. The production of the test coupons shall be representative of the full processing of the flight hardware.

c. The test coupon substrates shall represent the worst-case bending load parts of the flight panels.

5.5.1.6.4 Test

a. The instrumentation shall consist of one of the following:

   1. a number of strain gauges (e.g.10) bonded on the rear side or deflection measurement gauges;

   2. a deflection measurement device with a standard LVDT technique or the equivalent, to measure critical deflection versus bending.

b. The following provisions apply to the laboratory conditions:

   1. Crushing of the core substrate should be avoided.

   2. The test set-up shall be configured to eliminate any local momentum at the load application point or reaction supports.

   EXAMPLE The load can be transferred via vertical edge members and applied to the coupon via cylindrical rods.

c. The test shall simulate the equivalent loading of three sigma (r.m.s.) of acoustic qualification levels or the maximum bending due to worst-case handling and gravity.

d. The four-point bending test shall be performed at either maximum hot or maximum cold temperature, whichever is the design dimensioning case.

e. The tests shall be carried out in the following sequence:

   1. visual inspection;

   2. electrical performances;

   3. 10 vacuum thermal cycles (same test conditions as the fatigue thermal cycling for the qualification of the PVA coupon, see 5.5.1.3.3);

   4. 4-point bending test (compression: cell on top);

   5. visual inspection;

   6. electrical performance;

   7. four-point bending test (tension test);

   8. visual inspection;

   9. electrical performance.

f. The tests shall be carried out three times for residual hysteresis characterization, if any.

g. The tests may be repeated step-wise up to failure, for margin verification.

5.5.1.6.5 Pass-fail criteria

a. There shall be no evolution of cracks in the cell or coverglass.

b. The power output of the test coupon shall not degrade more than the value given in the SCD-PVA.

c. Pre-test and post-test measurements of a. and b. shall be done with the same test set-up (as this is a comparison measurement).

5.5.1.7 Electrostatic discharge (ESD) test

5.5.1.7.1 Purpose

The purpose of the ESD test is to demonstrate that the use of adequate design rules reduces the risk of ESD. This is done by demonstrating that ESD primary discharge does not lead to a self-sustained secondary arc, which can lead to loss of permanent power or insulation in the solar array.

The tests are performed on solar array coupons using instrumentation specially designed for that purpose.

The design rules and the test procedure are described in ECSS-E-20-06.

5.5.1.7.2 General

a. For LEO, it shall be verified that no discharge or leakage current is expected when the solar array is surrounded by a cold and dense plasma with an active potential equal to the bus voltage versus plasma potential.

b. It shall be verified that primary electrostatic discharges occur in direct voltage gradient (DVG) mode, using a passive coupon in representative flight configuration (in terms of temperature and irradiation) and having a representative irradiation energy ranging from 0 to the energy at which the electrons pass through the coupon.

   NOTE The direct voltage gradient (with negatively biased coverglasses) occurs when the solar array is not illuminated and is cold, i.e. in eclipse. In this situation it seems that secondary arcs are not self-sustaining.

c. It shall be verified that primary electrostatic discharges occur in inverted voltage gradient (IVG) mode.

d. The coupon shall be qualified for the expected electrical conditions during the mission and the primary discharges shall be characterized (voltage, current and time).

e. The coupon shall be qualified for the expected electrical conditions during the mission and the secondary arc shall be characterized (voltage, current and time, with respect to the absolute satellite capacitance and other parameters).

f. Visual inspection shall be performed to

   1. detect defects,
   2. assess the defects against survival of the PVA in orbit, and
   3. assess the cumulative effects of the defects against the survival of the PVA during its lifetime.

5.5.1.7.3 Coupon

a. The coupon shall be manufactured using the same qualified materials and processes as the flight panels.

b. The production of the test coupons shall be representative of the full processing of the flight hardware.

c. For the architecture the following provisions apply:

   1. two strings of at least two cells in series, bonded head to tail shall be used;
   2. the ends of each string may be connected separately at the connector;
   3. the gap between adjacent strings shall be equal to the minimum manufacturing gap on flight panels.

5.5.1.7.4 Test

a. The test coupon shall be loaded with a representative load that simulates the transient load variation during a flight, which shall be stated in the SCD-PVA.

b. The inverted voltage gradient may be obtained using a plasma or electron gun in a chamber.

5.5.1.7.5 Pass-fail criteria

a. The power output of the test coupon shall not have degraded more than the value given in the SCD-PVA.

b. Pre-test and post-test measurements of a. shall be done with the same test set-up (as this is a comparison measurement).

c. The electrical continuity acceptance criteria (as defined in 5.5.3.3.2) shall be met.

d. The electrical insulation acceptance criteria (as defined in 5.5.3.3.3) shall be met.

5.5.1.8 Atomic oxygen (ATOX)

5.5.1.8.1 Purpose

The purpose of the ATOX test is to demonstrate the resistivity of the PVA, in its application, against the ATOX environment.

5.5.1.8.2 General

Analysis and flight history may be used as a substitute for ATOX testing.

5.5.1.8.3 Coupon

a. The coupon shall be manufactured using the same qualified materials and processes as the flight panels.

b. The production of the test coupons shall be representative of the full processing of the flight hardware.

c. The ATOX critical areas of the solar array shall be included on the test coupon.

5.5.1.8.4 Test

The coupon shall be exposed to an ATOX environment with a margin of 1,5.

5.5.1.8.5 Pass-fail criteria

If layers are included in the design to erode under ATOX, the remaining thickness shall ensure that the requirements on the maximum erosion as stated in the SCD-PVA (that assure the survival in all environments) are satisfied.

5.5.1.9 Erosion of materials

The test sequence, test definitions and requirements for the tests for erosion of material shall be agreed between the supplier and the customer and stated in the SCD-PVA.

5.5.1.10 EMC

The test sequence, test definitions and requirements related to the EMC of the PVA shall be agreed between the supplier and the customer and given in the SCD-PVA.

5.5.2 Acceptance tests for coupons

5.5.2.1 Purpose

The acceptance tests are performed to check the workmanship of the supplier.

5.5.2.2 Applicability

Acceptance test are applicable to completed and qualified hardware, except if the acceptance tests are part of the qualification process.

5.5.2.3 Deliverables

The deliverable documentation shall be agreed with the customer.

NOTE The acceptance is dependant on this test and the documentation delivered.

5.5.2.4 Process

a. All acceptance tests shall be in accordance with 5.1.3.

b. All results of the acceptance test shall be reported in the end item data package (EIDP).

c. The standard sequence of acceptance tests for PVA shall be as presented in Table 3.

d. The bake-out test shall be performed as part of the coupon acceptance test sequence only in the cases where the bake-out is included in the manufacturing process or in the acceptance test of the flight panels.

Table 3: Acceptance test plan

Sequence number	Test
Add-on mass (5.5.3.1)	0
Full visual inspection (5.5.3.2)	1, 6, 10
Electrical health check (5.5.3.3)	2, 7, 11
Capacitance (5.5.3.5)	3, 13
Electrical performance (5.5.3.4)	4, 8,12
Bake-out (5.5.3.6)	5
Thermal cycling (5.5.3.7)	9
NOTE See 5.5.2.4.d.	

5.5.3 Definition of tests and checks

5.5.3.1 Add-on mass measurement

a. The mass of the panel shall be measured after the coupon is equipped with the PVA parts and the harness, and the add-on mass deduced.

b. The add-on mass of both the PVA and the harness shall be in accordance with the value given the SCD-PVA.

5.5.3.2 Full visual inspection

a. To detect imperfections in the completed hardware, a visual inspection shall be performed as follows:

1. Visually examine each component for workmanship, identification and finish.

2. Examine the deliverable items for conformance to general assembly drawings, with respect to critical dimensional parameters.

   NOTE The inspection methods to be used include:

- infrared inspection (optional);
- inspection with the naked eye;
- inspection using microscopes;
- any equivalent methods.

b. The visual inspection shall be performed by ad hoc trained personnel.

c. The solar cell and PVA suppliers shall jointly define the inspection criteria for solar cells on substrates, to be agreed by the customer, and included in the SCD-PVA.

d. The minimum visual inspection requirements shall conform to Annex G.

5.5.3.3 Electrical health check

5.5.3.3.1 Purpose

All tests specified in this subclause are part of the electrical health check. The purpose of the electrical health check together with the electrical performance measurement is to detect faults in the electrical functions of the electrically active parts of the PVA.

5.5.3.3.2 Electrical continuity check

All electrical circuits of the PVA shall be checked to ensure electrical continuity, and the test conditions shall be stated in the SCD-PVA.

5.5.3.3.3 Insulation resistance

a. An insulation test shall be performed at the voltage stated in the SCD-PVA to measure the insulation between the following:

1. the structure ground or substrate (-) and the solar cell circuits (+) including soldering and wiring;
2. adjacent solar cell strings if not parallel connected;
3. the thermal sensor (+) and the substrate (-);
4. the thermal sensor (+) and cell strings (-);
5. the cover glass network (-) to cell strings (+) if the coverglass network is grounded;
6. the cover glass network (+) to cell strings (-) if the coverglass network is grounded.

b. The insulation shall be in accordance with that stated in the SCD-PVA.

5.5.3.3.4 Grounding resistance test

a. All resistance at grounding spots shall be measured.

b. The grounding resistance shall be the value stated in the SCD-PVA.

5.5.3.3.5 Bleed resistor test

a. The resistance of the bleed resistor shall measured.

b. The resistance shall be the value stated in the SCD-PVA.

5.5.3.3.6 Blocking diode test

a. The reverse current of the blocking diode shall be measured of at a voltage at least twice the operational voltage of a string (usually 150 V).

b. The reverse current measured shall be negligible with respect to the string current (usually less than 5 μA).

c. The forward voltage drop of the blocking diode shall be measured with the string at maximum I_{sc} current.

d. Test conditions and requirements shall be stated in the SCD-PVA.

5.5.3.3.7 Shunt diode test

When all the cells are protected by shunt diodes:

a. The forward voltage of shunt diodes shall be measured by reverse mode measurement of the interconnected string at the maximum operating current and the measured voltage shall be equal to the sum of the individual diode forward voltages at the maximum current.

b. The supplier shall provide the test method and precautions to be taken.

c. During the test, the temperature increase of the shunt diode shall be uniform and shall not exceed the value stated in the SCD-PVA.

NOTE If the measured voltage is less than the sum of the individual diode forward voltages at the maximum current, techniques such as thermographic photo recordings may be used to locate the failed shunt diodes.

5.5.3.3.8 Thermal sensor test

a. The thermal sensor resistance shall be measured at room temperature.

b. The thermal sensor resistance shall be the value stated in the SCD PVA.

5.5.3.3.9 Resistance measurement

a. The resistance of the harness shall be measured at the interface connector by measuring the redundant coupon wiring in series (i.e. positive end to positive end and negative end to negative end).

b. Test conditions and requirements shall be described in the SCD-PVA.

5.5.3.4 Electrical performance measurement

5.5.3.4.1 Purpose

The power output is measured in order to be able to detect any degradation before and after testing.

5.5.3.4.2 Process

a. The electrical power performance at the string level shall be measured at a reference temperature of 25 °C at the interface connector.

b. The performance measurement shall be made under 1 S.C. (AM0).

NOTE The characteristics of the Sun simulator are given in Annex A.

c. The results shall be in accordance with those stated in the SCD-PVA.

d. The inaccuracies in current, voltage and power shall be specified in the SCD-PVA and include:

1. spectral mismatch;
2. uniformity of the test area;
3. dynamic electrical effects of the test area;
4. inaccuracies of the temperature sensors.

e. Calibration shall be done with an agreed primary standard reference and secondary working standard (SWS) in accordance with Annex A.

5.5.3.5 Capacitance measurements

a. The capacitance should be measured by one of the methods specified in Annexes H and I.

b. The method of measuring the capacitance shall be stated in the SCD-PVA.

c. The capacitance shall be measured at string level in accordance with the method referred to in b. above.

5.5.3.6 Bake-out

a. Measures to prevent outgassing, to be taken before exposure to vacuum conditions, shall be agreed with the customer.

b. If a vacuum bake-out at the panel level is specified in the solar array specification, a vacuum bake-out shall be performed on the PVA before thermal cycling at coupon level.

c. The vacuum bake-out conditions shall be the combination of time and temperature that corresponds to at least 90 % of the outgassing of the cell adhesives (according to the adhesives datasheets) and they shall be those stated in the SCD-PVA.

d. Acceptance criteria shall be as follows:

   1. The increment of I_{OP}, as a percentage of the nominal value, shall be less than the value stated in the SCD-PVA.

   2. At the end of the test, there shall be less than a 2 % increase in cracked cells or one cracked cell, whichever is higher, not cumulative with the results of the thermal cycling test.

5.5.3.7 Thermal cycling acceptance test

5.5.3.7.1 Purpose

The thermal cycle acceptance tests assess the reliability of the PVA under stress and verify the workmanship of the supplier. In this way infant mortality stresses are identified and these parts can be replaced.

5.5.3.7.2 General

a. Thermal vacuum cycling should be used.

b. Gaseous cycling tests may be used if the supplier can demonstrate the equivalence of the test method.

c. The temperature extremes of the thermal cycling shall be extended or a dedicated structural test shall be performed in cases where analysis demonstrates that the structural loading results in a greater stress than the thermal cycling.

5.5.3.7.3 Process

a. The panels shall be exposed to the number of thermal cycles for acceptance as stated in the SCD-PVA.

b. The number of cycles specified in a. above should be between 4 and 10.

c. The temperature profile shall be the worst-case nominal temperature profile with a 5 °C margin.

d. During thermal cycling, the electrical insulation shall be measured.

e. During thermal cycling, the continuity shall be measured at least during the last cycle.

f. Acceptance criteria shall be:

   1. A maximum increment of I_{OP}, and a minimum isolation, as stated in the SCD-PVA.

   2. The existence of electrical continuity (no open circuit).

   3. At the end of the test, there shall be less than a 2 % increase in cracked cells or one cracked cell, whichever is higher, not cumulative with the results of the bake-out test.

5.5.3.8 Reflectance

a. The reflectance of the solar cell surface shall be measured before and after the UV test to determine the possible degradation of the coverglass coatings.

b. The reflectance shall be measured over a range from 280 nm to 2 500 nm.

c. The reflectance shall not change during testing more than as stated in the SCD-PVA.

5.5.3.9 Transmission

a. The transmission of the control glasses shall be measured to prove that the sample was not contaminated during the test.

b. The transmission shall be measured over a range from 280 nm to 2 500 nm.

c. If evidence of contamination is detected by infrared spectroscopy or a similar technique,

   1. a NCR shall be produced, and
   2. it shall be analysed in order to assess the validity of the test.

   NOTE For NCR, see ECSS-Q-20-09.

d. The acceptance criteria shall be stated in the SCD-PVA.

5.5.3.10 X-Ray

a. X-ray photographs shall be taken of all busbars, wire collection strips and diode boards.

b. The acceptance criteria shall be stated in the SCD-PVA.

   NOTE Defects that cannot be detected by means of visual inspections (e.g. internal structural deformations or alterations in busbars and wire connections) can be traced by X-ray photographs. In the case of a failure, X-ray photos can supply the information to analyse the failure. There are no pass-fail criteria established.

5.5.3.11 Substrate integrity

5.5.3.11.1 Process

a. The effect of the PVA on the structural integrity of the substrate shall be inspected after thermal cycling.

b. A non-destructive test method should be used for the inspection specified in a.

c. If b. above cannot be satisfied, a destructive test shall be applied.

d. The test method shall be described in the SCD-PVA.

5.5.3.11.2 Pass-fail criteria

The pass-fail criteria shall be those stated in the SCD-PVA.

5.5.3.12 Vacuum thermal cycling

5.5.3.12.1 Purpose

Vacuum thermal cycling is performed in order to verify the integrity of components, assemblies and interfaces in a vacuum environment and to detect the outgassing materials.

5.5.3.12.2 Process

a. The PVA coupon shall be exposed to vacuum thermal cycling.

b. The coupon shall be exposed to 10 vacuum thermal cycles before the fatigue thermal cycling and to 10 vacuum thermal cycles after it.

c. The pressure shall be lower than 2×10^{-3} Pa.

d. The temperature profile shall be the worst-case nominal temperature profile with a 10 °C margin.

e. During vacuum thermal cycling the electrical continuity of the strings shall be recorded.

f. Electrical continuity of other components, for example, diodes, thermal sensor and resistance, should also be recorded.

g. The insulation resistance of the strings against the substrate should be recorded for a minimum of 2 cycles, without performing electrical continuity.

5.5.3.12.3 Pass-fail criteria

a. The PVA coupon electrical performance and insulation resistance shall not degrade more than as stated in the SCD-PVA.

b. No open circuit conditions shall be recorded during continuity testing.

c. There shall be less than a 2 % increase in cracked cells or one cracked cell, whichever is higher, not cumulative with the results of the fatigue thermal cycling test.

5.6 End item data package (EIDP)

The EIDP of coupons for the delivery review board (DRB) shall include, as a minimum, the following items:

a. table of contents;

b. certificate of conformance;

c. shipping documents;

d. configuration item data list (CIDL);

e. product manufacturing and control file (PMCF);

f. parts, materials and processes (PMP) list;

g. list of requests for deviations;

h. list of requests for concessions;

i. list of nonconformances, including copies of nonconformance reports (NCRs);

j. history record;

k. connector mate or de-mate record;

l. serialized components list;

m. in-process inspection test results, including positioning in the manufacturing flow chart;

n. open work or open test;

o. replacement or temporary installation record;

p. acceptance or qualification test procedure and results;

q. assembly drawings and circuit diagram;

r. notes and comments;

s. operation and maintenance manuals and user restrictions;

t. minutes of delivery review board (DRB) meetings;

u. lower level acceptance data packages (ADPs).

5.7 Failure definition

5.7.1 Failure criteria

The following shall constitute PVA failures:

a. Coupons that fail during subgroup tests for which the pass-fail criteria are inherent in the test method.

b. Coupons failing to conform to the requirements of the visual inspection as listed in the SCD-PVA.

c. Coupons that fail to conform to stress requirements as listed in the SCD-PVA.

d. Coupons that, when subjected to electrical performance measurements after qualification tests in accordance with the SCD-PVA, fail one or more of the stated limits.

5.7.2 Failed coupons

a. A coupon shall be considered as failed if it exhibits one or more of the failure modes detailed in 5.7.1.

b. Failure analysis of these coupons shall be performed by the supplier and the results provided to the customer, as part of an NRB documentation.

NOTE For NRB, see ECSS-Q-20-09.

5.8 Data documentation

5.8.1 General

a. A data documentation package shall be provided for the qualification approval records for each coupon.

b. This package shall consist of the following:

1. cover sheet or sheets;
2. final production test data;
3. qualification testing data;
4. failed coupons list and failure analysis report;
5. certificate of conformity.

c. Items listed in b. above should be grouped as sub-packages.

d. For identification purposes, each page of the data package shall include the following information:

1. coupon type;
2. manufacturer's name;
3. manufacturing coupon identification;
4. date of establishment of the document;
5. page number.

5.8.2 Coversheets

The coversheets of the data documentation package shall include, as a minimum, the following:

a. reference to the SCD-PVA, including issue and date;

b. reference to this Standard, including issue and date;

c. coupon type;

d. procurement coupon identification;

e. manufacturing coupon identification;

f. number of purchase order or contract;

g. deviations from, or additions to, the SCD-PVA and this Standard, if so specified in the order;

h. manufacturer's name and address;

i. location of the manufacturing plant;

j. signature on behalf of the manufacturer;

k. total number of pages of the data package.

5.8.3 Final production test data

A test result summary shall be compiled, showing the total number of coupons submitted to the acceptance test sequence, as specified in Table 3, and the total number rejected after it.

5.8.4 Qualification testing data

a. All data shall be linked to the manufacturing coupon numbers.

b. Data shall be provided showing a record of the total number of coupons submitted for test and the total number rejected from each of the test subgroups.

c. Detailed data shall be provided of all electrical measurements made in accordance with 5.5.3.4.

5.8.5 Failed coupon list and failure analysis

a. A failed coupon list shall be maintained up to date.

b. For each of the failures in the list specified in a., a failure analysis shall be performed.

c. The following data shall be derived from a. and b.:

   1. The reference number and description of the test or measurement as stated in this Standard or the SCD-PVA.
   2. The identification of the failed coupon.
   3. The failed parameter and the failure mode of the coupon.
   4. A detailed failure analysis report.

5.8.6 Certificate of conformity

A certificate of conformity with the PID shall be issued and submitted with each delivery.

5.9 Delivery

a. All deliverable hardware specified in the order shall be delivered together with documentation in as specified in 5.8.

b. One set of documents shall be sent to the customer.

5.10 Packaging, packing, handling and storage

For packaging, despatching, handling and storage of components delivered according to this Standard, see PSS-01-202.

6

Solar cell assemblies

6.1 General

6.1.1 Testing

Qualification testing of solar cell assemblies (SCAs) comprises acceptance and qualification tests.

Procurement testing of the qualified SCAs comprises acceptance tests and delta qualification tests as specified in 6.4.1.f.4.

6.1.2 Conditions and methods of test

a. In addition to this Standard, the conditions and methods of testing shall conform to the SCA source control drawing (SCD-SCA).

NOTE 1 The SCA specification consists of two parts, the generic specification (this Standard) and the SCD-SCA.

NOTE 2 For the preparation of the SCD-SCA, refer to Annex C.

b. The SCD-SCA shall be prepared by the supplier and provided to the customer for reviewing and agreement.

c. Any deviation from in-process, acceptance and qualification test procedures shall be justified in the SCD-SCA.

d. Deviations from this Standard applicable to the SCD-SCA shall:

1. be agreed between the customer and the supplier;
2. include alternative requirements equivalent to those of this Standard;
3. not affect the reliability and performances of the SCAs;
4. only be those specified in c.

6.1.3 Supplier's quality assurance organization

The supplier shall establish and implement a quality assurance organization.

NOTE For quality assurance see ECSS-Q-20.

6.1.4 Responsibility of suppliers for the performance of tests and inspections

a. The supplier shall ensure that the tests and inspections are performed.

b. These tests and inspections shall be performed at the manufacturer's plant or at a facility approved by the customer.

NOTE For test house requirements, see ECSS-Q-20-07.

6.1.5 Inspection access

The supplier shall provide access to monitor tests and inspections included in the test programme, in accordance with a procedure approved by the customer.

6.1.6 Additional tests

a. If additions to the specified test programme are proposed, the supplier shall provide details to the customer, including:

1. A description of the modified test methods, procedures and equipment to be used.
2. A statement specifying when, in the test sequence, these additional tests are performed.

b. The supplier shall not perform the tests referred in a. before they are approved by the customer.

6.1.7 Deliverable components

Delivered solar cell assemblies conforming to this Standard shall:

a. be produced and inspected in accordance with the requirements of the process identification document (PID) defined in 6.2, and

b. have completed all tests and inspections included in the SCD-SCA.

6.1.8 Marking

All delivered solar cell assemblies conforming to this Standard shall be permanently marked with a code to enable traceability of the cells at the level stated in the PID (see 6.2).

6.2 Production control (process identification document)

a. A process identification document (PID) for the SCA to be qualified shall be prepared by the supplier in accordance with 6.2.b.

b. The PID shall comprise copies of the definition documents of the SCA, and the manufacturing documents and testing procedures, and include the following:

1. a parts list (including materials);
2. a list of all manufacturing drawings;
3. the production flow chart;
4. the specifications for the process used;
5. procedures for the inspection performed;
6. the overall test programme (including in-process tests and acceptance tests);
7. a table of contents with reference number and issue;
8. the test matrix for acceptance tests, including requirements and failure criteria;
9. the traceability requirements.

c. When a document is company confidential or contains proprietary information, the complete document need not be included, it may be referred to by including a reference to it.

d. The supplier shall do the following:

1. maintain configuration control of all documents;
2. keep the issues of the documents effective at the date of acceptance by the customer;
3. provide the PID to the customer for review;
4. submit to the customer for review and approval any modifications or changes to documents in the PID with any quality and reliability implications.

6.3 Acceptance tests

6.3.1 General

a. Acceptance tests shall be performed on the following:

1. components for delivery;
2. components used for qualification.

b. Acceptance tests shall consist of the following:

1. visual inspection (100 %);
2. dimension and weight inspection (100 %);
3. electrical performance measurement (100 %).

c. The data documentation corresponding to the tests referred to in b. shall be delivered together with the delivered SCAs and the qualification test lot.

6.3.2 Test methods and conditions

The test methods and conditions specified in 6.4.3. shall be applied.

6.3.3 Documentation

Documentation on final production tests shall conform to 6.6.

6.4 Qualification tests

6.4.1 General

a. All SCA procurement lots shall be qualified.

b. Qualification shall be granted by the customer.

c. The qualification plan shall consist of the tests specified in Table 4.

d. The following requirements apply to the qualification plan:

1. If it is specified that preliminary data are provided for the cells before starting any electrical characterization tests, the priority of subgroups shall be given.

   EXAMPLE If it is specified to perform tests on cells from subgroups B and C (step 3) before any EP tests.

2. All cells in subgroup A shall be equipped with front interconnectors after step 3 (refer to Table 4).
3. All cells in subgroup E shall be equipped with front and rear interconnectors and covered with coverglasses after step 3 (refer to Table 4).

4. Welding parameters, the material and dimensions of the interconnectors, cementing conditions, adhesive and coverglass for the activities described in 2. and 3. above, shall be as specified in the customer-approved specification of the production process for solar panels that applies to the supplier of the SCD-SCA.
5. In subgroup B, step 14 shall be performed on a minimum of 6 SCAs.

e. The supplier shall provide details of the outcome of the qualification programme to the customer.

f. For a procurement lot of a previously qualified SCA, the qualification tests need not be repeated if the following conditions are satisfied:

1. No changes are made to the design, function or electrical or mechanical parameters of the solar cell assembly.
2. The same source control drawing is applicable.
3. No changes are made to the PID.
4. Delta qualification tests are performed to cover the requirements imposed by the new application.

g. For f.4. above, the new requirements shall be included in a new version of the SCD-SCA.

Table 4: Qualification test plan for SCA

			Bare cells (40 samples)		Solar cell assemblies (40 or 50 samples)		
Test	**Symbol**	**Method**	**A (20)**	**E (20)**	**B (20)**	**C (10) / (20)** (see 6.4.3.12.2 f.)	**D (10)**
Visual inspection	VI	6.4.3.2	1,4,8,12	1,4,8,12	1,13	1 / 1	1,9
Dimension and weight	DW	6.4.3.3			2	2 / 2	2
Electrical performance	EP	6.4.3.4	2,5,9	2,5,9	4,6,8,14	3,7 / 3,7,13	3,7,11
Temperature coefficients	TC	6.4.3.5			9	9 / 9,15	
Spectral response	SR	6.4.3.6			10	10 / 10,16	
Thermo-optical data	TO	6.4.3.7			11,15	11 / 17	
Thermal cycling	CY	6.4.3.8	7	7			
Humidity and temperature	HT	6.4.3.9					5
Coating adherence	CA	6.4.3.10					6
Interconnector adherence	IA	6.4.3.11	11	11			
Electron irradiation	EI	6.4.3.12				5 / 5,11	10
Photon irradiation and temperature annealing	PH	6.4.3.13			7	6 / 6,12	
Surface conductivity	SC	6.4.3.14					4,8,12
Cell reverse - diode characterization	DC	6.4.3.15			16	12 / 18	
Cell reverse - diode performance	DP	6.4.3.16	3,6,10	3,6,10		4,8 / 4,8,14	
Ultraviolet exposure	UV	6.4.3.17			12		
Capacitance	CP	6.4.3.18			5		
Flatness	FT	6.4.3.19			3		

NOTE 1 The numbers in the subgroup columns indicate the sequence in which the tests are performed; e.g. for subgroup A, the 1st test is VI, the 2nd test EP, the 3rd is DP, the 4th VI and so on.

NOTE 2 The reason for dividing the test samples into subgroups is to generally test for the following:
- Subgroup A: front interconnector adherence;
- Subgroup E: rear interconnector adherence;
- Subgroup B: BOL performance data and ultraviolet exposure;
- Subgroup C: EOL performance data;
- Subgroup D: surface conductivity and humidity on SCA.

NOTE 3 For additional requirements, refer to 6.4.1.d.

6.4.2 Qualification

6.4.2.1 Production and test schedule

a. Before starting production of the qualification lot, the manufacturer shall compile a production test schedule, showing by date and duration, production and test activities, including all major processing operations and key stages in the production and testing.

b. A production flow chart, process schedules and inspection procedures shall be provided.

6.4.2.2 Qualification test samples

a. The solar cell assemblies for qualification testing shall conform to the PID.

b. The supplier shall provide access to the customer to monitor the manufacture of the test samples in accordance with a procedure agreed with the customer.

c. The test samples shall be chosen statistically and at random from the first manufacturing lots of the procurement lot.

NOTE For sampling, see ISO 2859.

d. Facilities should be available to safely store the qualification lot for a minimum of 6 years (equivalent to five years in storage and one year in orbit).

6.4.2.3 Qualification testing

Qualification testing shall proceed as given in Table 4, with the following conditions:

a. The total quantity of test samples shall be a minimum of 80 SCAs (see 6.4.3.12.2.f.).

b. The qualification tests shall be divided into subgroups of tests, and the samples assigned to a subgroup shall be subjected to the tests in that subgroup in the sequence specified.

c. A failure in any subgroup shall constitute a failure in the qualification.

NOTE For a definition of failure see 6.5.

6.4.3 Test methods, conditions and measurements

6.4.3.1 Overview

The test methods, conditions and measurement requirements for the tests in Table 4 are detailed in the subclauses 6.4.3.2 to 6.4.3.19.

6.4.3.2 Visual inspection (VI)

6.4.3.2.1 Applicability

The requirements on visually observable defects defined in this subclause apply to granting qualification approval to high quality solar cell assemblies.

6.4.3.2.2 Test process

The SCA shall be visually inspected using a stereo-microscope with a magnification factor of up to 10, to verify requirements on the following:

a. defects on cell;

b. coverglass;

c. adhesive;

d. contacts;

e. interconnector.

6.4.3.2.3 Deviations

Any deviation from the visual inspection requirements on defects shall:

a. not affect performance or reliability,

b. be agreed with the customer, and

c. be justified.

6.4.3.2.4 Solar cell defects

a. The location and maximum dimensions of edge chips, corner chips and surface nicks shall be as specified in Figure 2 and Table 5.

b. The cumulative area of all defects of the types specified in a. shall not exceed 5 % of the total solar cell area.

c. Defects of the types specified in a. occurring in the contact weld area shall be prevented.

d. Cracks or fingerprints shall not be present on solar cells.

e. The maximum dimensions of hairline cracks, in mm, shall be stated in the SCD-SCA.

f. The total area of anti-reflection coating voids shall not exceed 3 % of the total active area of the cell.

6.4.3.2.5 Coverglass defects

a. The coverglasses shall be inspected to ensure 100 % coverage of the bare surface of the cells.

b. Chips and nicks may be present on coverglasses if the bare surface of the solar cell is 100 % covered.

c. Covers with dirty and contaminated surfaces shall be rejected.

d. The total area of ARC and conductive coating voids, including evaporation jig marks, shall not exceed 3 % of the area of the coverglass.

e. The coverglass shall not contain bubbles having a projected area larger than 0,02 mm^2.

f. Coverglasses shall be rejected if they contain hairline cracks with any one of the following characteristics:

   1. there is a visible separation between cracks;
   2. there are more than three per cover;
   3. meeting hairline cracks are separated by more than 2 mm at the non-meeting end.

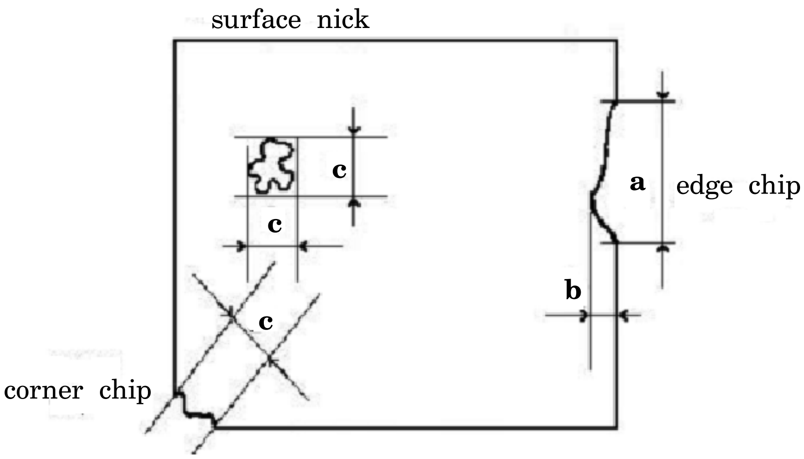

Figure 2: Definition of cell defects

Table 5: Maximum dimensions of corner chips, edge chips and surface nicks

Cell area (cm^2)	Dimensions of defects (mm)		
	a	b	c
4	4	0,7	1,5
8	6	0,8	2
12	8	0,9	2,5
25	10	1	4
32	12	1,1	5

6.4.3.2.6 Coverglass adhesive defects

a. There shall be no delamination or discolouration in the adhesive, except in the area opposite rear welds, where discolouration may be present.

b. Adhesive voids along the cover edge shall not exceed 0,6 mm in depth.

c. The maximum total projected area of additional bubbles shall not exceed 0,2 % of the cell area, discounting the following:

   1. bubbles less than 0,02 mm^2 in the projected area, and
   2. bubbles, discolourations and voids located less than 2 mm from the interconnector edges.

6.4.3.2.7 Front contact defects

a. Interruptions and delaminations in the front contact shall be prevented.

b. Over-coating (coating exceeding the area of the contact) along one side of each welding pad shall not exceed 0,1 mm.

c. The maximum total length of missing grids, short grids or non-continuous grids shall not exceed the total length of 3 grids.

6.4.3.2.8 Rear contact defects

a. For the rear side contact, outside the welding area:

   1. Drops and spatter shall not exceed 0,1 mm in diameter and 0,05 mm in height.
   2. The maximum deep of edge delaminations shall not exceed 0,75 mm.
   3. Other defects shall not exceed a total of 2 % of of the cell contact area.
   4. The maximum area of worm shaped bulges shall be stated as a percentage of total cell contact area in the SCD-SCA.
   5. The maximum length of the hypotenuse of the triangular area of visible semiconductor at the corners of the solar cell, shall be stated in the SCD-SCA.

b. In the interconnector weld area, except for the over-coating, 6.4.3.2.7.a. and 6.4.3.2.7.c. shall apply.

6.4.3.2.9 Interconnector defects

Breaking, tearing or deformation of the interconnector shall be prevented.

6.4.3.3 Dimensions and weight (DW)

a. The overall lateral dimensions of the SCA and the interconnector position shall be inspected for conformity to the dimensions and tolerances stated in the SCD-SCA.

b. The lateral dimensions of the coverglasses shall be such as to ensure 100 % coverage of the bare surface of the cells.

c. The weight of the SCA shall be verified by determining the average weight per qualification lot to ensure that this conforms to the value stated in the SCD-SCA.

6.4.3.4 Electrical performance (EP)

6.4.3.4.1 Purpose

The purpose of the EP test is to assess the corresponding electrical parameters of the SCA and to provide data for the design of the solar generator.

6.4.3.4.2 Process

a. The electrical current of SCA under 1 S.C. (AM0) shall be measured and recorded digitally at the voltages stated in the SCD-SCA, at a solar cell temperature of 25 °C or operating temperature.

b. The minimum current at test voltage (V_{test}) should be equal to the predicted operational voltage (V_{OP}).

c. The electrical parameters measured or processed from a. and identified in Figure 3 shall be recorded and supplied to the customer.

d. The accuracy of the SCA measured parameters (I_{sc}, V_{oc} and P_{max}) shall be provided to the customer.

e. During measurement, the SCAs shall be kept at a constant temperature.

f. A continuous or pulsed light source calibrated in accordance with Annex A shall be used to verify the requirements given in 6.4.3.4.3 for electrical characterization during both qualification and acceptance testing.

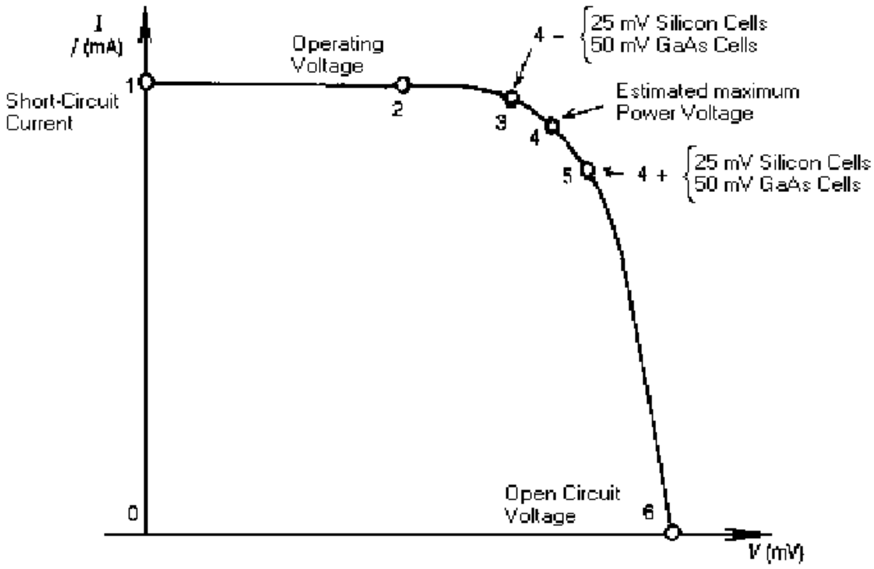

Figure 3: Test points for solar array design and modelling

6.4.3.4.3 Pass-fail criteria

a. The minimum current requirement for solar cell assemblies before and after electron radiation testing shall be stated in the SCD-SCA.

b. The maximum deviation in current measured at V_{test} between steps 5 and 9 for subgroups A and E (see Table 4) shall be 2 % for each individual cell.

c. After qualification tests, the maximum degradation of electrical performance shall be as specified in a. and b.

6.4.3.5 Temperature coefficients (TC)

a. Temperature coefficients of all samples in subgroup B and n/8 samples of subgroup C shall be measured.

b. The test described in 6.4.3.4 shall be repeated at six equidistant solar cell junction temperatures between two temperature extremes t_1 and t_2, calculated as follows, and stated in the SCD-SCA:

t_1 = highest nominal operating temperature + 25 °C

t_2 = lowest nominal operating temperature - 25 °C.

c. The temperature coefficients of short-circuit current, open-circuit voltage, voltage at maximum power and maximum power shall be derived by least-square curve fitting.

d. Data for the current at maximum power at the six solar cell junction temperatures shall be supplied to the customer.

6.4.3.6 Spectral response (SR)

6.4.3.6.1 Purpose

Spectral response data is used for the verification of the Sun simulator (see subclauses A.1.1 and A.1.2) for performance measurement error calculation, and for the characterization of the spectral response spread of production SCAs.

6.4.3.6.2 Process

a. Spectral response shall be measured on all samples of subgroup B and n/8 samples of subgroup C, by comparing the short-circuit current of the test SCAs against the output of a spectral standard of known relative spectral response under monochromatic irradiation.

b. The monochromatic irradiation shall be generated by one of the following methods:

1. With the aid of narrow-band interference filters, having the following characteristics:

   (a) for silicon solar cells, at least, at 14 discrete wavelength intervals between 0,3 μm and 1,1 μm;

   (b) for single-junction GaAs solar cells at least, at 14 discrete wavelength intervals between 0,3 μm and 1,1 μm and number of narrow band interference filters in the range 0,75 μm to 1,1 μm, as stated in the SCD-SCA.

   (c) for multi-junction GaAs solar cells, the number of narrow band interference filters and their wavelength are stated in the SCD-SCA.

2. By means of a high-intensity monochromator for continuous recording between 0,3 μm and 1,9 μm.

c. The irradiation intensity at all wavelengths shall be such as to ensure that the measurement is made in the region where the cell response short-circuit current versus irradiance is linear.

d. For multi-junction solar cells, it shall be ensured that the measurements are performed on the current limiting subcell, and that it is working under short-circuit conditions.

6.4.3.7 Thermo-optical data (TO)

6.4.3.7.1 Overview

Thermo-optical data is used for computation of the solar panel operational temperature.

6.4.3.7.2 Process

For solar absorptance and hemispherical emittance measurements, see PSS-01-709.

6.4.3.7.3 Pass-fail criteria

Pass-fail criteria for the SCAs thermo-optical properties shall be as stated in the SCD-SCA.

6.4.3.8 Thermal cycling (CY)

6.4.3.8.1 Purpose

The purpose of this test is to assess the reliability of test samples under a thermal stress equivalent to the number of eclipses that occur during one year in orbit for LEO missions, and 1 000 thermal cycles for GEO missions.

6.4.3.8.2 Process

The number of cycles and the extreme temperatures shall be as stated in the SCD-SCA.

6.4.3.9 Humidity and temperature (HT)

6.4.3.9.1 Purpose

This test is an accelerated shelf-life test to monitor the coverglass conductive coating in a humid atmosphere.

6.4.3.9.2 Process

a. All SCAs in subgroup D shall be placed in a chamber at ambient pressure.

b. The chamber temperature shall then be increased to 60 °C minimum.

c. Relative humidity shall be higher than 90 %.

d. The duration of the test shall be 30 days.

e. In the case of solar cells with aluminium content window layers, the HT test shall be extended to simulate on-ground expected duration and humidity and temperature conditions.

f. High-purity water shall be used, as per ASTM D1193-99, Type I.

g. Water condensation on the surface of the SCAs shall be prevented.

h. If there are requirements on specific environmental conditions (such as chemical vapours), they shall be stated in the SCD-SCA.

6.4.3.10 Coating adherence (CA)

6.4.3.10.1 Purpose

This test is performed to verify the durability of the coverglass conductive coating.

6.4.3.10.2 Process

a. All SCAs in subgroup D shall be subjected to a coating adherence test on the front cell face.

NOTE For test conditions see ECSS-Q-70-13.

b. Any visible delamination on parts of the coverglass conductive coating shall not exceed the limits specified in 6.4.3.2.4.f.

6.4.3.11 Interconnector adherence (IA)

6.4.3.11.1 Purpose

The purpose of this test is to monitor the bond strength of interconnectors under mechanical and thermal stress and to verify the electrical stability after interconnector welding.

6.4.3.11.2 Process

a. A gradually increasing pull force shall be applied to the interconnector tabs at a pull speed stated in the SCD-SCA.

b. The ultimate pull strength of each tab shall be as stated in the SCD-SCA.

c. The initial pull direction shall be parallel to the cell surface, and it shall be changed as follows:

1. to 45° with respect to the cell surface if previous experience shows that the interconnector tab breaks before the pull strength specified in b. is reached;
2. to 90° if at 45° the interconnector tab still breaks.

6.4.3.12 Electron irradiation (EI)

6.4.3.12.1 Purpose

This test is an accelerated shelf-life test to check the solar cell performance degradation under electron particle irradiation.

6.4.3.12.2 Process

a. The SCAs shall be subjected to 1 MeV electron irradiation.

NOTE ISO 23038 outlines a methodology to perform this test.

b. The flux density and energy shall be uniform over the cell area to within ±10 %.

c. During irradiation, the cells shall be protected from oxidation using either a vacuum (below 10^{-3} Pa) or a dry atmosphere of nitrogen or argon at a temperature of (20 ± 10) °C.

d. The nominal rate shall be lower than 5×10^{11} e^{-} cm^{-2} s^{-1}.

e. The irradiation facility, including dosimetry, shall be approved by the customer.

f. The irradiation is performed as follows:

1. The expected dose for the envisaged application, Φ_p, shall be stated in the SCD-SCA.
2. If the BSC was qualified according to the same specific mission requirements of the SCA (Subgroup C2 of the of the BSC qualification programme, see Table 7):
   (a) the dose shall be Φ_p, as a minimum;
   (b) tests on Subgroup C (see Table 4) may be performed on 10 cells only.
3. If qualified BSC was submitted for general characterization (Subgroup C1 of the BSC qualification programme, see Table 7):

(a) Subgroup C (see Table 4) shall be performed on 20 cells, divided in two batches of 10 samples;

(b) one batch of 10 samples shall be irradiated 2 times at $\Phi_p/2$, as a minimum;

(c) The second batch shall be irradiated 2 times at Φ_p, as a minimum.

NOTE This results in data for 10 samples at $\Phi_p/2$, at $\Phi_p \times 2$, and data for 20 samples at Φ_p.

g. The sequence of tests in Table 4 shall be arranged so SCAs of subgroup D are irradiated at Φ_p.

h. After combined electron and photon irradiation, the SCAs shall conform to the requirements stated in the SCD-SCA.

i. Electron irradiation at a dose corresponding to the dose at transfer orbit shall be added when specified by the mission requirements; this dose shall be included in the SCD-SCA.

6.4.3.13 Photon irradiation and temperature annealing (PH)

6.4.3.13.1 Purpose

This test is to verify the stability of SCA performance under the equivalent light and temperature of 1 S.C. (AM0).

6.4.3.13.2 Process

a. During the test, SCAs in subgroups B and C shall be subjected to the following:

1. irradiated with 1 S.C. (AM0) for 48 h;
2. be kept at (25 ± 5) °C;
3. arranged in an open circuit condition.

b. Multi-junction solar cells shall be subsequently temperature annealed for 24 h at 60 °C.

c. After the tests the SCAs shall be kept at temperatures below 50 °C until they are electrically measured.

6.4.3.14 Surface conductivity (SC)

6.4.3.14.1 Purpose

This test is to verify the average conductivity across the total surface.

6.4.3.14.2 Process

a. The surface conductivity of coverglasses for SCAs of subgroup D shall be measured.

b. The measurement specified in a. shall be performed between the cover contact dots or by the method described in the SCD-SCA.

6.4.3.14.3 Pass-fail criteria

The average conductivity across the total surface shall conform to the requirements stated in the SCD-SCA.

6.4.3.15 Cell reverse - diode characterization (DC)

6.4.3.15.1 Purpose

The purpose of diode characterization tests is to provide data for array level design. Although most of the test processes are identical to “cell reverse - diode performance” tests (see 6.4.3.16), for characterization purposes, the pass-fail criteria are not applicable, the range of test parameters for cell reverse - diode characterization is normally more severe, and in some cases the test may be destructive.

6.4.3.15.2 Process

a. The test shall be performed at an illumination of 1 S.C. (AM0).

b. For SCAs without a protection diode, the reverse I/V characteristics of the SCA shall be recorded
   - in darkness and under illumination,
   - with a limiting power supply (to avoid destructive breakdown),

   for the following variables as given in the SCD-SCA:
   1. at different temperatures (including maximum and minimum sustained operation temperatures, with margins);
   2. for different times;
   3. up to an operating point.

   NOTE Usually (as historically for silicon cells), the SCA is tested up to a fixed voltage in order to avoid destructive breakdown. However, under some circumstances it can be more appropriate to test up to a fixed current.

c. For SCAs with a protection diode electrically connected to the cell, the forward characteristic of the diode shall be recorded
   - in darkness and under illumination,
   - with temperature control imposed (to avoid thermal runaway),

   for the following variables, as stated in the SCD-SCA:
   1. At different temperatures (including maximum and minimum sustained operation temperatures, with margins).
   2. For different times.
   3. Up to current, $I_{DIODE\text{-}FORWARD}$.

   NOTE In this case, any shunt effect of the protection diode at $V_{DIODE\text{-}REVERSE}$ is detectable in the photovoltaic characteristic of the cell, so a potential shunt effect can be identified without further test.

d. For SCAs with a protection diode electrically isolated from the cell:
   1. The cell shall be tested as in b. above.
   2. The test under illumination need not be performed if the protection diode can be shown to have a negligible photovoltaic response (stated in the SCD-SCA).
   3. The forward and reverse I/V characteristics of the diode shall be recorded
      - in darkness and under illumination,
      - with a limiting power supply (to avoid destructive breakdown), and
      - with temperature control imposed (to avoid thermal runaway),

      for the following variables, as stated in the SCD-SCA:

      (a) At different temperatures (including maximum and minimum operational temperature with margins and sustained operation in forward bias).

      (b) For different times.

      (c) Up to a forward current, $I_{DIODE\text{-}FORWARD}$.

      (d) For the reverse voltage, $V_{DIODE\text{-}REVERSE}$.

4. The electrical isolation of cell and diode shall be tested by measuring the current when a voltage (as stated in the SCD-SCA) is applied between the front contacts of the protection diode and of the cell at the temperatures stated in the SCD-SCA.

6.4.3.16 Cell reverse - diode performance (DP)

6.4.3.16.1 Purpose

The purpose of cell reverse - diode performance tests is to monitor the performance of the cell and, where applicable, the protection diode before, for example, environmental tests, and to subsequently check for performance degradation after these tests. Although most of the test processes are identical to “cell reverse - diode characterization” (see 6.4.3.15), for these tests pass-fail criteria apply, the appropriate range of test parameters is likely to be less severe, and the tests are not intended to be destructive.

6.4.3.16.2 Process

a. The tests under illumination shall be performed at 1 S.C. (AM0).

b. For SCAs without protection diode:

1. The reverse I/V characteristics of the cell shall be recorded
   — in darkness and under illumination,
   — with a limiting power supply (to avoid destructive breakdown),

   for the following variables as given in the SCD-SCA:

   (a) at different temperatures;

   (b) for different times;

   (c) up to an operating point.

   NOTE Usually (as historically for silicon cells), the SCA is tested up to a fixed voltage in order to avoid destructive breakdown. However, under some circumstances it can be more appropriate to test up to a fixed current.

2. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-SCA):

   (a) at the given temperature and frequency;

   (b) when the cell is connected “on” at forward voltage, $V_{CELL\text{-}FORWARD}$, and “off” at reverse bias voltage, $V_{CELL\text{-}REVERSE}$;

   (c) over a period of time t;

   (d) in darkness and under illumination.

c. For SCAs with a protection diode electrically connected to the cell:

1. The forward characteristic of the diode shall be recorded in darkness and under illumination for the following variables as given in the SCD-SCA:

   (a) at different temperatures;

   (b) for different times;

   (c) at a current, $I_{DIODE\text{-}FORWARD}$, which is as a minimum equal to the expected string current at the solar array level;

   NOTE In this case, any shunt effect of the protection diode at $V_{DIODE\text{-}REVERSE}$ is detectable in the photovoltaic characteristic of the cell, so a potential shunt effect can be identified without further test.

2. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-SCA):

   (a) at a given temperature and frequency;

   (b) when the diode is connected "on" at forward voltage, $V_{DIODE\text{-}FORWARD}$, (which is, as a minimum, equal to the expected string current at solar array level) and "off" at reverse bias voltage, $V_{DIODE\text{-}REVERSE}$;
   (c) over a period of time t;
   (d) in darkness and under illumination.

d. For SCAs with a protection diode electrically isolated from the cell:
   1. The cell shall be tested as in b. above.
   2. The test under illumination need not be performed if the protection diode can be shown to have a negligible photovoltaic response.
   3. The forward and reverse I/V characteristics of the diode shall be recorded
      — in darkness and under illumination,
      — with a limiting power supply (to avoid destructive breakdown),

      for the following variables, as stated in the SCD-SCA:
      (a) at different temperatures;
      (b) for different times;
      (c) at a forward current, $I_{DIODE\text{-}FORWARD}$;
      (d) for a reverse voltage, $V_{DIODE\text{-}REVERSE}$.
   4. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-SCA):
      (a) at a given temperature and frequency;
      (b) when the diode is connected "on" at forward voltage, $V_{DIODE\text{-}FORWARD}$ (which is, as a minimum, equal to the expected string current at solar array level), and at reverse bias voltage, $V_{DIODE\text{-}REVERSE}$;
      (c) in darkness and under illumination.
   5. The electrical isolation of cell and diode shall be tested by measuring the current when a voltage (as stated in the SCD-SCA) is applied between the front contacts of the protection diode and of the cell, at the temperatures as stated in the SCD-SCA.

6.4.3.16.3 Pass-fail criteria

The diode performance test shall satisfy the pass-fail criteria stated in the SCD-SCA.

6.4.3.17 Ultraviolet exposure test (UV)

6.4.3.17.1 Purpose

This test is an accelerated shelf-life test with the purpose of checking the stability of the solar cells assembly under ultraviolet light exposure.

6.4.3.17.2 Process

a. The integrated intensity of the photons shall be measured with a Sun-blind photo-diode.

b. For photons with a wavelength between 200 nm to 400 nm, the integrated intensity at the end of test shall be as follows:
   1. equal to (100 - 150) Sun-hours or 1 % of the mission life, whichever is the longer period;
   2. have a UV irradiation acceleration factor of less than 10 Suns, and stated in the SCD-SCA.

c. The test shall be performed in a vacuum (i.e. pressure less than 10^{-3} Pa).

d. The temperature of the SCAs shall be the nominal operational temperature ±5 °C (refer to SCD-SCA).

e. Control samples should be included in the UV chamber in order to identify potential contaminations occurring during the test.

6.4.3.18 Capacitance test (CT)

6.4.3.18.1 Purpose

The purpose of this test is to gather data for the panel level by extrapolating the data obtained on the capacitance of the SCA.

6.4.3.18.2 Process

a. The capacitance should be measured by one of the methods specified in Annexes H and I.

b. The method for measuring the capacitance shall be stated in the SCD-SCA.

c. The capacitance shall be measured at SCA level in accordance with the method referred in b. at the temperature range stated in the SCD-SCA.

6.4.3.19 Flatness test (FT)

6.4.3.19.1 Purpose

The purpose of this test is to determine the flatness of the SCA.

6.4.3.19.2 Process

The flatness shall be determined by measuring the maximum deflection, d, of the SCA measured on an optically flat surface in an orientation as stated in the SCD-SCA.

6.4.4 Documentation

Documentation on environmental tests shall conform to 6.6.4.

6.5 Failure definition

6.5.1 Failure criteria

The following shall constitute SCA failures:

a. SCAs which fail during subgroup tests for which the pass-fail criteria are inherent in the test method.

b. SCAs failing to conform to the requirements of the visual inspection specified in 6.4.3.2.

c. SCAs that fail to conform to stress requirements stated in the SCD-SCA.

d. SCAs that, when subjected to electrical performance measurements after qualification tests in accordance with the SCD-SCA, fail one or more of the specified limits.

6.5.2 Failed SCAs

a. An SCA shall be considered as failed if it exhibits one or more of the failure modes detailed in 6.5.1.

b. Failed SCAs shall be identified as such and be included in the delivery.

c. Failure analysis of these SCAs shall be performed by the supplier and the results provided to the customer, as part of an NRB documentation.

NOTE For NRB, see ECSS-Q-20-09.

6.6 Data documentation

6.6.1 General

a. A data documentation package shall be provided for the qualification approval records and for each SCA delivery lot.

b. This package shall consist of the following:

1. cover sheet or sheets;
2. final production test data;
3. for qualification sub-lot only, qualification testing data;
4. failed SCA list and failure analysis report;
5. certificate of conformity.

c. Items listed in b. above should be grouped as sub-packages.

d. For identification purposes, each page of the data package shall include the following information:

1. SCA type;
2. manufacturer's name;
3. manufacturing lot identification;
4. date of establishment of the document;
5. page number.

6.6.2 Coversheets

The coversheets of the data documentation package shall include as a minimum the following:

a. reference to the SCD-SCA, including issue and date;

b. reference to this Standard, including issue and date;

c. SCA type;

d. procurement lot identification;

e. manufacturing lot identification;

f. number of purchase order or contract;

g. deviations from, or additions to, the generic specification (this Standard) and the SCD, if so specified in the order;

h. manufacturer's name and address;

i. location of the manufacturing plant;

j. signature on behalf of the manufacturer;

k. total number of pages of the data package.

6.6.3 Final production test data

A test result summary shall be compiled, showing the total number of SCAs submitted to, and the total number rejected after, each of the following tests:

a. visual inspection;

b. control of dimensions;

c. electrical performance measurements.

6.6.4 Qualification testing data

a. All data shall be linked to the manufacturing lot numbers.

b. Data shall be provided showing a record of the total number of items submitted for test and the total number rejected from each of the test subgroups.

c. Detailed data shall be provided of all electrical measurements made in accordance with Table C-1 of the SCD-SCA, and Figure 3.

6.6.5 Failed component list and failure analysis

a. A failed SCA list shall be maintained up to date.

b. For each of the failures in the list specified in a., a failure analysis shall be performed.

c. The following data shall be derived from a. and b.:

1. The reference number and description of the test or measurement as stated in this Standard or the SCD-SCA.
2. The identification of the failed SCA.
3. The failed parameter and the failure mode of the SCA.
4. A detailed failure analysis report.

6.6.6 Certificate of conformity

A certificate of conformity with the PID shall be issued and submitted with each delivery.

6.7 Delivery

a. All deliverable hardware specified in the order shall be delivered together with documentation in accordance with the requirements specified in 6.6.

b. One set of documents shall be sent to the customer.

6.8 Packaging, packing, handling and storage

For packaging, despatching, handling and storage of SCAs delivered according to this Standard, see PSS-01-202.

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7

Bare solar cells

7.1 Testing, deliverable components and marking

7.1.1 Testing

7.1.1.1 Tests for qualification and procurement

Testing for the qualification of bare solar cells (BSCs) comprises acceptance and qualification testing.

Testing for the procurement of qualified solar cells comprises acceptance tests and delta qualification tests as specified in 7.4.1 e.4.

7.1.1.2 Conditions and methods of tests

a. In addition to this Standard, the conditions and methods of testing shall conform to the bare solar cell source control drawing (SCD-BSC).

NOTE 1 The bare solar cell specification consists of two parts, the generic specification (this Standard) and the SCD-BSC. The SCD-BSC contains the technical specification for a cell type relevant to acceptance testing, as well as for the qualification testing.

NOTE 2 For the preparation of the SCD-BSC for bare solar cells, refer to Annex D.

b. The SCD-BSC shall be prepared by the supplier and reviewed and provided to the customer for reviewing and agreement.

c. Any deviation from in-process, acceptance and qualification test procedures shall be justified in the SCD-BSC.

d. Deviations from this Standard applicable to the SCD-BSC shall:

1. be agreed between the customer and the supplier;
2. include alternative requirements equivalent to those of this Standard;
3. not affect the reliability and performances of the BSCs;
4. only be those specified in c.

7.1.1.3 Supplier's quality assurance organization

The supplier shall establish and implement a quality assurance organization.

NOTE For quality assurance see ECSS-Q-20.

7.1.1.4 Responsibility of supplier for the performance of tests and inspections

a. The supplier shall ensure that the tests and inspections are performed.

b. These tests and inspections shall be performed at the manufacturer's plant or at a facility approved by the customer.

NOTE For test house requirements, see ECSS-Q-20-07.

7.1.2 Deliverable components

Delivered solar cells conforming to this Standard shall:

a. be processed and inspected in accordance with the requirements of the process identification document (PID) defined in 7.2, and

b. have completed all tests and inspections specified herein in accordance with the SCD-BSC.

7.1.3 Marking

All delivered solar cells conforming to this Standard shall be permanently marked with a code to enable traceability of the cells at the level specified in the PID (see 7.2).

7.2 Production control (process identification document)

a. The process identification document (PID) for the bare solar cell (BSC) to be qualified shall be prepared by the supplier in accordance with 7.2.b.

b. The PID shall comprise copies of the definition documents of the BSC, and the manufacturing documents and testing procedures, and include the following:

1. a material list;
2. a list of all manufacturing drawings;
3. the production flow chart;
4. a list of the procedures for the process;
5. a list of the procedures for the inspections to be performed;
6. the overall test programme (including in-process tests and acceptance tests);
7. a table of contents with reference number and issue;
8. the test matrix for acceptance tests including requirements and failure criteria;
9. details of the traceability of the cells including the requirements of the customer.

c. When a document is company confidential or contains proprietary information, the complete document need not be included, it may be referred to by including a reference to it.

d. The supplier shall do the following:

1. maintain configuration control of all documents;
2. keep the issues of the documents effective at the date of acceptance by the customer;
3. provide the PID to the customer for review;
4. submit to the customer for review and approval any modifications or changes to documents in the PID with any quality and reliability implications.

7.3 Acceptance tests

7.3.1 General

a. Acceptance tests shall be performed on the following:

1. components for delivery;
2. components used for qualification.

b. Acceptance tests shall consist on the tests specified in Table 6.

c. The generic specification to be used for each of the tests specified in Table 6 shall be agreed with the customer.

d. The sample size should be as specified in Table 6, but it may be modified depending on the specific project requirements as stated in SCD-BSC.

e. The data documentation corresponding to the tests referred to in b. shall be delivered together with the delivered cells and the qualification test lot.

Table 6: Acceptance test matrix

Test	Verification method	Sample Size
Visual inspection	7.5.2	100 %
Dimension and weight	7.5.3	1 %
Contact uniformity and surface finish	7.5.10	1 %
Electrical performance	7.5.4	100 %
Hemispherical reflectance (*)	7.5.7.2	1 %
Humidity and temperature,	7.5.8.2	1 %
Coating adherence	7.5.9	1 %
Humidity and temperature, and pull	7.5.8.2 and 7.5.11	1 %
Cell reverse - diode performance	7.5.16	100 %
Coverglass gain - loss	7.5.7.3	1 %
(*) only for BSR solar cells.		

7.3.2 Test methods and conditions

The test methods and conditions shall conform to 7.5.

7.3.3 Documentation

Documentation on acceptance tests shall conform to 7.7.

7.4 Qualification tests

7.4.1 General

a. Qualification shall be granted by the customer.

b. The qualification plan shall consist of the tests specified in Table 7.

c. During the qualification, all cells in subgroup A shall be equipped with front and rear interconnectors (as specified in 7.5.11.2) after step 5 (refer to Table 7).

d. The supplier shall provide details of the outcome of the qualification programme to the customer.

e. For a procurement lot of a previously qualified solar cells, the qualification tests need not be repeated if the following conditions are satisfied:

1. No changes are made to the design, function or electrical or mechanical parameters of the bare solar cell.

2. The same source control drawing is applicable.
3. No changes are made to the PID.
4. Delta qualification tests are performed to cover the requirements imposed by the new application.

f. The new requirements referred in e.4. above shall be included in a new version of the SCD-BSC.

Table 7: Qualification test plan for bare solar cells

			Bare cells (108)					
Test	**Symbol**	**Method**	**A (20)**	**B (20)**	**C1 (24)**	**C2 (24)**	**O (20)**	**P (24)**
Visual inspection	VI	7.5.2	1,7	1	1	1	1,7,12	1
Dimensions and weight	DW	7.5.3	2	2	2	2	2	2
Electrical performance	EP	7.5.4	3	5,7	3,8	3,5,8,14	3,6,9	3,8
Temperature coefficients	TC	7.5.5		8	10	10,16		10
Spectral response	SR	7.5.6		9	4,11	5,11,17		4,9
Optical properties	OP	7.5.7		10				
Humidity and temperature 1	HT1	7.5.8.1					5	
Humidity and temperature 2	HT2	7.5.8.2	5					
Coating adherence	CA	7.5.9					11	
Contact uniformity and surface finish	CU	7.5.10	4					
Pull	PT	7.5.11	6					
Electron irradiation	EI	7.5.12			6	6,12		
Proton irradiation	PI	7.5.13						6
Photon irradiation and temperature annealing	PH	7.5.14		6	7	7,13		7
Cell reverse - diode characteristics	DC	7.5.15		11	12	18		
Cell reverse - diode performance	DP	7.5.16			5,9	4,9,15	4,10	5,11
Thermal cycling	CY	7.5.17					8	
Active-passive interface	IF	7.5.18		3				
Flatness	FT	7.5.19		4				

NOTE 1 The numbers in the subgroup columns indicate the sequence in which the tests are performed; e.g. for subgroup O, the 1st test is VI, the 2nd test DW, the 3rd is CA, the 4th is CU and so on.

NOTE 2 The reason for dividing the test samples into subgroups is to generally test for the following:
Subgroup A: contact adherence (front and rear side)
Subgroup B: BOL performance
Subgroup C1: Electron irradiation (general)
Subgroup C2: Electron irradiation (mission specific) [optional]
Subgroup O: Extended storage simulation
Subgroup P: Proton irradiation

NOTE 3 For additional requirements, refer to 7.4.1.c.

7.4.2 Qualification

7.4.2.1 Production and test schedule

a. Before starting production of the qualification lot, the manufacturer shall compile a production test schedule showing by date and duration the production and test activities, including all major processing operations and key stages in the production and testing.

b. A production flow chart, process schedules and inspection procedures shall be provided.

7.4.2.2 Qualification test samples

a. The solar cells for qualification testing shall conform to the PID.

b. The supplier shall provide access to quality assurance personnel of the customer to monitor the manufacture of the test samples in accordance with a procedure agreed with the customer.

c. The test samples shall be chosen statistically and at random from a minimum number of cells, stated in the SCD-BSC, and from the first n batches, where n is also stated in the SCD-BSC.

NOTE For sampling see ISO 2859.

d. For the tests defined in this Standard, the total number of samples shall be divided into three equal groups, referred to as high-grade, mid-grade and low-grade according to their current at operating voltage.

e. Facilities should be available to safely store the qualification lot for a minimum of 6 years (equivalent to five years in storage and one year in orbit).

7.4.2.3 Qualification testing

Qualification testing shall proceed as given in Table 7, with the following conditions:

a. The total quantity of test samples shall be a minimum of 108 (either subgroup C1 or C2) bare solar cells.

b. The qualification tests shall be divided into subgroups of tests, and the samples assigned to a subgroup subjected to the tests in that subgroup in the sequence specified.

c. More than one failure in any subgroup, or more than two failures in total, shall constitute a failure in the qualification.

NOTE For a definition of failure see 7.6.

7.5 Test methods, conditions and measurements

7.5.1 Overview

The test methods, conditions and measurement requirements for the tests in Table 7 are detailed in subclauses 7.5.2 to 7.5.19. For failure criteria, see 7.6.

7.5.2 Visual inspection (VI)

7.5.2.1 Applicability

The requirements on visually observable defects defined in this subclause apply to granting qualification approval to a high quality bare solar cell.

7.5.2.2 Test process

The solar cells shall be visually inspected using a stereo-microscope with a magnification factor of up to 10 to verify the requirements for defects on solar cell and contacts.

7.5.2.3 Deviations

Any deviation from the visual inspection requirements on defects (7.5.2.4 and 7.5.2.5) shall:

a. not affect performance or reliability,

b. be agreed with the customer, and

c. be justified.

7.5.2.4 Solar cell defects

7.5.2.4.1 Edge chips, corner chips and surface nicks

a. The location and maximum dimensions and of edge chips, corner chips and surface nicks shall as specified in Figure 4 and Table 8.

b. The cumulative area of all edge chips, corner chips and surface nicks shall not exceed 5 % of the total cell area.

c. Edge chips, corner chips and surface nicks shall not be present in the contact weld area.

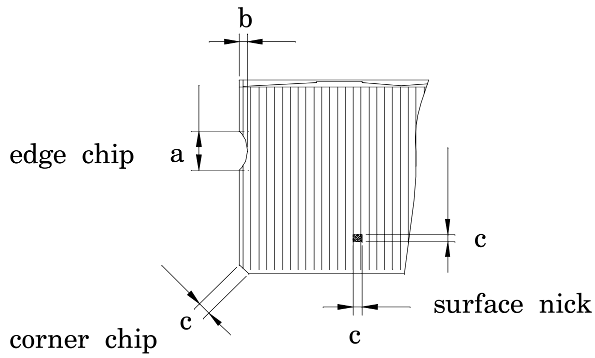

Figure 4: Definition of bare solar cell defects

Table 8: Maximum dimensions of corner chips, edge chips and surface nicks

Cell area (cm^2)	Dimensions of defects (mm)		
	a	b	c
4	4	0,7	1,5
8	6	0,8	2
12	8	0,9	2,5
25	10	1	4
32	12	1,1	5

7.5.2.4.2 AR coating

a. For acceptance, the SCD-BSC shall include the maximum value of the total uncoated area and the maximum value of the spatter.

b. For qualification, the maximum value of the total area of anti-reflection coating voids shall be 3 % of the total cell area.

c. The AR coating may contain discolourations.

7.5.2.4.3 Cracks, hairline cracks and fingerprints

a. Cracks and fingerprints shall not be present.

b. The SCD-BSC shall state the acceptance criteria for hairline cracks.

7.5.2.5 Solar cell contact area defects

7.5.2.5.1 General

a. The solar cell contact area shall be free of digs, scratches, and probe prints, unless metalization is still present.

b. Peeling, blistering and delamination of contacts shall not be present.

c. Digs or depressions deeper than 0,025 mm shall not be present.

7.5.2.5.2 Front and rear side contact welding area

a. The maximum dimension of voids or bubbles shall be 0,25 mm in diameter.

b. The maximum dimension of drops and spatter shall be 0,1 mm in diameter and 0,03 mm in height.

c. Over-coating (coating exceeding the area of the contact) along one side of each pad shall not exceed 0,1 mm.

7.5.2.5.3 Front bus bar and grids

a. There shall be no interruptions in the front bus bar.

b. The maximum total length of missing grids, short grids or non-continuous grids shall not exceed a total length of 3 grids.

7.5.2.5.4 Rear side contact outside the welding area

a. Drops and spatter shall not exceed 0,1 mm in diameter and 0,05 mm in height.

b. The cumulative area of voids, bubbles and drops shall not exceed 2 % of the total area.

c. Edge delaminations shall not be deeper than 0,75 mm.

d. The maximum area of worm shaped bulges shall be stated as a a percentage of total cell contact area in the SCD-BSC.

e. The maximum length of the hypotenuse of the triangular area of visible semiconductor at the corners, shall be included in the SCD-BSC.

7.5.3 Dimensions and weight (DW)

a. The measurement method to be used shall be as stated in the SCD-BSC.

b. The overall lateral dimensions of the cell (including thickness), contact dimensions and interconnector position shall conform to the requirements stated in the SCD-BSC.

c. The weight of the solar cell shall be verified by determination of the average weight per qualification lot or weight per contacts vacuum evaporation batch (sample base).

7.5.4 Electrical performance (EP)

7.5.4.1 Purpose

The purpose of the EP test is to assess the corresponding electrical parameters of the solar cells and to provide data for the design of the solar generator.

7.5.4.2 Process

a. The electrical current of solar cells under 1 S.C. (AM0) shall be measured and recorded digitally at the voltages stated in the SCD-BSC, at a solar cell temperature of 25 °C or operating temperature.

b. The electrical parameters measured or processed from a. above and identified in Figure 3 shall be recorded and supplied to the customer.

c. The accuracy of the bare solar cell measured parameters (I_{sc}, V_{oc} and P_{max}) shall be provided to the customer.

d. During measurement, the cells shall be kept at a constant temperature.

e. A continuous or pulsed light source calibrated in accordance with Annex A shall be used to verify the requirements given in the SCD-BSC for electrical characterization during both qualification and acceptance testing.

f. For qualification tests, there shall be a maximum of 3 % deviation in the current at the test voltage V_t, from the measurements before test, after the humidity and thermal cycling test in subgroup O.

7.5.4.3 Electrical grading in acceptance tests

7.5.4.3.1 Test conditions

The test conditions shall be as follows:

a. A value of 1 S.C (AM0).

b. The nominal value for V_{OP}, as stated in the SCD-BSC, in mV, and a value of 2 mV as the tolerance for V_{OP}.

c. The interval for $T_{JUNCTON}$ in °C, as stated in the SCD-BSC.

7.5.4.3.2 Pass-fail criteria

The pass-fail criteria and the grading intervals (in mA) for the groups in Table 7 shall be stated in the SCD-BSC.

7.5.5 Temperature coefficients (TC)

a. Temperature coefficients of all samples in subgroup B and on a minimum of 12 samples from each of subgroups C1, C2 and P shall be measured.

b. The electrical performance test described in 7.5.4. shall be repeated, as a minimum, as follows:

   1. In the temperature range between 25 °C and 80 °C with intermediate temperatures at 40 °C and 60 °C, (subgroups B, C1 and P).
   2. For mission specific qualification (subgroup B, C2 and P) at six equidistant solar cell junction temperatures between two temperature extremes t_1 and t_2 calculated as follows:

      t_1 = highest nominal operation temperature + 25 °C

      t_2 = lowest nominal operation temperature – 25 °C

c. The temperature coefficients of short-circuit current, open circuit voltage, voltage at maximum power and maximum power shall be derived by least-square curve fitting.

d. Averaged data for the short-circuit current, open circuit voltage, maximum power, voltage at maximum power and current at maximum power shall be supplied at the measured solar cell junction temperatures.

7.5.6 Spectral response (SR)

7.5.6.1 Purpose

Spectral response data is used for the verification of the Sun simulator (see subclauses A.1.1 and A.1.2) for performance measurement error calculation, for the characterization of the spectral response spread of production cells, for EOL degradation evaluation and for current matching investigation in multi-junction solar cells.

7.5.6.2 Process

a. Spectral response shall be measured on all samples of subgroup B and half of the samples of subgroup C1, C2 and P, by comparing the short-circuit current of the test cells against the output of a spectral standard of known relative spectral response under monochromatic irradiation.

b. The monochromatic irradiation shall be generated by one of the following methods:

   1. The irradiation shall be generated with the aid of narrow-band interference filters, having the following characteristic:

      (a) for silicon solar cells, at least, at 14 discrete wavelength intervals between 0,3 μm and 1,1 μm;

      (b) for single-junction GaAs solar cells at least, at 14 discrete wavelength intervals between 0,3 μm and 1,1 μm and number of narrow band interference filters in the range 0,75 μm to 1,1 μm, as stated in the SCD‐BSC.

      (c) for multi-junction GaAs solar cells, the number of narrow band interference filters and their wavelength are stated in the SCD‐BSC.

   2. By means of a high intensity monochromator for continuous recording between 0,3 μm and 1,9 μm.

c. The irradiation intensity at all wavelengths shall be such as to ensure that the measurement is made in the region where the cell response short-circuit current versus irradiance is linear.

d. For multi-junction solar cells, it shall be ensured that the measurements are performed on the current limiting subcell, and that it is working under short-circuit conditions.

7.5.7 Optical properties (OP)

7.5.7.1 General

Optical data is used for the definition of acceptance criteria for silicon BSR solar cells and coverglass gain loss parameter, and to provide data on the solar absorptance of the cell.

7.5.7.2 Hemispherical reflectance (HR)

a. Hemispherical reflectance shall be measured in the wavelength region from 250 nm to 2 500 nm.

b. The reflectance value for the acceptance of silicon BSR solar cells at 1,5 μm shall be stated in the SCD‐BSC.

7.5.7.3 Coverglass gain-loss (GL)

a. For single junction solar cells, the coverglass gain-loss stated in the SCD‐BSC shall be determined by using n-Amyl alcohol in order to simulate the optical properties of the adhesive.

b. For multi-junction solar cells, the agent to be used to simulate the optical properties of the adhesive shall be stated in the SCD-BSC.

c. The coverglass as stated in the SCD-BSC shall be used.

d. The solar cells shall be submitted to an electrical performance test before and after applying the coverglass, as defined in a. , b. and c., according to 7.5.4 under the following test conditions:

   1. at an illumination of 1 S.C. (AM0);
   2. a junction temperature interval, as stated in the SCD-BSC.

e. The pass-fail criteria shall be stated in the SCD-BSC.

7.5.7.4 Solar absorptance (α_S)

For solar absorptance measurements, see PSS-01-709.

7.5.8 Humidity and temperature (HT)

7.5.8.1 HT1 for qualification testing (subgroup O)

7.5.8.1.1 Purpose

This test is an accelerated shelf-life test to monitor the stability of contacts, anti-reflection coatings and integrated diode in a humid atmosphere.

7.5.8.1.2 Process

a. All cells in subgroup O shall be placed in a chamber at ambient pressure.

b. The chamber temperature shall then be increased to 60 °C minimum.

c. Relative humidity shall be higher than 90 %.

d. The duration of the test shall be 30 days.

e. In the case of solar cells with Aluminium content window layers, this test shall be extended to simulate on-ground expected duration, and humidity and temperature conditions.

f. High-purity water shall be used (ASTM D1193-99, Type I).

g. Water condensation on the surface of the cells shall be prevented.

h. If there are requirements on specific environmental conditions, such as chemical vapours, they shall be stated in the SCD-BSC.

7.5.8.2 HT2 for qualification (subgroup A) and acceptance testing

7.5.8.2.1 Purpose

This test is to verify the adherence of the contacts to the solar cell and diode, if available.

7.5.8.2.2 Process

a. All cells shall be placed in a chamber at ambient pressure.

b. The chamber temperature shall then be increased to 95 °C minimum.

c. Relative humidity shall be higher than 90 %.

d. The duration of the test shall be 24 h.

e. High-purity water shall be used (ASTM D1193-99, Type I).

f. Water condensation on the surface of the cells shall be prevented.

g. If there are requirements on specific environmental conditions, such as chemical vapours, they shall be stated in the SCD-BSC.

7.5.9 Coating adherence (CA)

7.5.9.1 Purpose

This test is performed to verify the durability of the anti-reflection coating, the contacts of cell and integrated diode.

7.5.9.2 Process

a. All cells shall be subjected to a coating adherence test on both cell faces.

b. Test conditions shall be established according to a standard agreed with the customer.

NOTE For the test conditions of the coating adherence test, see ECSS-Q-70-13.

c. The tape adhesion strength shall be 670 g/cm with a tolerance of ±10 %.

d. Any visible delamination on parts of the contacts or of the anti-reflection coating shall not exceed the limits specified in 7.5.2.4 and 7.5.2.5.

7.5.10 Contact uniformity and surface finish (CU)

7.5.10.1 Purpose

The contact uniformity test verifies the uniformity of the contact thickness and surface finish of the solar cell contacts.

7.5.10.2 Process

a. The uniformity of the thickness of the metal contact in the interconnector weld area shall be checked with a betascope, or a similar instrument as stated in the SCD-BSC.

b. The surface finish in the interconnector weld area shall be checked with a micro surface-roughness tester.

c. The uniformity of the contact thickness and the surface finish of the metal layers of the cell contact shall conform to the requirements of the interconnection process (as stated in the SCD-BSC), and the certified procurement specification of the supplier.

7.5.11 Pull test (PT)

7.5.11.1 Purpose

The objective of the pull test is to check the bond strength of the front and rear side contacts under mechanical and environmental stress.

7.5.11.2 Process

a. Interconnector tabs shall be welded or soldered on both the front and rear side contacts of the solar cells.

b. Welding or soldering parameters, the material and dimensions of the interconnectors shall be stated in the SCD-BSC.

c. A humidity and temperature test HT2 shall be performed.

d. A gradually increasing pull force shall be applied to the interconnector tabs at a pull speed as stated in the SCD-BSC.

e. The ultimate pull strength of each tab shall be as stated in the SCD-BSC.

f. The initial pull direction shall be parallel to the cell surface, and it shall be changed as follows:

1. to 45° with respect to the cell surface if previous experience shows that the interconnector tab breaks before the pull strength specified in e. is reached;
2. to 90° if at 45° the interconnector tab still breaks.

7.5.12 Electron irradiation (EI)

7.5.12.1 Purpose

This test is an accelerated shelf-life test to check the solar cell performance degradation under electron particle irradiation.

7.5.12.2 Process

a. The solar cells shall be subjected to 1 MeV electron irradiation.

   NOTE ISO 23038 outlines a methodology to perform this test.

b. The flux density and energy shall be uniform over the cell area within ±10 %.

c. During irradiation, the cells shall be protected from oxidation, using either vacuum (below 10^{-3} Pa) or a dry atmosphere of nitrogen or argon at a temperature of (20 ± 10) °C.

d. The nominal rate shall be lower than 5×10^{11} e^{-} cm^{-2} s^{-1}.

e. The irradiation facility, dosimetry included, shall be approved by the customer.

f. For general characterization of solar cells (subgroup C1):

   1. The dosages stated in the SCD-BSC (for specific cell types and to cover typical applications) shall be applied;

   2. only cells from mid-grade shall be used (see 7.4.2.2.d.).

g. For mission specific qualification (Subgroup C2) the irradiation is performed as follows:

   1. the expected dose for the envisaged application, Φ_p, shall be stated in the SCD-BSC.

   2. Subgroup C2 (see Table 7) shall be divided in two batches of 12 samples as a minimum, constituted as follows (see 7.4.2.2.d.):

      (a) a minimum of 8 mid-grade cells;

      (b) a minimum of 2 high-grade cells;

      (c) a minimum of 2 low-grade cells.

   3. The batches specified in 2. shall be irradiated as follows:

      (a) the first batch, twice at Φ_p;

      (b) the second batch, twice at $\Phi_p/2$.

      NOTE This results in data for 12 samples at $\Phi_p/2$, at $\Phi_p \times 2$, and data for 24 samples at Φ_p.

h. After electron irradiation, photon irradiation and temperature annealing, the requirements in 7.5.4.2.e. shall be satisfied.

i. Electron irradiation at a dose corresponding the dose at transfer orbit (as stated in the SCD-BSC) shall be added.

7.5.13 Proton irradiation (PI)

7.5.13.1 Purpose

The purpose of this test is to monitor the degradation of solar cell performance under proton particle irradiation.

7.5.13.2 Process

a. The solar cells shall be subjected to a fluence, of X_1 and X_2 MeV proton radiation, where X_1 and X_2 are as stated in the SCD-BSC.

NOTE Usually, the total radiation flux for a particular space environment (including all particles and energies) is translated into an equivalent dose of 1 MeV electrons.

b. Two proton energies shall be used in order to confirm the validity of the calculated equivalent dose of 1 MeV electrons.

c. The flux of the proton irradiation, in $p^+ \, cm^{-2} \, s^{-1}$, shall be as stated in the SCD-BSC.

7.5.14 Photon irradiation and temperature annealing (PH)

7.5.14.1 Purpose

This test is to verify the stability of solar cell performance under the equivalent light and temperature of 1 S.C. (AM0).

7.5.14.2 Process

a. During the test, solar cells of subgroups B, C1, C2 and P shall be subjected to the following:
   1. irradiated with 1 S.C. (AM0) for 48 h;
   2. be kept at (25 ± 5) °C;
   3. be in an open circuit condition.

b. The cells shall be subsequently temperature annealed for 24 h at 60 °C.

c. After the tests, the cells shall be kept at temperatures below 50 °C until they are electrically measured.

7.5.15 Cell reverse - diode characterization (DC)

7.5.15.1 Purpose

The purpose of diode characterization tests is to provide data for array level design. Although most of the test processes are identical to "cell reverse - diode performance" tests (see 7.5.16), for characterization purposes, the pass-fail criteria are not applicable, the range of test parameters for cell reverse - diode characterization is normally more severe, and in some cases the test can be destructive.

7.5.15.2 Process

a. The test shall be performed at an illumination of 1 S.C. (AM0).

b. For bare solar cells without a protection diode, the reverse I/V characteristic of the cell shall be recorded
   — in darkness and under illumination,
   — with a limiting power supply (to avoid destructive breakdown),

   for the following variables as given in the SCD-BSC:
   1. At different temperatures (including maximum and minimum sustained operating temperatures, with margins).
   2. For different times.
   3. Up to an operating point.

      NOTE Usually (as historically for silicon cells), the cell is tested up to a fixed voltage in order to avoid destructive breakdown. However, under some circumstances it can be more appropriate to test up to a fixed current.

c. For bare solar cells with a protection diode electrically connected to the cell, the forward characteristic of the diode shall be recorded

— in darkness and under illumination,

— with temperature control imposed (to avoid thermal runaway),

for the following variables, as stated in the SCD-BSC:

1. At different temperatures (including maximum and minimum sustained operation temperatures, with margins).
2. For different times.
3. Up to current, $I_{DIODE\text{-}FORWARD}$.

NOTE In this case, any shunt effect of the protection diode at $V_{DIODE\text{-}REVERSE}$ is detectable in the photovoltaic characteristic of the cell, so a potential shunt effect can be identified without further test.

d. For bare solar cells with a protection diode electrically isolated from the cell:

1. The cell shall be tested as in b. above.
2. The test under illumination need not be performed if the protection diode can be shown to have a negligible photovoltaic response.
3. The forward and reverse I/V characteristics of the diode shall be recorded

— in darkness and under illumination,

— with a limiting power supply (to avoid destructive breakdown), and

— with temperature control imposed (to avoid thermal runaway),

for the following variables, as stated in the SCD-BSC:

(a) At different temperatures (including maximum and minimum operating temperature with margins and sustained operation in forward bias).

(b) For different times.

(c) Up to a forward current, $I_{DIODE\text{-}FORWARD}$.

(d) For the reverse voltage, $V_{DIODE\text{-}REVERSE}$.

4. The electrical isolation of cell and diode shall be tested by measuring the current when a voltage (as stated in the SCD-BSC) is applied between the front contacts of the protection diode and of the cell at the temperatures as stated in the SCD-BSC.

7.5.16 Cell reverse - diode performance (DP)

7.5.16.1 Purpose

The purpose of cell reverse - diode performance tests is to monitor the performance of the cell and, where applicable, the protection diode before, for example, environmental tests, and to subsequently check for performance degradation after these tests. Although most of the test processes are identical to “cell reverse - diode characterization” (see 7.5.15), for these tests pass-fail criteria apply, the appropriate range of test parameters is likely to be less severe, and the tests are not intended to be destructive.

7.5.16.2 Process

a. The tests under illumination shall be performed at 1 S.C. (AM0).

b. For bare solar cells without protection diode:

1. The reverse I/V characteristics of the cell shall be recorded

— in darkness and under illumination,

— with a limiting power supply (to avoid destructive breakdown), for the following variables as given in the SCD-BSC:

(a) For different temperatures.

(b) For different times.

(c) Up to an operating point.

NOTE Usually (as historically for silicon cells), the cell is tested up to a fixed voltage in order to avoid destructive breakdown. However, under some circumstances it can be more appropriate to test up to a fixed current.

2. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-BSC):

(a) at the given temperature and frequency;

(b) when the cell is connected "on" at forward voltage, $V_{CELL\text{-}FORWARD}$, and "off" at reverse bias voltage, $V_{CELL\text{-}REVERSE}$;

(c) over a period of time t;

(d) in darkness and under illumination.

c. For bare solar cells with a protection diode electrically connected to the cell:

1. The forward characteristic of the diode shall be recorded in darkness and under illumination for the following variables as given in the SCD-BSC:

(a) at different temperatures;

(b) for different times;

(c) at a current, $I_{DIODE\text{-}FORWARD}$, which is, as a minimum, equal to the expected string current at the solar array level;

NOTE In this case, any shunt effect of the protection diode at $V_{DIODE\text{-}REVERSE}$ is detectable in the photovoltaic characteristic of the cell, so a potential shunt effect can be identified without further test.

2. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-BSC):

(a) at a given temperature and frequency;

(b) when the diode is connected "on" at forward voltage, $V_{DIODE\text{-}FORWARD}$, (which is, as a minimum, equal to the expected string current at solar array level) and "off" at reverse bias voltage, $V_{DIODE\text{-}REVERSE}$;

(c) over a period of time t;

(d) in darkness and under illumination.

d. For bare solar cells contains a protection diode which is electrically isolated from the cell:

1. The cell shall be tested as in b. above.

2. The test under illumination need not be performed if the protection diode can be shown to have a negligible photovoltaic response, as stated in the SCD-BSC.

3. The forward and reverse I/V characteristics of the diode shall be recorded

— in darkness and under illumination,

— with a limiting power supply (to avoid destructive breakdown),

for the following variables, as stated in the SCD-BSC:

(a) At different temperatures.

(b) For different times.

(c) At a forward current, $I_{DIODE\text{-}FORWARD}$ (which is, as a minimum, equal to the expected string current at solar array level).

(d) For a reverse voltage, $V_{DIODE\text{-}REVERSE}$.

4. A number of cycles of controlled on-off switching shall be performed under the following conditions (as stated in the SCD-BSC):

   (a) at a given temperature and frequency;

   (b) when the diode is connected “on” at forward voltage, $V_{DIODE\text{-}FORWARD}$ (which is, as a minimum, equal to the expected string current at solar array level), and reverse bias voltage, $V_{DIODE\text{-}REVERSE}$;

   (c) in darkness and under illumination.

5. The electrical isolation of cell and diode shall be tested by measuring the current when a voltage (as stated in the SCD-BSC) is applied between the front contacts of the protection diode and of the cell at the temperatures as stated in the SCD-BSC.

7.5.16.3 Pass-fail criteria

The diode performance test shall satisfy the pass-fail criteria stated in the SCD-BSC.

7.5.17 Thermal cycling (CY)

7.5.17.1 Purpose

The purpose of this test is to assess the reliability of test samples under a thermal stress equivalent of one year in orbit.

7.5.17.2 Process

The number of cycles and the extreme temperatures shall be those stated in the SCD-BSC.

7.5.18 Active-passive interface evaluation test (IF)

7.5.18.1 Purpose

This test is performed to determine if the single junction GaAs-Ge cell have got an active or passive interface layer.

7.5.18.2 Process

a. Test 7.5.4 shall be repeated using a non infrared-rich simulator having a maximum deviation of the total energy in the spectral region of 0,8 μm to 1,1 μm (as described in A.1.1) of a percentage value stated in the SCD-BSC.

b. The delta value of the open circuit voltage of bare cells with an active interface under the two solar simulator conditions (1 S.C (AM0) and non-infrared rich) shall be less than the value stated in the SCD-BSC.

7.5.19 Flatness test (FT)

7.5.19.1 Purpose

The purpose of this test is to determine the flatness of the bare solar cell.

7.5.19.2 Process

The flatness shall be determined by measuring the maximum deflection, d, of the bare solar cell measured on an optically flat surface with an orientation and method as stated in the SCD-BSC.

7.6 Failure definition

7.6.1 Failure criteria

The following shall constitute failures:

a. Components that fail during subgroup tests for which the pass-fail criteria are inherent in the test method.

b. Components failing to conform to the requirements of visual inspection stated in the SCD-BSC.

c. Components whose marking fails to conform to the requirements of 7.1.3.

d. Components that fail to meet the stress requirements stated in the SCD-BSC.

e. Components that, when subjected to electrical performance measurements after acceptance tests in accordance with the SCD-BSC, fail to meet one or more of the specified limits.

7.6.2 Failed components

a. A component shall be considered to have failed if it exhibits one or more of the failure modes specified in 7.6.1.

b. Failed components shall be identified as such and included in the delivery.

c. Failure analysis of these components shall be performed by the supplier and the results provided to the customer as part of an NRB documentation.

NOTE For NRB, see ECSS-Q-20-09.

7.7 Data documentation

7.7.1 General

a. A data documentation package shall be provided for the qualification approval records and for each component delivery lot.

b. The package referred in a. shall consist of the following:

1. cover sheet or sheets;
2. final production test data;
3. for the qualification sub-lot only, qualification testing data;
4. certificate of conformity.

c. Items listed in b. should be grouped as sub-packages.

d. For identification purposes, each page of the data package shall include the following information:

1. component type;
2. manufacturer's name;
3. manufacturing lot identification;
4. date of establishment of the document;
5. page number.

7.7.2 Cover sheets

The coversheets of the data documentation package shall include as a minimum the following:

a. reference to applicable SCD, including issue and date;

b. reference to this Standard, including issue and date;

c. component type;

d. procurement or lot identification;

e. manufacturing lot identification;

f. number of purchase order or contract;

g. deviations from, or additions to, the SCD-BSC and this Standard, if the order specifies;

h. manufacturer name and address;

i. location of the manufacturing plant;

j. signature on behalf of the manufacturer;

k. total number of pages of the data package.

7.7.3 Acceptance test data

A test result summary shall be compiled, showing the total number of components submitted to, and the total number rejected after, each of the acceptance tests (see 7.3.1).

7.7.4 Qualification testing data

a. All data shall be linked to the manufacturing lot numbers.

b. Data shall be provided showing a record of the total number of items submitted for test and the total number rejected from each of the test subgroups.

c. Detailed data shall be provided for all electrical measurements made in accordance with the SCD-BSC.

7.7.5 Failed component list and failure analysis

a. A failed BSC list shall be maintained up to date.

b. For each failure in the list specified in a., a failure analysis shall be performed.

c. The following data shall be derived from a. and b.:

   1. The reference number and description of the test or measurement as stated in this Standard or the SCD-BSC.
   2. The identification of the failed BSC.
   3. The failed parameter and the failure mode of the BSC.
   4. A detailed failure analysis report.

7.7.6 Certificate of conformity

A certificate of conformity shall be issued and submitted with each delivery.

7.8 Delivery

a. All deliverable hardware specified in the order shall be delivered together with documentation in accordance with the requirements specified in 7.7.

b. One set of documents shall be sent to the customer.

7.9 Packaging, packing, handling and storage

For packaging, despatching, handling and storage of components delivered according to this Standard, see PSS-01-202.

8

Coverglasses

8.1 General

8.1.1 Purpose

This Clause defines the generic requirements for the manufacture, test and qualification of coated coverglasses (CVG) for solar cell photovoltaics in the space environment and the quality assurance requirements to guarantee the performance of a manufacturing lot.

This Clause, along with the source control drawing for coverglasses (SCD-CVG) and process identification document, defines the performance requirements for the coverglass component.

8.1.2 Description

The coverglasses are designed for use as a transparent protective shield for a range of solar cells.

Coverglass substrates are either made of fused silica or a borosilicate microsheet. The latter has a nominal concentration of cerium dioxide to increase the radiation stability of the coverglass and selectively filter out the short wavelength ultraviolet radiation to protect the underlying coverglass bonding adhesive. In the case of fused silica, a UV reflective coating is used to protect the underlying adhesive.

The glass is defined by its elemental composition, which is measured throughout the production cycle to ensure consistent physical characteristics.

8.1.3 Interfaces

The design of the coverglasses shall enable bonding to solar cells with space qualified adhesives.

8.2 Testing, deliverable components and marking

8.2.1 Testing

8.2.1.1 Tests for qualification and procurement

Tests for qualification of coverglasses comprise acceptance and qualification tests.

Tests for procurement of qualified coverglasses comprise acceptance tests.

8.2.1.2 Conditions and methods of tests

a. In addition to this Standard, the conditions and methods of testing shall conform to the coverglass source control drawing (SCD-CVG).

NOTE 1 The coverglass specification consists of two parts, this Standard and the SCD-CVG.

NOTE 2 For the preparation of the SCD-CVG, refer to Annex E.

b. The SCD-CVG shall be prepared by the supplier and provided to the customer for reviewing and agreement.

c. Any deviation from in-process, acceptance and qualification test procedures shall be justified in the SCD-CVG.

d. Deviations from this Standard applicable to the SCD-CVG shall:

1. be agreed between the customer and the supplier;
2. include alternative requirements equivalent to those of this Standard;
3. not affect the reliability and performances of the coverglasses;
4. only be those specified in c.

8.2.1.3 Responsibility of supplier for the performance of tests and inspections

a. The supplier shall ensure that the tests and inspections are performed.

b. These tests and inspections shall be performed at the plant of the manufacturer or at a facility approved by the customer.

NOTE For test house requirements, see ECSS Q-20-07.

8.2.2 Deliverable components

Delivered coverglasses complying with this Standard shall:

a. be processed and inspected in accordance with the requirements of the process identification document (PID) defined in 8.3, and

b. have completed all tests and inspections stated in the SCD-CVG.

8.2.3 Marking (coating orientation)

a. The coated face of the component shall be identified using as a minimum the methods shown in Figure 5.

b. The orientation method along with associated dimensional tolerances shall be stated in the SCD-CVG.

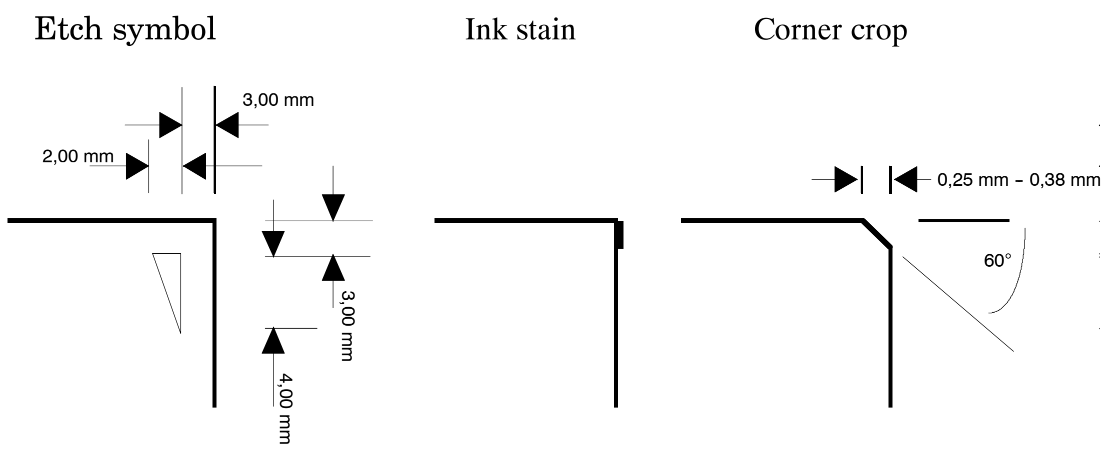

Figure 5: Methods of defining coverglass orientation

8.3 Production control (Process identification document)

a. A process identification document (PID) for the coverglasses to be qualified shall be prepared by the supplier in accordance with 8.3.b.

b. The PID shall comprise copies of the definition documents of the coverglasses, and the manufacturing documents and testing procedures and include the following:

1. a material list;
2. a list of all manufacturing drawings;
3. the production flow chart;
4. a list of the procedures for the process;
5. a list of the procedures for the inspections to be performed;
6. the overall test programme (including in-process tests and acceptance tests);
7. a table of contents with reference number and issue;
8. the test matrix for final acceptance tests including requirements and failure criteria;
9. details of the traceability of the coverglasses including the customer requirements.

c. When a document is company confidential or contains proprietary information, the complete document need not be included, it can be referred to by including a reference to it.

d. The supplier shall do the following:

1. maintain configuration control of all documents;
2. keep the issues of the documents effective at the date of acceptance by the customer;
3. provide the PID to the customer for review;
4. submit to the customer for review and approval any modifications or changes to documents in the PID with any quality and reliability implications.

8.4 Acceptance tests

8.4.1 Acceptance test samples

a. A minimum of 40 test samples should be chosen statistically and at random from the shipment lot.

b. Sample size may be modified depending on specific project requirements, as stated in SCD-CVG.

NOTE For sampling see ISO 2859.

8.4.2 Acceptance test sequence

a. Acceptance tests shall be performed on the following:

1. components for delivery;
2. components used for qualification.

b. Acceptance tests shall consist on the following:

1. 50 % of the samples (as selected in 8.4.1) shall be submitted to the following tests:
   (a) transmission into air;
   (b) dimensions;

   (c) weight;
   (d) thickness.
2. The remaining 50 % of the samples (as selected in 8.4.1) shall be submitted to the following tests:
   (a) visual inspection and transmission into air;
   (b) humidity and temperature HT2;
   (c) visual inspection and transmission into air;
   (d) abrasion resistance;
   (e) visual inspection;
   (f) thermal cycling;
   (g) coating adhesion;
   (h) visual inspection.

c. The data documentation corresponding to the tests referred in b. above shall be delivered together with the delivered coverglasses and the qualification test sub-lot.

8.4.3 Test methods and conditions

The test methods and conditions shall conform to 8.6.

8.4.4 Documentation

Documentation on acceptance tests shall conform to 8.8.

8.5 Qualification tests

8.5.1 General

a. Qualification shall be granted by the customer.

b. All coverglass procurement lots shall be qualified.

c. If a purchase order is placed for a procurement lot of a previously qualified coverglass, the qualification tests need not to be repeated if the following conditions are satisfied:
   1. No changes are made to the design, function or mechanical parameters of the coverglass.
   2. The same SCD-CVG is applicable.
   3. No changes are made to the PID.

d. Qualification shall consist of the tests specified in Table 9.

e. The supplier shall provide details of the outcome of the qualification programme to the customer.

8.5.2 Qualification

8.5.2.1 Production and test schedule

a. Before starting production of the qualification lot, the manufacturer shall compile a production test schedule, showing by date and duration, production and test activities, including all major processing operations and key stages in the production and testing.

b. Process schedules and inspection procedures shall be provided.

8.5.2.2 Qualification test samples

a. The supplier shall provide access to the customer to monitor the manufacture of the coverglass qualification set.

b. The coverglass qualification set shall be chosen statistically and at random from the first coating lots, as stated in the SCD-CVG.

NOTE For sampling see ISO 2859.

8.5.2.3 Qualification testing

a. Qualification testing shall proceed as given in Table 9, with the following conditions:

1. The total quantity of test samples (in Table 9) shall be agreed between the customer and supplier.

EXAMPLE 20 coverglasses for each subgroup and 5 for every radiation dose.

2. The qualification tests shall be divided into subgroups of tests.
3. The samples assigned to a subgroup shall be subjected to the tests in that subgroup in the sequence specified.

b. A failure in any subgroup shall constitute a failure in the qualification.

Table 9: Qualification test plan for coverglasses

			Uncoated	Coated or uncoated coverglasses						
Test	**Symbol**	**Method**	**A (20)**	**B (20)**	**U (20)**	**O (20)**	**V (20)**	**C (20)**	**P (20)**	**S (10)**
Visual inspection	VI	8.6.1	1	1	1,4	1,4, 7,11	1,4	1,4	1,4	
Transmission into air	TA	8.6.2	2	2	2,5	2,5, 9	2,5	2,5	2,5	
Physical properties	PP	8.6.3	3	3						
Mechanical properties	MP	8.6.4		4						
Reflectance properties	OP	8.6.5		5						
Normal emittance	NE	8.6.6		6			6	6		
Surface resistivity	SC	8.6.7		7			7	7		
Flatness	FT	8.6.8		8						
Transmission into adhesive	TH	8.6.9		9						
Boiling water	BW	8.6.10			3					
Humidity and temperature1	HT1	8.6.11.1				3				
UV exposure	UV	8.6.12					3			
Electron irradiation	EI	8.6.13						3		
Proton irradiation	PI	8.6.14							3	
Breaking strength	BS	8.6.15								1
Thermal cycling	CY	8.6.16				8				
Abrasion resistance	AE	8.6.17				6				
Coating adhesion	TD	8.6.18				10				

NOTE 1 The numbers in the subgroup columns indicate the sequence in which the tests are performed; e.g. for subgroup A, the 1st test is VI, the 2nd test TA, the 3rd is PP, and so on.

NOTE 2 The reason for dividing the test samples into subgroups is to generally test for the following:
Subgroup A: Physical properties of coverglass substrate material
Subgroup B: Mechanical properties and BOL data
Subgroup U: Coating adherence (Solubility)
Subgroup O: Humidity and temperature coating stability
Subgroup V: UV exposure
Subgroup C: Electron irradiation
Subgroup P: Proton irradiation
Subgroup S: Breaking strength

8.6 Test methods, conditions and measurements

8.6.1 Visual inspection (VI)

8.6.1.1 Purpose

The coverglass shall be visually inspected with the naked eye to verify the requirements for defects on coverglasses as specified in 8.6.1.2.

8.6.1.2 Defects

8.6.1.2.1 Coated coverglasses

a. The coated area shall have a uniform appearance, with no visible evidence of pinholes, voids or spatter.

NOTE See MIL-PRF-13830.

b. For a coated coverglass, the uncoated area due to coating tools shall not exceed 1 % of the total coverglass area or 8 mm^2, whichever is greater.

8.6.1.2.2 Scratch and dig

The maximum dimensions of scratches and digs shall be stated in the SCD-CVG.

NOTE See MIL-PRF-13830.

8.6.1.2.3 Bubbles and inclusions

The projected area of any bubble or inclusions in the coverglass shall not be larger than 0,02 mm^2.

NOTE See MIL-PRF-13830.

8.6.1.2.4 Edge chips

a. The projection into the coverglass face, defined by "b" in Figure 6, shall not exceed 0,25 mm.

b. The length of the chip, defined by "a" in Figure 6, shall not exceed 0,6 mm.

c. Edge chips with a dimension of the projection into the coverglass face of b < 0,1 mm and a length of the chip a < 0,2 mm (see Figure 6) may be ignored.

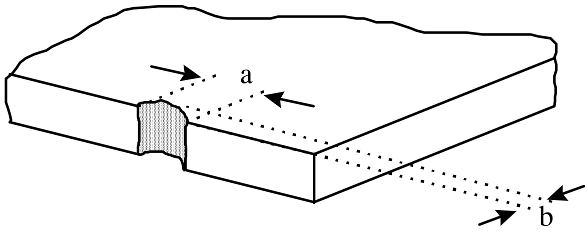

Figure 6: Edge chip parameters

8.6.1.2.5 Corner chips

a. The length of the hypotenuse, as defined by "d" in Figure 7, of any corner chip in the coverglass, shall not exceed 0,75 mm.

b. The SCD-CVG shall state a requirement specifying the maximum number of chips per coverglass.

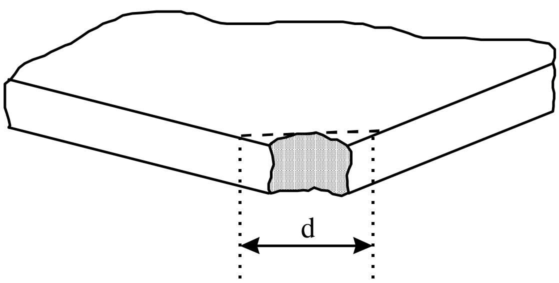

Figure 7: Corner chip parameters

8.6.1.2.6 Cracks

Surface, edge or corner cracks shall not be present on a coverglass.

NOTE See MIL-PRF-13830.

8.6.1.2.7 Dirty and contaminated surfaces

Coverglasses shall not have dirty or contaminated surfaces.

NOTE See MIL-PRF-13830.

8.6.2 Transmission into air (TA)

a. The transmission into air of the coverglass shall be measured (for λ and T as specified in b. below) using a calibrated spectro-photometer as follows:

1. at an incidence angle of less than 10°,
2. with a wavelength tolerance of (λ ± 2) nm, and
3. an absolute transmission tolerance of (T ± 1) %.

b. The transmission values before and after testing shall be specified in the SCD-CVG for the following λ:

1. Discrete wavelength: 400 nm, 450 nm, 500 nm and 600 nm.
2. Wavelength range: 300 nm - 320 nm, 400 nm - 450 nm, 600 nm - 800 nm, 450 nm - 1 100 nm and 900 nm - 1 800 nm.

8.6.3 Physical properties (PP)

8.6.3.1 Density

The density and tolerances of a sample of the glass, weighed in air and water using an analytical balance at 25 °C, shall conform to the requirements stated in the SCD-CVG.

NOTE Density is calculated from the measured specific gravity and the density of water at 25 °C.

8.6.3.2 Thermal expansion coefficient

a. The coefficient of expansion shall be measured using a horizontal silica push rod dilatometer consisting of a concentric rod and tube of silica which transmits the expansion movement of a 50 mm sample to a linear voltage displacement transducer (LVDT).

b. Heating shall be provided by a wire wound furnace controlled to give a temperature rise of 5 °C/min.

c. The thermal expansion coefficient, its tolerances, and measurement temperature range shall be stated in the SCD-CVG.

8.6.3.3 Young’s modulus and Poisson’s ratio

The values and tolerances of the Young’s modulus and Poisson’s ratio, measured using the following resonance technique, shall be as stated in the SCD-CVG:

a. Hold a small bar of glass at its mid point.

b. Use piezoelectric or electrostatic transducers to excite and detect vibrations in the sample.

c. Use the resonant frequency to calculate the elastic coefficients from a knowledge of the sample dimensions and the density.

8.6.3.4 Bulk and surface resistivity

The values and tolerances of the bulk resistivity and surface resistivity, derived from an electrical measurement made between two geometrically defined, evaporated electrical contacts on the glass substrate, shall be stated in the SCD-CVG.

8.6.3.5 Refractive index

The values and tolerances of the refractive index, measured using the following V-block refractometer method, shall be stated in the SCD-CVG:

a. Prepare the samples by cutting 22 mm × 22 mm square samples and clamp them together to give a small block approximately 6 mm in thickness.

b. Place this block into the V of a V-block prism made of a glass of refractive index similar to that of the sample under test.

c. To achieve the optical contact, use a matching refractive index fluid.

d. Measure first a reference block of known refractive index in order to calibrate the apparatus.

NOTE The instrument gives an absolute measurement referenced to this Standard with an accuracy better than $\pm 10^{-4}$ over the range of 1,47 to 1,65.

e. Use a sodium d-line as the light source.

8.6.4 Mechanical properties

8.6.4.1 Dimension and weight

a. The dimensions and associated tolerances of the coverglass shall be stated in the SCD-CVG and conform to the tolerance limits defined in Figure 8.

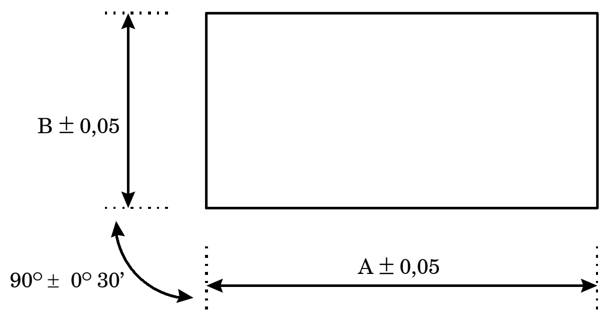

Figure 8: Coverglass manufacturing tolerance limits

b. The values and tolerances of the weight of the coverglass, verified by determining the average weight per shipping lot, shall be as stated in the SCD-CVG.

8.6.4.2 Thickness

a. The coverglass thickness along with the associated tolerances shall be as stated in the SCD-CVG.

b. The thickness shall be measured using a calibrated micrometer.

8.6.4.3 Edge parallelism

a. The edge parallelism shall be as stated in the SCD-CVG.

b. The edge parallelism shall be measured using a calibrated micrometer.

8.6.4.4 Perpendicularity of sides

a. The perpendicularity of the sides of the coverglass shall be measured using an optical instrument with a reference normal.

b. The perpendicularity shall be as stated in the SCD-CVG.

8.6.5 Reflectance properties (OP)

8.6.5.1 Reflectance

a. The reflectance shall be measured using a calibrated spectro-photometer using a W-reflectance method or integrating sphere.

b. The wavelength tolerance shall be $\lambda \pm 2$ nm and a reflectance tolerance of $(R \pm 1)$ %, where λ and R are as stated in the SCD-CVG.

8.6.5.2 Reflectance cut-on

8.6.5.2.1 Definition

The reflectance cut-on is defined as the wavelengh that corresponds to 50 % absolute measured reflectance in the low wavelength side of the reflectance band.

8.6.5.2.2 Purpose

The reflectance cut-on is used to measure high reflectance bands.

NOTE There can be more than one high reflectance band in the coated coverglass component.

8.6.5.2.3 Requirement

The reflectance cut-on shall be as stated in the SCD-CVG.

8.6.5.3 Reflectance cut-off

8.6.5.3.1 Definition

The reflectance cut-off is defined as the wavelength that corresponds to 50 % absolute measured reflectance in the high wavelengths range of the reflectance band.

8.6.5.3.2 Purpose

The reflectance cut-off is used to measure high reflectance bands.

NOTE There can be more than one high reflectance band in the coated coverglass component.

8.6.5.3.3 Requirement

The reflectance cut-off shall be as stated in the SCD-CVG.

8.6.5.4 Reflectance bandwidth

8.6.5.4.1 Definition

The reflectance bandwidth is the width in nanometres measured between the reflectance cut-on and cut-off divided by the centre wavelength of the reflectance band which is defined with the following equation;

$$\lambda_c = \frac{2\lambda_1\lambda_2}{(\lambda_1 + \lambda_2)}$$

where

λ_c is centre wavelength of the reflectance band;

λ_1 is the reflectance cut-on;

λ_2 is the reflectance cut-off.

8.6.5.4.2 Requirement

The reflectance bandwidth shall be as stated in the SCD-CVG.

8.6.6 Normal emittance (ε_N) (NE)

a. Normal emittance shall be measured by using either the Gier Dunkle 100 IR reflectometer or similar equipment stated in the SCD-CVG or an absolute reflectance method.

NOTE Normal emittance varies according to glass type and thickness.

b. If an absolute reflectance method is used, the normal emittance shall be calculated as follows:

1. Measure the reflectance on a dispersive IR spectro-photometer from 5 μm to 50 μm.
2. Calculate the weighted reflectance, R_{wtd}, by integrating over the Plankian black-body emission spectrum between 5 μm and 50 μm, P(λ), at 300 K.
3. Repeat steps 1. and 2. a minimum of three times, and calculate R_{avge} as the average of the three values obtained for R_{wtd}.
4. Calculate the normal emittance, ε_N, from, $\varepsilon_N = 1 - R_{avge}$.

c. The normal emittance shall be as stated in the SCD-CVG.

8.6.7 Surface resistivity

a. When a conductive coating is incorporated in the coverglass, the surface resistivity shall be measured, using the equipment stated in the SCD-CVG, as follows:

1. Measure the resistance between two indium-tin soldered buzzbars applied to the coverglass, as shown in Figure 9.
2. Calculate the surface resistivity from the resistance and the lenght a, and b, defined in Figure 9 using the following equation:

$$R_S = (aR)/b$$

where

R is the measured resistance;

R_S is the surface resistivity.

b. The surface resistivity shall conform to the requirements defined in the SCD-CVG.

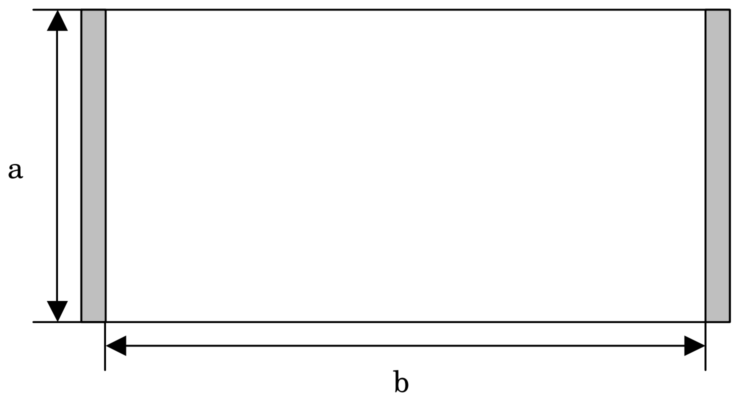

Figure 9: Schematic for calculating surface resistivity

8.6.8 Flatness or bow (FT)

a. Flatness or bow shall be measured by measuring the maximum deflection, d (as stated in the SCD-CVG) of the coverglass measured on an optically flat surface in the orientation shown in Figure 10.

b. For localized flatness deformations, the maximum displacement of the coverglass from an optically flat surface over a specified distance shall not exceed the values stated in the SCD-CVG.

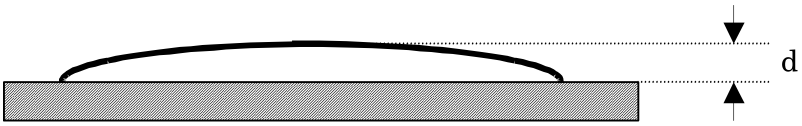

Figure 10: Definition of coverglass flatness

8.6.9 Transmission into adhesive (TH)

a. The transmission into the adhesive shall be measured as in 8.6.2, using a fused silica or uncoated coverglass backing piece laminated onto the coverglass component and a matching fluid with a refractive index of 1,41.

b. The transmission shall be corrected for reflectance losses at the backing piece-air interface by using Fresnel's equation as stated in the SCD-CVG.

c. The transmission into adhesive values shall be as stated in the SCD-CVG.

8.6.10 Boiling water test (BW)

The single-coated coverglass shall be immersed in boiling de-ionized water for a minimum continuous period of:

a. 5 minutes for multi-layer coated coverglasses;

b. 15 minutes in any other case.

8.6.11 Humidity and temperature

8.6.11.1 HT1 for qualification testing (subgroup O)

8.6.11.1.1 Purpose

This test is an accelerated shelf-life test to monitor the stability of the coverglass coatings stability in a humid atmosphere.

8.6.11.1.2 Process

a. All coverglasses of subgroup O shall be placed in a chamber at ambient pressure.

b. The chamber temperature shall then be increased from ambient temperature to 50 °C at a minimum.

c. Relative humidity shall be higher than 90 %.

d. The duration of the test shall be 10 days.

e. High-purity water shall be used (ASTM D1193-99, Type I).

f. Water condensation on the surface of the coverglasses shall be prevented.

g. If there are requirements on specific environmental conditions (such as chemical vapours), they shall be stated in the SCD-CVG.

8.6.11.2 HT2 for acceptance testing

8.6.11.2.1 Purpose

This test is to verify the adherence of coatings to the coverglass.

8.6.11.2.2 Process

a. All coverglasses shall be placed in a chamber at ambient pressure.

b. The chamber temperature shall then be increased from ambient temperature to 50 °C at a minimum.

c. Relative humidity shall be higher than 90 %.

d. The duration of the test shall be 72 h.

e. High-purity water shall be used (ASTM D1193-99, Type I).

f. Water condensation on the surface of the cells shall be prevented.

g. If there are requirements on specific environmental conditions (such as chemical vapours), they shall be stated in the SCD-CVG.

8.6.12 UV exposure (UV)

8.6.12.1 Purpose

This test is an accelerated shelf-life test with the purpose of checking the stability of the coverglass coatings under ultraviolet light exposure.

8.6.12.2 Process

a. The integrated intensity of the photons shall be measured with a Sun-blind photo-diode.

b. For photons with a wavelength between 200 nm to 400 nm, the integrated intensity at the end of test shall be as follows:

   1. equal to (100 - 150) Sun-hours or 1 % of the mission life, whichever is the longer period;

   2. have a UV irradiation acceleration factor of less than 10 S.C. (AM0) as stated in the SCD-CVG.

c. The test shall be performed in a vacuum (i.e. pressure less than 10^{-3} Pa).

d. The temperature of the coverglass shall be kept below 50 °C during the test.

e. Control samples should be included the UV chamber in order to identify potential contaminations occurring during the test.

8.6.13 Electron irradiation (EI)

8.6.13.1 Purpose

This test is an accelerated shelf-life test with the purpose of checking coverglass coating stability under electron particle irradiation.

8.6.13.2 Process

a. The coverglasses shall be subjected to 1 MeV electron irradiation.

b. If the front surface coating is tested, low electron energies should be considered.

c. The flux density and energy shall be uniform over the coverglass area to within ±10 %.

d. The nominal rate shall be lower than the value stated in the SCD-CVG.

e. Tests shall be performed in vacuum (pressure below 10^{-3} Pa) or in inert gas atmosphere.

f. The irradiation shall be performed at doses representative of LEO and GEO mission environments and at least $2 \times \Phi_p$, as stated in the SCD-CVG.

8.6.14 Proton irradiation (PI)

8.6.14.1 Purpose

This test is an accelerated shelf-life test with the purpose of verifying the stability of coverglass coatings under proton particle irradiation.

8.6.14.2 Process

a. The coverglasses shall be subjected to a proton irradiation of the value stated in the SCD-CVG.

b. If the front surface coating is tested, low proton energies should be considered.

c. The flux density and energy shall be uniform over the coverglass area within ±10 %.

d. The nominal rate shall be lower than the value stated in the SCD-CVG.

e. Tests shall be performed in a vacuum (pressure below 10^{-3} Pa).

f. The irradiation shall be performed at doses representative of LEO and GEO mission environments, and at least $2 \times \Phi_p$, as stated in the SCD-CVG.

8.6.15 Breaking strength (BS)

a. The coverglass breaking strength shall exceed the limits set in the SCD-CVG.

b. The breaking strength test method shall be as stated in the SCD-CVG.

8.6.16 Thermal cycling (CY)

a. The coverglasses shall be exposed to the number of cycles over the range of temperature (both as stated in the SCD-CVG) with a total cycle duration not greater than 10 minutes.

b. After exposure, the coverglasses shall show no signs of physical degradation when inspected in accordance with a standard agreed with the customer

NOTE For inspection of the coverglass, see MIL-PRF-13830.

c. The coverglasses shall show no degradation in the measured optical performance.

8.6.17 Abrasion resistance (coated surface) (AE)

a. The coverglass shall be subjected to 20 strokes with a 6 mm diameter pencil type eraser conforming to MIL-E-12397, loaded to 10 N.

b. The coverglass shall show no evidence of physical degradation.

8.6.18 Coating adhesion (TD)

a. The coverglass shall be subjected to an adhesion test in accordance with a standard agreed with the customer.

NOTE For the test conditions, see ECSS-Q-70-13.

b. The coating shall show no evidence of delamination.

NOTE See also MIL-M-13508.

8.7 Failure definition

8.7.1 Failure criteria

The following shall constitute failures:

a. Components that fail during subgroup tests for which the pass-fail criteria are inherent in the test method.

b. Components failing to conform to the requirements of visual inspection stated in the SCD-CVG.

c. Components that fail to meet the stress requirements stated in the SCD-CVG.

8.7.2 Failed components

a. A component shall be considered as failed if it exhibits one or more of the failure modes specified in 8.7.1.

b. Failed components shall be identified as such and included in the delivery.

c. Failure analysis of these components shall be performed by the supplier and the results provided to the customer as part of an NRB documentation.

NOTE For NRB, see ECSS-Q-20-09.

8.8 Data documentation

8.8.1 General

a. A data documentation package shall be provided for the qualification approval records and for each component delivery lot.

b. The package referred in a. above shall consist of the following:

1. cover sheet or sheets;
2. final production test data;
3. for qualification sub-lot only, qualification testing data;
4. certificate of conformity.

c. Items listed in b above should be grouped as sub-packages.

d. For identification purposes, each page shall include the following information:

1. component type;
2. manufacturer's name;
3. manufacturing lot identification;
4. date of establishment of the document;
5. page number.

8.8.2 Cover sheets

The coversheets of the data documentation package shall include as a minimum the following:

a. reference to the applicable SCD-CVG, including issue and date;

b. reference to this Standard, including issue and date;

c. component type;

d. procurement lot identification;

e. manufacturing lot identification;

f. number of purchase order or contract;

g. additional information if the order specifies deviations from or additions to the applicable SCD-CVG and this Standard;

h. manufacturer's name and address;

i. location of the manufacturing plant;

j. signature on behalf of the manufacturer;

k. total number of pages of the data package.

8.8.3 Acceptance test data

A test result summary shall be compiled, showing the total number of components submitted to, and the total number rejected after, each of the mentioned afore acceptance tests (see 7.3.1).

8.8.4 Qualification testing data

a. All data shall be linked to the manufacturing lot numbers.

b. Data shall be provided showing a record of the total number of items submitted for test and the total number rejected from each of the test subgroups.

8.8.5 Failed component list and failure analysis

a. A failed coverglass list shall be maintained up to date.

b. For each failure in the list specified in a., a failure analysis shall be performed.

c. The following data shall be derived from a. and b.:

    1. The reference number and description of the test or measurement as stated in this Standard or the SCD-CVG.
    2. The identification of the failed coverglass.
    3. The failed parameter and the failure mode of the coverglass.
    4. A detailed failure analysis report.

8.8.6 Certificate of conformity

A certificate of conformity shall be issued and submitted with each delivery.

8.9 Delivery

a. All deliverable hardware specified in the order shall be delivered together with documentation in accordance with the requirements specified in 8.8.

b. One set of documents shall be sent to the customer.

8.10 Packaging, packing, handling and storage

For packaging, despatching, handling and storage of components delivered to this Standard, see PSS-01-202.

Annex A (normative)

Sun simulators and calibration procedures

A.1 Sun simulators

A.1.1 Spectral distribution

A.1.1.1 AM0 spectrum

The AM0 spectrum in the 0,2 μm to 1,9 μm wavelength range shall be as specified in Table A-1.

NOTE This table is based on the compilation of Christoph Wehrli, of the Physikalisch-Meteorologisches Observatorium World Radiation Center, and is compatible with Annex E of ISO 15387.

Table A-1: AM0 solar spectral irradiance (WM0) from 0,2 mm to 1,9 mm

λ (nm)	E_o (λ) (mW/cm^2 × 5 nm)
200 - 205	0,000795
205 - 210	0,001415
210 - 215	0,00326
215 - 220	0,00402
220 - 225	0,00522
225 - 230	0,00482
230 - 235	0,00497
235 - 240	0,004835
240 - 245	0,00584
245 - 250	0,0053
250 - 255	0,005455
255 - 260	0,01117
260 - 265	0,01556
265 - 270	0,026615
270 - 275	0,02173
275 - 280	0,01886
280 - 285	0,02385
285 - 290	0,03325
290 - 295	0,0558
295 - 300	0,048775
300 - 305	0,05172
305 - 310	0,0582
310 - 315	0,06639
315 - 320	0,07154
320 - 325	0,07055
325 - 330	0,09512
330 - 335	0,09639
335 - 340	0,089385
340 - 345	0,093505
345 - 350	0,09205
350 - 355	0,102975
355 - 360	0,09259
360 - 365	0,102445
365 - 370	0,12038
370 - 375	0,105855
375 - 380	0,11761
380 - 385	0,09477
385 - 390	0,102945
390 - 395	0,104725
395 - 400	0,123805
400 - 405	0,17054
405 - 410	0,16605
410 - 415	0,173185
415 - 420	0,17302
420 - 425	0,17187
425 - 430	0,15934
430 - 435	0,15951
435 - 440	0,176375
440 - 445	0,19012
445 - 450	0,197325
450 - 455	0,20275
455 - 460	0,2039
460 - 465	0,204675
465 - 470	0,198545
470 - 475	0,20015
475 - 480	0,20281
480 - 485	0,20243
485 - 490	0,18431
490 - 495	0,194205
495 - 500	0,196235
500 - 505	0,188705
505 - 510	0,193635
510 - 515	0,191095
515 - 520	0,175625
520 - 525	0,188285
525 - 530	0,18545
530 - 535	0,19003
535 - 540	0,18881
540 - 545	0,1853
545 - 550	0,187345
550 - 555	0,18754
555 - 560	0,18356
560 - 565	0,184385
565 - 570	0,18371
570 - 575	0,185025
575 - 580	0,183335
580 - 585	0,18539
585 - 590	0,178065
590 - 595	0,1788
595 - 600	0,17805
600 - 605	0,17588
605 - 610	0,17544
610 - 615	0,171405
615 - 620	0,169535
620 - 625	0,169125
625 - 630	0,16819333
630 - 635	0,16517333
635 - 640	0,165335
640 - 645	0,162325
645 - 650	0,15942
650 - 655	0,1588
655 - 660	0,14827
660 - 665	0,15633
665 - 670	0,15449
670 - 675	0,15203
675 - 680	0,15061
680 - 685	0,14831897
685 - 690	0,1463313
690 - 695	0,14489948
695 - 700	0,14256588
700 - 705	0,13948741
705 - 710	0,13990393
710 - 715	0,13787845
715 - 720	0,13486309
720 - 725	0,13423259
725 - 730	0,13376152
730 - 735	0,13206086
735 - 740	0,12962429
740 - 745	0,12754
745 - 750	0,12776
750 - 755	0,12608
755 - 760	0,124705
760 - 765	0,123655
765 - 770	0,120045
770 - 775	0,120335
775 - 780	0,11918
780 - 785	0,11822
785 - 790	0,11766
790 - 795	0,1149
795 - 800	0,114295
800 - 805	0,1132919
805 - 810	0,11109754
810 - 815	0,11135466
815 - 820	0,10908937
820 - 825	0,10762759
825 - 830	0,10748561
830 - 835	0,10508207
835 - 840	0,10478422
840 - 845	0,10353397
845 - 850	0,10070994
850 - 855	0,09701586
855 - 860	0,09706157
860 - 865	0,09942
865 - 870	0,09420136
870 - 875	0,09806638
875 - 880	0,09731114
880 - 885	0,095575
885 - 890	0,095075
890 - 895	0,093865
895 - 900	0,092725
900 - 905	0,090295
905 - 910	0,087985
910 - 915	0,087115
915 - 920	0,08586
920 - 925	0,08268
925 - 930	0,082905
930 - 935	0,0828019
935 - 940	0,08089436
940 - 945	0,0792869
945 - 950	0,07878754
950 - 955	0,07722328
955 - 960	0,07689959
960 - 965	0,07667862
965 - 970	0,07660158
970 - 975	0,0762319
975 - 980	0,07630618
980 - 985	0,07653897
985 - 990	0,07643221
990 - 995	0,07588879
995 - 1000	0,07466897
1000 - 1005	0,07435886
1005 - 1010	0,073765
1010 - 1015	0,07327
1015 - 1020	0,072048
1020 - 1025	0,070673
1025 - 1030	0,070488
1030 - 1035	0,069112
1035 - 1040	0,069005
1040 - 1045	0,068295
1045 - 1050	0,068136
1050 - 1055	0,066269
1055 - 1060	0,065039
1060 - 1065	0,064317
1065 - 1070	0,064222

λ (nm)	E_o (λ) (mW/cm^2 × 5 nm)
1070 - 1075	0,063761
1075 - 1080	0,062974
1080 - 1085	0,062052
1085 - 1090	0,061452
1090 - 1095	0,061057
1095 - 1100	0,060186
1100 - 1105	0,060592
1105 - 1110	0,060217
1110 - 1115	0,060092
1115 - 1120	0,058952
1120 - 1125	0,0579
1125 - 1130	0,056991
1130 - 1135	0,0566
1135 - 1140	0,056261
1140 - 1145	0,055765
1145 - 1150	0,05547
1150 - 1155	0,05476
1155 - 1160	0,055101
1160 - 1165	0,054052
1165 - 1170	0,053169
1170 - 1175	0,053157
1175 - 1180	0,052461
1180 - 1185	0,051517
1185 - 1190	0,051213
1190 - 1195	0,050996
1195 - 1200	0,050239
1200 - 1205	0,049652
1205 - 1210	0,049361
1210 - 1215	0,049108
1215 - 1220	0,04961
1220 - 1225	0,048347
1225 - 1230	0,048139
1230 - 1235	0,04827
1235 - 1240	0,047791
1240 - 1245	0,047557
1245 - 1250	0,046847
1250 - 1255	0,047153
1255 - 1260	0,046196
1260 - 1265	0,044569
1265 - 1270	0,043891
1270 - 1275	0,044069
1275 - 1280	0,044884
1280 - 1285	0,04376
1285 - 1290	0,043739
1290 - 1295	0,044083
1295 - 1300	0,043852
1300 - 1305	0,043683
1305 - 1310	0,042887
1310 - 1315	0,041991
1315 - 1320	0,041639
1320 - 1325	0,041535
1325 - 1330	0,041087
1330 - 1335	0,040513
1335 - 1340	0,040039
1340 - 1345	0,039774

λ (nm)	E_o (λ) (mW/cm^2 × 5 nm)
1345 - 1350	0,039361
1350 - 1355	0,038726
1355 - 1360	0,038213
1360 - 1365	0,037748
1365 - 1370	0,037091
1370 - 1375	0,0369
1375 - 1380	0,036761
1380 - 1385	0,036452
1385 - 1390	0,036322
1390 - 1395	0,035865
1395 - 1400	0,035661
1400 - 1405	0,035313
1405 - 1410	0,034987
1410 - 1415	0,034626
1415 - 1420	0,034413
1420 - 1425	0,034378
1425 - 1430	0,034592
1430 - 1435	0,033765
1435 - 1440	0,033126
1440 - 1445	0,032635
1445 - 1450	0,031982
1450 - 1455	0,032027
1455 - 1460	0,031038
1460 - 1465	0,031492
1465 - 1470	0,031178
1470 - 1475	0,031048
1475 - 1480	0,0307
1480 - 1485	0,030287
1485 - 1490	0,02993
1490 - 1495	0,030196
1495 - 1500	0,029987
1500 - 1505	0,029639
1505 - 1510	0,029448
1510 - 1515	0,029065
1515 - 1520	0,028948
1520 - 1525	0,028704
1525 - 1530	0,028844
1530 - 1535	0,0282
1535 - 1540	0,027517
1540 - 1545	0,027474
1545 - 1550	0,0274
1550 - 1555	0,0273
1555 - 1560	0,027174
1560 - 1565	0,026861
1565 - 1570	0,026339
1570 - 1575	0,026026
1575 - 1580	0,025861
1580 - 1585	0,025513
1585 - 1590	0,025161
1590 - 1595	0,024678
1595 - 1600	0,024613
1600 - 1605	0,024622
1605 - 1610	0,024291
1610 - 1615	0,024361
1615 - 1620	0,024274

λ (nm)	E_o (λ) (mW/cm^2 × 5 nm)
1620 - 1625	0,024091
1625 - 1630	0,024309
1630 - 1635	0,024087
1635 - 1640	0,023713
1640 - 1645	0,023452
1645 - 1650	0,023474
1650 - 1655	0,023413
1655 - 1660	0,023387
1660 - 1665	0,023261
1665 - 1670	0,022939
1670 - 1675	0,022709
1675 - 1680	0,022117
1680 - 1685	0,022061
1685 - 1690	0,021926
1690 - 1695	0,021835
1695 - 1700	0,021504
1700 - 1705	0,021596
1705 - 1710	0,021148
1710 - 1715	0,020534
1715 - 1720	0,020992
1720 - 1725	0,020474
1725 - 1730	0,019639
1730 - 1735	0,019065
1735 - 1740	0,018939
1740 - 1745	0,018996
1745 - 1750	0,018604
1750 - 1755	0,0187
1755 – 1760	0,018809
1760 – 1765	0,018439
1765 – 1770	0,018161
1770 – 1775	0,017713
1775 – 1780	0,017326
1780 - 1785	0,017163
1785 - 1790	0,017
1790 - 1795	0,016965
1795 - 1800	0,017196
1800 - 1805	0,016939
1805 - 1810	0,016709
1810 - 1815	0,016104
1815 - 1820	0,015987
1820 - 1825	0,015874
1825 - 1830	0,015639
1830 - 1835	0,015522
1835 - 1840	0,015117
1840 - 1845	0,015235
1845 - 1850	0,015087
1850 - 1855	0,0148
1855 - 1860	0,014513
1860 - 1865	0,014326
1865 - 1870	0,014196
1870 - 1875	0,013604
1875 - 1880	0,013565
1880 - 1885	0,013909
1885 - 1890	0,013813
1890 - 1895	0,013726

A.1.1.2 Spectral distribution of the Sun simulator

The spectral distribution of the Sun simulator light incident on the test plane shall be matched to the AM0 spectrum to such an extent that at least one of the following conditions is satisfied:

a. Maximum deviation of the total energy per spectral region:

   1. When characterizing single junction solar cells, the maximum deviation of total energy per spectral region is as follows:

      (a) 0,35 μm to 0,5 μm: ±20 %;

      (b) 0,5 μm to 0,8 μm: ±10 %;

      (c) 0,8 μm to 1,1 μm: ±10 %.

   2. When characterizing multi-junction solar cells, multi-source solar simulators are used, which are grouped in the classes defined in A-2, according to their maximum deviation of total energy, AM0 equivalent, for the spectral regions listed.

b. For a test lot of cells, the spectral response of the Sun simulator with respect to the AM0 spectrum shall have a maximum deviation of 1 %.

Table A-2: Classes of solar simulators for characterizing multi-junction solar cells

	Class A	Class B	Class C
0,3 μm – 0,5 μm	±15 %	±20 %	±25 %
0,5 μm - 1,1 μm (0,1 μm bins)	±15 %	±20 %	±25 %
1,1 μm - 1,9 μm (0,2 μm bins)	±15 %	±20 %	±25 %

A.1.2 Verification of spectral match

The following methods shall be used to verify conformity to the requirements of A.1.1:

a. For A.1.1.2.a., proceed as follows:

   1. Apply one of the following methods:

      (a) Direct measurement with a calibrated spectro-radiometer.

      (b) Measurement with a two-channel spectro-radiometer against a calibrated reference light source.

      (c) Measurement using a set of three solar cells that have broadband filters of the corresponding wavelength intervals attached and which, thereafter, are calibrated.

      NOTE For guidelines on the calibration method, refer to ISO 15387.

   2. Calculate the deviation of the total energy per spectral region with reference to the AM0 spectrum using the following expression:

$$Dev_{REL}(E(\lambda)_{SIM}) = \frac{\left[\int_{Range} E(\lambda)_{SIM}\, d\lambda\right] / \left[\int_{Total} E(\lambda)_{SIM}\, d\lambda\right] - \left[\int_{Range} E(\lambda)_{AM0}\, d\lambda\right] / \left[\int_{Total} E(\lambda)_{AM0}\, d\lambda\right]}{\left[\int_{Range} E(\lambda)_{AM0}\, d\lambda\right] / \left[\int_{Total} E(\lambda)_{AM0}\, d\lambda\right]}$$

where

$E(\lambda)_{SIM}$ is the spectral irradiance of the solar simulator;

$E(\lambda)_{AM0}$ is the AM0 spectral irradiance;

Range is the spectral region of interest.

b. For A.1.1.2.b., apply one of the following:

1. The short-circuit current of 10 solar cells accepted by the customer as representing a worst-case simulation of the spectral response spread of the cells to be tested, shall be measured at the constant nominal intensity of the Sun simulator.
2. From the measured spectral response of the cells (according to 7.5.6) and the AM0 spectrum given in Table A.1:
   (a) The short-circuit current is calculated and multiplied by a common factor which adjusts the average calculated short-circuit current to the average current resulting from the simulator measurements.
   (b) The difference between the calculated and measured current of each individual cell shall not exceed 1 % of the measured current.

A.1.3 Irradiance uniformity

a. The irradiance in the test plane over the full extent of the nominated test area, measured with a suitable detector, shall be uniform to the degree specified for the relevant class of solar simulator in Table A-3.

b. For bare solar cells and SCAs, testing, the largest dimension of the detector shall be less than half of the smallest dimensions of the cell.

c. In the case of coupons, the detector shall not be bigger than the SCAs bonded to it.

d. The nonconformity in the uniformity of the irradiance shall be calculated as follows:

$$\text{Nonconformity (\%)} = \pm \frac{\text{maximum irradiance} - \text{minimum irradiance}}{\text{maximum irradiance} + \text{minimum irradiance}} \times 100$$

where the maximum and minimum irradiance are those measured with the detectors over the nominated test area (corrected for temporal instability).

Table A-3: Classes of solar simulators with respect to nonconformity of irradiance uniformity

	Class A	Class B	Class C
Nonconformity (%)	≤±2	≤±5	≤±10

A.1.4 Irradiance stability

a. At the time of data acquisition, the irradiance shall be stable to the degree specified for the corresponding class of solar simulator in Table A-4.

b. The temporal instability shall be calculated with the following expression:

$$\text{Temporal instability (\%)} = \pm \frac{\text{maximum irradiance} - \text{minimum irradiance}}{\text{maximum irradiance} + \text{minimum irradiance}} \times 100$$

where the maximum and minimum irradiance are those measured with the detector at any particular point of the test plane during the time of data acquisition.

Table A-4: Classes of solar simulators with respect to temporal instability of the irradiance

	Class A	Class B	Class C
Temporal instability (%)	≤ ± 1	≤ ± 5	≤ ± 10

A.2 Standard cell and Sun simulator calibration

A.2.1 Primary standards

a. Single junction or component primary standard cells, calibrated using a method defined in ISO 15387, shall be used for setting light sources to standard illumination conditions.

b. The number and type of primary standard cells shall be mutually agreed upon between the supplier and the customer.

A.2.2 Secondary working standards (SWS)

A.2.2.1 Selection of secondary working standards

a. For single junctions, 10 solar cells representing a spectral response range similar to that of the cells to be tested, shall be calibrated for their AM0 equivalent short-circuit current using a Sun simulator, conforming to Annex A.1, using the accepted primary standards (see A.2.1).

b. For multi-junctions, three sets of component solar cells representing a spectral response range similar to the cells to be tested, shall be calibrated for their AM0 equivalent short-circuit current using a multi-source solar simulator, conforming to Annex A.1, using the accepted primary standards (see A.2.1).

A.2.2.2 Verification of secondary working standards

a. The spectral response of the SWS shall be measured according to 6.4.3.6.

b. The spectral mismatch error shall be calculated from the spectral response and the AM0 and Sun simulator spectral irradiance curves.

c. The calculated error shall be a maximum of 1 % for any SWS.

A.2.2.3 Irradiated secondary working standards

a. Electron or proton irradiated secondary working standards shall be calibrated to adjust solar simulator irradiance at the test plane to AM0 equivalent intensity when measuring the electrical performance of bare cells or SCAs irradiated with the same dose and particle energy.

b. The number of irradiated SWS shall be agreed between the supplier and the customer.

A.2.3 Stability of the sensitivity of secondary working standards

a. The stability of the sensitivity of the SWS under operating conditions shall be verified by comparing the short-circuit current of five of the SWS before and after a photon-irradiation test with the short-circuit current of the remaining five SWS which are kept in the dark.

b. If the average short-circuit current of the photon-irradiated cells deviates by more than 1 % from the original values, a new set of SWS shall be selected from a different production process established to yield stable cells.

c. The adequacy of the spectral response range of these cells shall be verified by spectral response measurements and the subsequent calculation of mismatch errors between the SWS and production cells.

d. The maximum error shall be a maximum of 1 %.

A.2.4 Sun simulator calibration and maintenance

A.2.4.1 Sun simulator calibration

a. The irradiance in the test plane shall be adjusted to the AM0 equivalent intensity by means of an SWS for single junction solar cells, deviation from the calibrated short-circuit current of the SWS shall not be higher than 1 %.

b. For multi-junction solar cells, the irradiance in the test plane shall be adjusted to AM0 equivalent conditions for each component cell with a maximum allowable deviation of 1 % in the calibrated short-circuit current of each SWS component cell.

c. The simulator intensity shall be verified with the aid of the SWS at regular intervals.

d. The length of the intervals specified in c. above shall be:

1. such as to guarantee an intensity drift of less than 1 % between two subsequent SWS measurements;
2. specified by the manufacturer in the product assurance plan.

A.2.4.2 Sun simulator maintenance

a. Correlation measurements between the SWS in daily use and a primary standard shall be made at intervals mutually agreed upon between the supplier and the customer.

b. The spectral irradiance of the Sun simulator shall be determined periodically by means of one of the procedures specified in A.1.2 or an equivalent procedure proposed by the supplier and accepted by the customer.

c. The procedure in b. above shall be performed on the following occasions:

1. immediately after the Sun simulator lamp or any part of the optical system has been changed, cleaned or repaired;
2. every 500 hours (continuous illumination) or every 5 000 flashes (pulsed) of lamp use.

A.2.5 Maintenance of standards

a. All standard solar cells (primary and SWS) shall be kept at temperatures below 50 °C during operation and storage.

b. The standard cells should be kept in the dark during extended storage periods.

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Annex B (normative)

Source control drawing for photovoltaic assembly (SCD-PVA) DRD

B.1 DRD identification

B.1.1 Requirement identification and source document

ECSS-E-20-08, 5.1.3.b.

B.1.2 Purpose and objective

The source control drawing for photovoltaic assembly (SCD-PVA) contains the specific project dependent requirements, and together with this Standard, which contains the general requirements, constitutes the whole set of requirements for the qualification and acceptance of photovoltaic assemblies.

The SCD-PVA can be produced as a standalone document or as part of a system-level specification document.

The information on traceability to high level requirements can be included in the SCD-PVA itself or in the requirements traceability in the design justification file (DJF). In either case a cross reference is made.

NOTE For the design justification file, see ECSS-E-10 Part 1.

The SCD-PVA is a major input to the qualification plan.

B.2 Expected response

B.2.1 Response identification

The requirements for project identification contained in ECSS-M-50 shall be applied to the SCD-PVA.

B.2.2 Scope and content

The SCD-PVA shall provide the information presented in the following sections:

<1> **Introduction**

The SCD-PVA shall contain a description of the purpose, objective, content and the reasons prompting its preparation.

<2> **Applicable and reference documents**

The SCD-PVA shall list the applicable and reference documents to support the generation of the document.

<3> **Terms and definitions, abbreviated terms and symbols**

The SCD-PVA shall include any additional definition, abbreviation or symbol used.

<4> **Deviations from ECSS-E-20-08**

As specified in 5.1.3, the SCD-PVA shall include the description and justification for any deviation in the in-process, acceptance and qualification tests.

<5> **Qualification test coupons**

As specified in 5.3.3.2, the SCD-PVA shall include the following:

a. PVA coupon drawings

The front and rear side drawings of each qualification coupons with physical dimensions and including tolerances.

b. Number of repaired cells

The number of repaired cells to be included on each qualification coupon.

<6> **In-process tests**

a. Mass measurement

The SCD-PVA shall state the maximum value of the mass of the coupon, in g, obtained from the mass measurement specified in 5.4.3.2.

b. Wet insulation

As specified in 5.4.3.3, the SCD-PVA shall state:

1. The test voltage, in V.
2. The fluid to use.
3. The minimum value for the wet insulation, in MΩ.

NOTE 1 The fluid used is normally ethyl or isopropyl.

NOTE 2 A usual value for the wet insulation is 100 MΩ.

c. Adherence to substrate

As specified in 5.4.3.4, the SCD-PVA shall state the minimum flatwise tensile strength, in N.

d. In-process visual inspection

As specified in 5.4.3.5, the SCD-PVA shall state the visual inspection procedure.

e. In-process continuity

As specified in 5.4.3.6, the SCD-PVA shall state the maximum value of the resistance, in Ω.

<7> Qualification tests

a. Fatigue thermal cycling

As specified in 5.5.1.3, the SCD-PVA shall state the following:

1. The following test conditions:
   — the number of cycles to perform;
   — the temperature limits, in °C.
2. For the acceptance criteria:
   — the maximum variation of I_{OP}, in %, where I_{OP} is the thermal cycling power output loss taken into account in the power output analysis;
   — the minimum insulation, in MΩ.

b. Humidity

As specified in 5.5.1.4, the SCD-PVA shall state:

1. The maximum increment of I_{OP}, in %.
2. The chemical contents (type and % in the mist) of the humid environment when there are specific requirements on the contents of the environment.

c. UV exposure

As specified in 5.5.1.5, the SCD-PVA shall state the following test conditions:

1. The value of the UV irradiation acceleration factor (less than 10 Suns).
2. The test temperature, in °C.

d. Four-point bending

As specified in 5.5.1.6, the SCD-PVA shall state:

1. The analysis technique, algorithm or equivalent finite element method used to calculate the maximum bending.
2. The maximum increment of I_{OP}, in %.

e. Electrostatic discharge

As specified in 5.5.1.7, the SCD-PVA shall state:

1. The test coupon load in V.
2. The maximum increment of I_{OP}, in %.

f. ATOX

As specified in 5.5.1.8, the SCD-PVA shall state the maximum erosion of the different layers of PVA components.

g. Erosion of materials

As specified in 5.5.1.9, the SCD-PVA shall state the test sequence, test definitions and requirements for the erosion of materials test.

h. EMC

As specified in 5.5.1.10, the SCD-PVA shall state the test sequence, test definitions and requirements for the EMC test.

<8> Definition of tests and checks

a. Add-on mass

As specified in 5.5.3.1, the SCD-PVA shall state the maximum add-on mass of the coupon, in g, obtained from a mass measurement.

b. Full visual inspection

The SCD-PVA shall state:

1. The maximum number of cell cracks on the coupons (see G.5.2.a.1).
2. The maximum number of gridlines that a cell crack can cross (see G.5.2 a.2).
3. The inspection criteria for solar cells on substrates (as specified in 5.5.3.2 b).

c. Electrical health

1. Electrical continuity check

   As specified in 5.5.3.3.2, the SCD-PVA shall state the following conditions for checking the continuity of the strings:

   — current to be applied, in A, or voltage to be measured, in V.

   — specified illumination to performed the measurement.

2. Insulation resistance

   The SCD-PVA shall state the minimum insulation resistance, in MΩ, at a test voltage specified in V, for the configurations specified in 5.5.3.3.3..

3. Grounding spot resistance

   As specified in 5.5.3.3.4, the SCD-PVA shall state:

   — The maximum value, in Ω, of the resistance of bleed resistor lead (+) to substrate (-).

   — The maximum value, in Ω, of the grounding spots (+) to substrate (-).

4. Bleed resistor test

   As specified in 5.5.3.3.5, the SCD-PVA shall state the range of values, in kΩ, of the bleed resistor.

5. Blocking diode test

   As specified in 5.5.3.3.6, the SCD-PVA shall state:

   — The $I_{FORWARD}$ in A, and the $V_{REVERSE}$ in V, of the blocking diode.

   — The values for $V_{FORWARD}$, in V, and $I_{REVERSE}$, in A, to be obtained from the test.

6. Shunt diode

   As specified in 5.5.3.3.7, the SCD-PVA shall state:

   — The $I_{FORWARD}$, in A, to be used, and the maximum drop of forward voltage, in V, per cell, to be obtained from the test.

   — The test method to be used.

   — The maximum temperature, specified in °C.

7. Thermal sensor test

   As specified in 5.5.3.3.8, the SCD-PVA shall state:

   — The resistance of the thermal sensor as a function of the temperature.

   — The range of resistance to be obtained from the test, in Ω.

   NOTE A reference to a calibration table, included in the SCD, can be used.

8. Resistance measurements

   As specified in 5.5.3.3.9, the SCD-PVA shall state the maximum value of the resistance, in Ω, between the (+)/(+) and (–)/(–) ends of the harness.

d. Electrical performance

   As specified in 5.5.3.4.2, the SCD-PVA shall state the values listed in 1. to 5. below, together with their inaccuracies, recalculated to 25 °C, for 1 S.C. (AM0) (as defined in Annex A), providing the test voltage V_{OP} range (specified in V), and the temperature range (specified in °C).

   1. the nominal value of the $I_{OP,MIN}$, in A;
   2. the nominal value of $V_{P,MAX}$., in V;
   3. the nominal value of V_{OC}, in V;
   4. the nominal value of $I_{P,MAX}$, in A;
   5. the nominal value of I_{SC}, in A.

e. Capacitance

   As specified in 5.5.3.5, the SCD-PVA shall state a procedure to measure the capacitance, including the test temperature.

f. Bake-out

   As specified in 5.5.3.6, the SCD-PVA shall state:

   1. The test conditions, as a combination of time and temperature.
   2. For the acceptance criteria, the maximum value for the increment of I_{OP}, in % of the nominal value.

g. Acceptance thermal cycling test

   As specified in 5.5.3.7, the SCD-PVA shall state:

   1. The following test conditions for the tests specified in 5.5.3.7:
      — The number of cycles to perform.
      — The temperature limits, in °C.
   2. For the acceptance criteria:
      — The maximum increment of I_{OP}, in %.
      — The minimum insulation, in MΩ .

h. Reflectance

   As specified in 5.5.3.8, the SCD-PVA shall state the maximum reflectance change, in %, for the following wavelength bands:

   1. $\lambda \leq 300$ nm;
   2. 300 nm < $\lambda \leq 900$ nm;
   3. 900 nm< $\lambda \leq 1800$ nm.

i. Transmission

   As specified in 5.5.3.9, the SCD-PVA shall state the acceptance criteria for the change in transmission due to contamination in the band of 280 nm < $\lambda \leq 2500$ nm.

j. X-ray

   As specified in 5.5.3.10, the SCD-PVA shall state the acceptance criteria, for the integrity of:

   1. busbars,
   2. wire collection strips, and
   3. diode boards.

k. Substrate integrity

As specified in 5.5.3.11, the SCD-PVA shall state:

1. The test method, after airscan, or C-scan, or destructive test, for the integrity of the skin to honeycomb.
2. The acceptance criteria.

l. Vacuum thermal cycling

As specified in 5.5.3.12, the SCD-PVA shall state the maximum acceptable degradation, as follows:

1. The maximum increment for I_{OP}, in %.
2. The minimum insulation, in $M\Omega$.

Annex C (normative)

Source control drawing for solar cell assembly (SCD-SCA) DRD

C.1 DRD identification

C.1.1 Requirement identification and source document

ECSS-E-20-08, 6.1.2.b.

C.1.2 Purpose and objective

The source control drawing for solar cell assembly (SCD-SCA) contains the specific project dependent requirements, and together with this Standard, which contains the general requirements, constitutes the whole set of requirements for the qualification and acceptance of solar cell assemblies.

The SCD-SCA can be produced as a standalone document or as part of a system-level specification document.

The information on traceability to high level requirements can be included in the SCD-SCA itself or in the requirements traceability in the design justification file (DJF). In either case a cross-reference is made.

NOTE For the design justification file, see ECSS-E-10 Part 1.

The SCD-SCA is a major input to the qualification plan.

C.2 Expected response

C.2.1 Response identification

The requirements for project identification contained in ECSS-M-50 shall be applied to the SCD-SCA.

C.2.2 Scope and content

The SCD-SCA shall provide the information presented in the following sections:

<1> Introduction

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

<2> Applicable and reference documents

The SCD-SCA shall list the applicable and reference documents to support the generation of the document.

<3> Terms and definitions, abbreviated terms and symbols

The SCD-SCA shall include any additional definition, abbreviation or symbol used.

<4> Deviations from ECSS-E-20-08

As specified in 6.1.2, the SCD-SCA shall include the justification for any deviation in the in-process, acceptance and qualification tests.

<5> Materials

The SCD-SCA shall include the following solar cell characteristics:

a. For silicon solar cells: growth technique, doping element, base resistivity, and thickness.

b. For single or multi-junction solar cells:

   1. for the substrate: doping element, orientation, and resistivity;

   2. for each sub-cell: growth technique, materials, type of layers, doping elements, and thickness.

c. For contacts: all metal layers and their thickness.

d. For ARC: materials of all layers.

e. For coverglass: material, thickness, ARC, and conductive coating.

f. For coverglass adhesive, material and outgassing rates.

   NOTE See ECSS-Q-70-02.

<6> Test methods, conditions and measurements

a. Visual inspection

   The SCD-SCA shall include the following:

   1. As specified in 6.4.3.2.4, the maximum dimensions of hairline cracks, in mm.

   2. As specified in 6.4.3.2.8, the maximum value of worm shaped bulges area, as a percentage (%) of total cell contact area.

   3. As specified in 6.4.3.2.8, the maximum visible semiconductor length at the corners, in mm.

b. Dimensions and weight

   As specified in 6.4.3.3, the SCD-SCA shall include:

   1. A figure, showing the physical dimensions of the solar cell assembly, including both, the nominal values and tolerances.

   2. The average weight (per lot) of solar cell assemblies including the interconnector, in g.

c. Electrical performance

   As specified in 6.4.3.4, the SCD-SCA shall include, the information shown in Table C-1, extended if there are several operational voltages at a solar cell temperature of 25 °C, under illumination of 1 S.C (AM0).

Table C-1: Minimum current requirement for solar assemblies (25 °C or operating temperature)

Sample	**Irradiation dose**	**Test voltage V_t (mV)**	**Current at V_t (mA)**
Minimum for individual solar cell assemblies	BOL	[Insert value]	[Insert value]
	EOL	[Insert value]	[Insert value]
Minimum average for solar cell assemblies	BOL	[Insert value]	[Insert value]
	EOL	[Insert value]	[Insert value]
Test temperature: [Insert value]			
NOTE EOL is defined as 1 MeV Φ_p electron dose (see 6.4.3.12) plus photon irradiation and temperature annealing (see 6.4.3.13).			

d. Temperature coefficient

As specified in 6.4.3.5, the SCD-SCA shall include the six equidistant solar cell junction temperatures to which the test is performed.

e. Spectral response

As specified in 6.4.3.6, the SCD-SCA shall include:

1. For single-junction GaAs solar cells, the number and wavelength of narrow band interference filters in the range between 0,75 μm to 1,1 μm.
2. For multi-junction GaAs solar cells, the number of narrow band interference filters and their wavelength.

f. Thermo-optical properties

As specified in 6.4.3.7, the SCD-SCA shall include the following:

1. The maximum value of the solar absorptance as a percentage of SCAs with tolerances.
2. The maximum value of normal emittance as a percentage (%) of SCAs with tolerances.

g. Thermal cycling

As specified in 6.4.3.8, the SCD-SCA shall include the number of cycles to be performed and their extreme temperatures, to simulate the number of eclipses occurring during one year in orbit for LEO missions, and 1000 thermal cycles for GEO missions..

h. Humidity and temperature

As specified in 6.4.3.9, the SCD-SCA shall include the chemical contents (type and % in the mist) to be added to the humid environment, when there are specific requirements on the contents of the environment.

i. Interconnector adherence

As specified in 6.4.3.11, the SCD-SCA shall include:

1. the value of the pull speed, in mm/min;
2. the value of the separation pull strength of interconnectors, in N.

j. Electron irradiation

As specified in 6.4.3.12, the SCD-SCA shall include:

1. for mission specific qualification, the expected dose for the envisaged application, Φ_p, at 1MeV, in e^- cm^{-2};
2. the electron irradiation at transfer orbit dose at 1MeV, in e^- cm^{-2}, when specified by the mission requirements.

k. Surface conductivity

As specified in 6.4.3.14, the SCD-SCA shall describe:

1. The method to perform the surface conductivity test.
2. The minimum value, in Ω, and the maximum variation after any test, in Ω, of the cover conductivity before and after qualification tests of SCA of subgroup D (refer to Table 4).

l. Cell reverse - diode characteristics

As specified in 6.4.3.15, the SCD-SCA shall include:

1. For SCAs without protection diode, for the performance of the I/V characteristics:
   — the temperatures,
   — the times, and
   — the operating points,
2. For SCAs with protection diode electrically connected to the cell, for the performances of the SCA diode forward characteristics:
   — the temperatures,
   — the times,
   — the forward current.
3. For SCAs with protection diode electrically isolated from the cell:
   — For the performance of the SCA reverse I/V characteristics:
     * the temperatures,
     * the times,
     * the operating points.
   — The maximum current, in mA, when the photovoltaic response can be considered negligible.
   — For the performance of the forward and reverse SCA diode characteristics:
     * the temperatures,
     * times,
     * forward current;
     * reverse voltage.
   — The temperatures and voltage for the performance of the electrical insulation test of cell and diode.

m. Cell reverse - diode performance

As specified in 6.4.3.16, the SCD-SCA shall include:

1. For SCAs without protection diode:
   (a) For the performance of test specified in 6.4.3.16.2.b.1.
     * the temperatures,
     * the times,
     * the operating points.
   (b) The following pass-fail criteria for the test specified in 6.4.3.16.2.b.1.:
     * the maximum absolute value of the reverse current, in mA or voltage, in V;
     * the maximum change in the value of reverse current ΔI, in mA or voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) For the test specified in 6.4.3.16.2.b.:
   * the number of cycles of controlled on-off switching;
   * the temperature in °C;
   * the frequency in Hz;
   * the forward ($V_{CELL\text{-}FORWARD}$) and reverse ($V_{CELL\text{-}REVERSE}$) bias voltage in V;
   * the time of application in s.

(d) The following pass-fail for the test specified in 6.4.3.16.2.b.:
   * the maximum value of the change, ΔI, in mA;
   * the value of the reverse current measured at the specified reverse voltage before and after the test.

2. For SCAs with protection diode electrically connected to the cell:

(a) For the test specified in 6.4.3.16.2.c.1.:
   * the temperatures,
   * the times,
   * the forward current.

(b) The following pass-fail criteria for the test in 6.4.3.16.2.c.1.:
   * the maximum absolute value of the forward voltage, in V;
   * the maximum change in the value of the forward voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) For the test specified in 6.4.3.16.2.c.2.:
   * the number of cycles of controlled on-off switching;
   * the temperature in °C;
   * the frequency in Hz;
   * the forward and reverse bias voltage in V;
   * the time of application in s.

(d) The following pass-fail criteria for the test described in 6.4.3.16.2.c.2.: the maximum value of the change, ΔI, in mA, in the value of reverse current measured at the specified reverse voltage before and after the test.

3. For SCAs with protection diode electrically isolated from the cell.

(a) For the test in 6.4.3.16.2.d.1.:
   * the temperatures,
   * the times,
   * the operating points.

(b) The following pass-fail criteria for the test in 6.4.3.16.2.d.1.:
   * the maximum absolute value of the reverse current, in mA or voltage, in V.;
   * the maximum change in the value of reverse current ΔI, in mA or voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) The maximum current, in mA, when the photovoltaic response is to be considered negligible.

(d) For the test specified in 6.4.3.16.2.d.3.:

* the temperatures, in °C,
* the times,
* the forward current ($I_{DIODE-FORWARD}$),
* the reverse voltage ($V_{DIODE-REVERSE}$).

(e) The following pass-fail criteria for the test in 6.4.3.16.2.d.3.:

* the maximum absolute value of the forward voltage in V, or reverse current in mA;
* the maximum change in the value of the forward voltage ΔV in V, from the initial value of the same parameter when measured as delivered;
* the maximum change in the value of the reverse current ΔI in mA, from the initial value of the same parameter when measured as delivered.

(f) For the test specified in 6.4.3.16.2.d.4.:

* the number of cycles of controlled on-off switching,
* the temperature in °C,
* the frequency in Hz,
* the forward ($V_{DIODE-FORWARD}$) and reverse ($V_{DIODE-REVERSE}$) bias voltage in V,
* the time of application in s.

(g) The pass-fail criteria for the test specified in 6.4.3.16.2.d.4. in terms of the maximum value of the change, ΔI, in mA, in the value of reverse current measured at the specified reverse voltage before and after the test.

(h) The temperatures and voltage for the test specified in 6.4.3.16.2.d.5.

(i) The following pass-fail criteria for the test specified in 6.4.3.16.2.d.5.:

* the maximum absolute value of current in mA;
* the maximum change in the value of current ΔI, in mA, from the initial value of the same parameter when measured as delivered.

n. Ultraviolet exposure

As specified in 6.4.3.17, the SCD-SCA shall include the following test conditions:

1. The test temperature, in °C.
2. The value of the UV irradiation acceleration factor.

o. Capacitance

As specified in 6.4.3.18, the SCD-SCA shall include the test temperature, in °C and the capacitance test method.

p. Flatness

As specified in 6.4.3.19, the SCD-SCA shall include the minimum flatness, as a maximum deviation given in mm.

Annex D (normative)

Source control drawing for bare solar cell (SCD-BSC) DRD

D.1 DRD identification

D.1.1 Requirement identification and source document

ECSS-E-20-08, 7.1.1.2.a.

D.1.2 Purpose and objective

The source control drawing for bare solar cell (SCD-BSC) contains the specific project dependent requirements, and together with this Standard, which contains the general requirements, constitutes the whole set of requirements for the qualification and acceptance of bare solar cells.

The SCD-BSC can be produced as a standalone document or as part of a system-level specification document.

The information on traceability to high level requirements can be included in the SCD-BSC itself or in the requirements traceability in the design justification file (DJF). In either case a cross-reference is made.

NOTE For the design justification file, see ECSS-E-10 Part 1.

The SCD-BSC is a major input to the qualification plan.

D.2 Expected response

D.2.1 Response identification

The requirements for project identification contained in ECSS-M-50 shall be applied to the SCD-BSC.

D.2.2 Scope and content

The SCD-BSC shall provide the information presented in the following sections:

<1> Introduction

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

<2> Applicable and reference documents

The SCD-BSC shall list the applicable and reference documents to support the generation of the document.

<3> Terms and definitions, abbreviated terms and symbols

The SCD-BSC shall include any additional definition, abbreviation or symbol used.

<4> Deviations from ECSS-E-20-08

As specified in 7.1.1.2.c., the SCD-BSC shall include the justification for any deviation in the in-process, acceptance and qualification tests.

<5> Materials

The SCD-BSC shall include:

a. Reference to the procurement specification of the supplier.

b. For silicon solar cells, the following characteristics of the cells:

   1. growth technique;
   2. doping element;
   3. orientation;
   4. main breakage direction;
   5. base resistivity;
   6. thickness.

c. For single and multi-junction III-V solar cells, the following characteristics of the cells:

   1. substrate material and orientation;
   2. doping element of the substrate;
   3. substrate resistivity;
   4. sequence of cell structures.

<6> Acceptance tests

a. Visual inspection.

   The SCD-BSC shall list the following solar cell and contact defects requirements:

   1. As specified in 7.5.2.4.2, the maximum value of the total uncoated area as a percentage (%) of the total area and the maximum value of the spatter in mm.
   2. As specified in 7.5.2.4.3, the acceptance criteria for hairline cracks.
   3. As specified in 7.5.2.5.4, the maximum value of worm shaped bulges area, as a percentage (%) of total cell contact area.
   4. As specified in 7.5.2.5.4, the maximum visible semiconductor length at the corners, in mm.

b. Dimensions and weight

As specified in 7.5.3, the SCD-BSC shall include:

1. The dimensions shown in Figure D-1 to Figure D-3 including tolerances.
2. The measurement method used to perform the test.
3. The interval of the thickness of the silicon layer, in μm, for silicon solar cells.
4. The interval of the thickness of the substrate with epi-layers, in mm, for III-IV cells.
5. The maximum weight, in mg, of the average shipment lot.

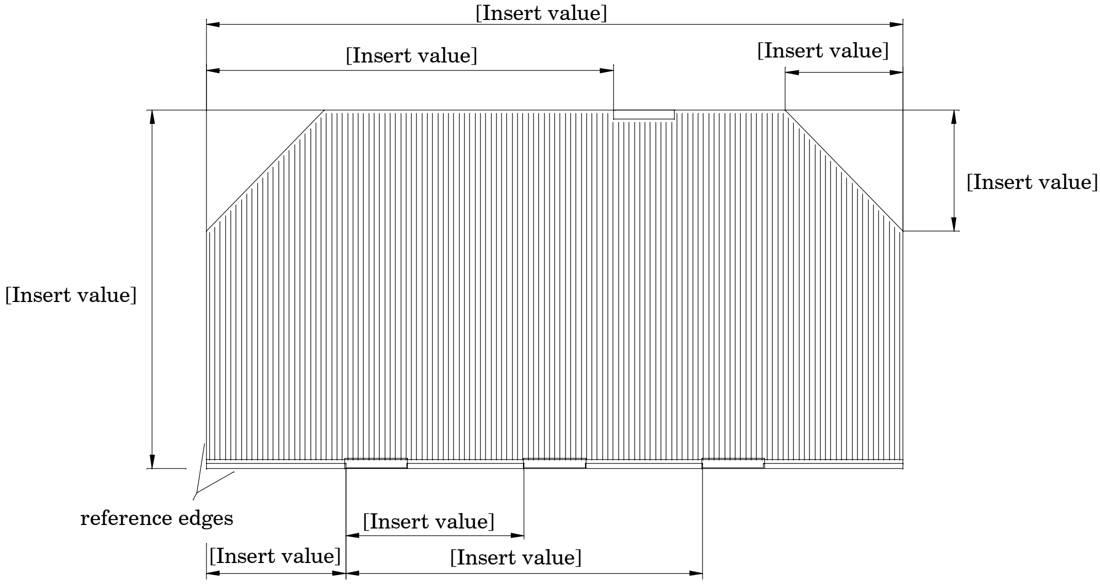

Figure D-1: Front side

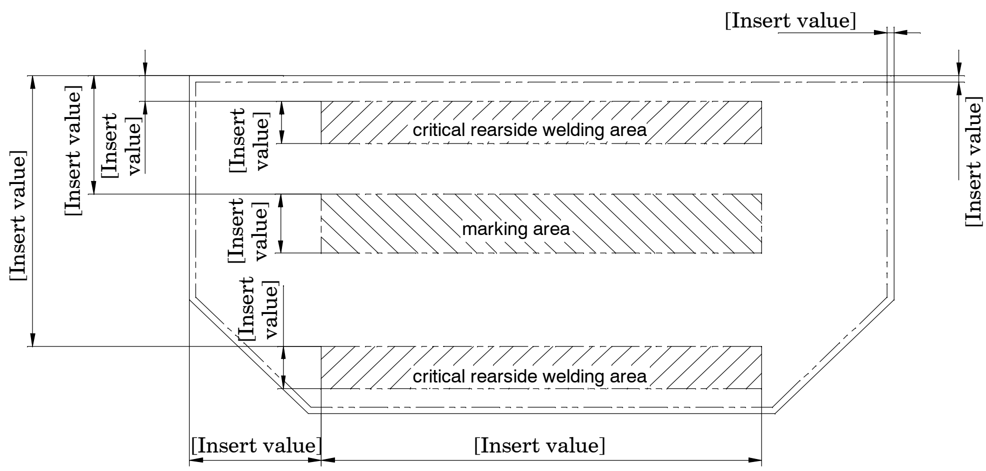

Figure D-2: Rear side

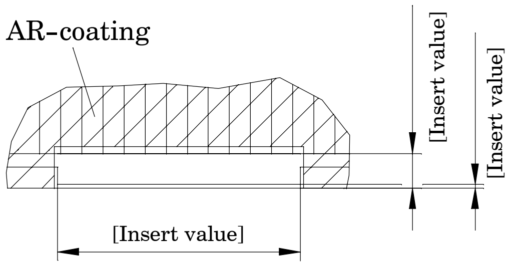

Figure D-3: Contact

c. Contact uniformity and surface finish

As specified in 7.5.10, the SCD-BSC shall include:

1. For the contact uniformity:
   — the equipment to measure the contact thickness;
   — the maximum and minimum values of the contact thickness in μm.
2. For the surface finish (R_z) its maximum value in μm.

d. Electrical performance

1. As specified in 7.5.4.3.1, the SCD-BSC shall include the following test conditions:
   — the V_{OP} interval, in mV;
   — the junction temperature interval, in °C;
   — the cells used as reference and their traceability to primary standards.
2. As specified in 7.5.4.3.2 and 7.5.4.2 f, for the pass-fail criteria, the following requirements shall be included:
   — the nominal value for $I_{OP,MIN}$, in mA;
   — the average value for $I_{OP,MIN}$, in mA;
   — the intervals in mA for electrical grading.

e. Hemispherical reflectance

As specified in 7.5.7.2, the SCD-BSC shall include the interval of reflectance for silicon BSR cells, at 1,5 μm, as a percentage (%).

f. Humidity and temperature

As specified in 7.5.8.2.2, the SCD-BSC shall include the chemical contents (type and % in the mist) to be added to the humid environment when there are specific requirements on the contents of the environment.

g. Pull

As specified in 7.5.11, the SCD-BSC shall include:

1. the interconnection technique parameter;
2. the material and dimension of the interconnectors;
3. the value of the pull speed in mm/min;
4. the value of the ultimate pull strength in N.

h. Diode performance

As specified in 7.5.16, the SCD-BSC shall include for cells with protection diode electrically isolated from the cell:

1. The maximum current, in mA, when the photovoltaic response can to be considered negligible.
2. For the test specified in 7.5.16.2.d.3.:
   - the temperatures,
   - the times,
   - the forward current,
   - the reverse voltage.
3. The pass-fail criteria for the test specified in 7.5.16.2.d.3.:
   - the maximum absolute value of the forward voltage in V;
   - the reverse current in mA;
   - the maximum change in the value of the forward voltage ΔV in V, from the initial value of the same parameter when measured as delivered;
   - the maximum change in the value of the reverse current ΔI in mA, from the initial value of the same parameter when measured as delivered.
4. For the test specified in 7.5.16.2.d.5.:
   - the temperatures,
   - the voltage.
5. The pass-fail criteria for the test specified in 7.5.16.2.d.5.:
   - the maximum absolute value of current in mA,
   - the maximum change in the value of current ΔI, in mA, from the initial value of the same parameter when measured as delivered.

i. Cell coverglass gain-loss

As specified in 7.5.7.3, the SCD-BSC shall include:

1. the agent used to simulate the properties of the adhesive;
2. the coverglass used for the test;
3. for the test conditions, the junction temperature interval, in °C.
4. for the pass-fail criteria, the maximum I_{SC}, in %.

<7> Qualification

a. Qualification test samples

As specified in 7.4.2.2, the SCD-BSC shall include:

1. The number of cells of the set from which the cell for qualification are selected.
2. The number of the first production batches from which the set is obtained.

b. Visual inspection

The SCD-BSC shall include the same provisions as in the visual inspection for the acceptance tests (see D.2.2<6>a.).

c. Dimensions and weight

The SCD-BSC shall include the same provisions as in the dimensions and weight for the acceptance tests (see D.2.2<6>b.).

d. Electrical performance

As specified in 7.5.4.2, the SCD-BSC should include the pass-fail values shown in Table D-1, for

1. the individual solar cells, and
2. the minimum average.

Table D-1: Electrical performance pass-fail criteria

		Remaining Factors (at 25 °C)		
	BOL	EOL([Insert value]) (particles/cm²)a)	EOL([Insert value]) (particles/cm²)a)	EOL([Insert value]) (particles/cm²)a)
Parameter		**Ratio**	**Ratio**	**Ratio**
V_{OC} [mV]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
I_{SC} [mA/cm^2]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
V_{MAX} [mV]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
I_{MAX} [mA/cm^2]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
P_{MAX} [mW/cm^2]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
$I_{(Vt)}$ [mA]	[Insert value]	[Insert value]	[Insert value]	[Insert value]
a) particles are electrons or protons after photon irradiation and temperature annealing				

e. Spectral response

As specified in 7.5.6.2, the SCD-BSC shall include:

1. For single-junction GaAs solar cells, the number and wavelength of narrow band interference filters in the range between 0,75 µm to 1,1 µm.
2. For multi-junction GaAs solar cells the number of narrow band interference filters and their wavelength.

f. Optical properties

1. Hemispherical reflectance

   The SCD-BSC shall include the same provisions as in the hemispherical reflectance for acceptance tests (see D.2.2 <6>e.).

2. Coverglass gain-loss

   The SCD-BSC shall include the same provisions as in the coverglass gain-loss for acceptance tests (see D.2.2 <6>i.).

g. Humidity and temperature

The SCD-BSC shall include the same provisions as in the humidity and temperature for acceptance tests (see D.2.2 <6>f.).

h. Contact uniformity and surface finish

The SCD-BSC shall include the same provisions as in the contact uniformity and surface finish for acceptance tests (see D.2.2<6>c.).

i. Pull

The SCD-BSC shall include the same provisions as in the pull test for acceptance tests (see D.2.2<6>g.).

j. Electron irradiation

As specified in 7.5.12.2, the SCD-BSC shall include:

1. For general characterization of solar cells, the dosages at 1 MeV, in e^{-} cm^{-2}.
2. For mission specific qualification, the expected dose for the envisaged application, Φ_p, at 1MeV, in e^{-} cm^{-2}.

3. The electron irradiation at transfer orbit dose at 1MeV, in $e^- cm^{-2}$, when specified by the mission requirements.

k. Proton irradiation

As specified in 7.5.13.2, the SCD-BSC shall include:

1. The two energies to which cells of subgroup P are irradiated (X_1 and X_2 in MeV);
2. For each of the two energies defined in 1. above, the flux in $p^+ cm^{-2} s^{-2}$.

l. Cell reverse - diode characteristics

As specified in 7.5.15.2, the SCD-BSC shall include:

1. For cells without protection diode, for the performance of the cell reverse I/V characteristics:
   - the temperatures,
   - the times, and
   - the operating points,
2. For cells with protection diode electrically connected to the cell, for the performance of the cell diode forward characteristics:
   - the temperatures,
   - the times,
   - the forward current.
3. For cells with protection diode electrically isolated from the cell:
   - For the performance of the cell reverse I/V characteristics:
     * the temperatures,
     * the times,
     * the operating points.
   - The maximum current, in mA, when the photovoltaic response can be considered negligible.
   - For the performance of the forward and reverse cell diode characteristics:
     * the temperatures,
     * times,
     * forward current;
     * reverse voltage.
   - The temperature and voltage for the performance of the electrical insulation test of cell and diode.

m. Cell reverse - diode performance

As specified in 7.5.16.2, the SCD-BSC shall include:

1. For cells without protection diode:
   (a) For the test specified in 7.5.16.2.b.1., for the performance of the cell reverse I/V characteristics:
     * the temperatures,
     * the times,
     * the operating points.

(b) The following pass-fail criteria for the test specified in 7.5.16.2.b.1.:
   * the maximum absolute value of the reverse current, in mA or voltage, in V;
   * the maximum change in the value of reverse current ΔI, in mA or voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) For the test specified in 7.5.16.2.b.2.:
   * the number of cycles of controlled on-off switching;
   * the temperature in °C;
   * the frequency in Hz;
   * the forward and reverse bias voltage in V;
   * the time of application in s.

(d) The following pass-fail criteria for the test specified in 7.5.16.2.b.2.:
   * the maximum value of the change, ΔI, in mA;
   * the value of the reverse current measured at the specified reverse voltage before and after the test.

2. For cells with protection diode electrically connected to the cell:

(a) For the test specified in 7.5.16.2.c.1.:
   * the temperatures,
   * the times, and
   * the forward current

(b) The following pass-fail criteria for the test specified in 7.5.16.2.c.1.:
   * the maximum absolute value of the forward voltage, in V;
   * the maximum change in the value of the forward voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) For the test specified in 7.5.16.2.c.2.:
   * the number of cycles of controlled on-off switching;
   * the temperature in °C;
   * the frequency in Hz;
   * the forward and reverse bias voltage in V;
   * the time of application in s.

(d) The following pass-fail criteria for the test specified in 7.5.16.2.c.2.: the maximum value of the change, ΔI, in mA, in the value of reverse current measured at the specified reverse voltage before and after the test;

3. For cells with protection diode electrically isolated from the cell.

(a) For the test specified in 7.5.16.2.d.1.:
   * the temperatures,
   * the times,
   * the operating points.

(b) The following pass-fail criteria for the test specified in 7.5.16.2.d.1.:

* the maximum absolute value of the reverse current, in mA or voltage, in V.;
* the maximum change in the value of reverse current ΔI, in mA or voltage ΔV, in V, from the initial value of the same parameter when measured as delivered.

(c) The maximum current, in mA, when the photovoltaic response is to be considered negligible.

(d) For the test specified in 7.5.16.2.d.3.:

* the temperatures,
* the times,
* the forward current,
* the reverse voltage.

(e) The following pass-fail criteria for the test specified in 7.5.16.2.d.3.:

* the maximum absolute value of the forward voltage in V, or reverse current in mA;
* the maximum change in the value of the forward voltage ΔV in V, from the initial value of the same parameter when measured as delivered;
* the maximum change in the value of the reverse current ΔI in mA, from the initial value of the same parameter when measured as delivered.

(f) For the test specified in 7.5.16.2.d.4.:

* the number of cycles of controlled on-off switching,
* the temperature in °C,
* the frequency in Hz,
* the forward and reverse bias voltage in V,
* the time of application in s.

(g) The following pass-fail criteria for the test specified in 7.5.16.2.d.4.: the maximum value of the change, ΔI, in mA, in the value of reverse current measured at the specified reverse voltage before and after the test.

(h) For the test specified in 7.5.16.2.d.5.:

* the temperature, and
* the voltage.

(i) The following pass-fail criteria for the test specified in 7.5.16.2.d.5.:

* the maximum absolute value of current in mA;
* the maximum change in the value of current ΔI, in mA, from the initial value of the same parameter when measured as delivered.

n. Thermal cycling

As specified in 7.5.17, the SCD-BSC shall include the number of thermal cycles to be performed before pull test on subgroup A and after humidity and temperature test in subgroup O, and their extreme temperatures.

o. Active-passive interface evaluation

As specified in 7.5.18, the SCD-BSC shall include:

1. The deviation of total energy in the spectral region of 0,8 μm to 1,1 μm as a percentage, using a non-infrared rich solar simulator.
2. The maximum delta in V_{oc} of the cell under both solar simulator conditions (1 S.C. (AM0) and non-infrared rich).

p. Flatness

As specified in 7.5.19, the SCD-BSC shall include:

1. The measurement method used to determine the flatness.
2. The minimum flatness, as the maximum value, in mm, of the deformation.

Annex E (normative)

Source control drawing for coverglass (SCD-CVG) DRD

E.1 DRD identification

E.1.1 Requirement identification and source document

ECSS-E-20-08 clause 8.2.1.2.b.

E.1.2 Purpose and objective

The source control drawing for coverglass (SCD-CVG) contains the specific project dependent requirements, and together with this Standard, which contains the general requirements, constitutes the whole set of requirements for the qualification and acceptance of coverglass.

The SCD-CVG can be produced as a standalone document or as part of a system-level specification document.

The information on traceability to high level requirements can be included in the SCD-CVG itself or in the requirements traceability in the design justification file (DJF). In either case a cross-reference is made.

NOTE For the design justification file, see ECSS-E-10 Part 1.

The SCD-CVG is a major input to the qualification plan.

E.2 Expected response

E.2.1 Response identification

The requirements for project identification contained in ECSS-M-50 shall be applied to the SCD-CVG.

E.2.2 Scope and content

The SCD-CVG shall provide the information presented in the following sections:

<1> Introduction

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

<2> Applicable and reference documents

The SCD-CVG shall list the applicable and reference documents to support the generation of the document.

<3> Terms and definitions, abbreviated terms and symbols

The SCD-CVG shall include any additional definition, abbreviation or symbol used.

<4> Deviations from ECSS-E-20-08

As specified in 8.2.1.2.c., the SCD-CVG shall include the justification for any deviation in the in-process, acceptance and qualification tests.

<5> Materials

The SCD-CVG shall include the following coverglass materials characteristics:

a. Coverglass base material, including doping elements and percentage (%).

b. Front surface coatings (including conductive coatings).

c. Rear surface coatings.

<6> Marking (coating orientation)

As specified in 8.2.3, the SCD-CVG shall include a figure defining the coating orientation method for coverglass front surface coating identification.

NOTE This figure can be the same as the one mentioned in E.2.2<8>d.

<7> Acceptance tests

a. Sample size for acceptance

As specified in 8.4.1.b., the SCD-CVG shall include the sample size for acceptance.

b. Transmission into air

The SCD-CVG shall include the same provisions as for the transmission into air for qualification tests (see E.2.2<8> c.).

c. Dimensions, weight and thickness.

The SCD-CVG shall include the same provisions as for the mechanical properties for the qualification tests (see <8>e.1., <8>e.2., and <8>e.3.).

d. Visual inspection

The SCD-CVG shall include the same provisions as for the visual inspection for qualification tests (see E.2.2<8> a.).

e. Humidity and temperature HT2

As specified in 8.6.11.2, the SCD-CVG shall state the chemical contents (type and percentage (%) in the mist) of the humid environment when there are specific requirements on the contents of the environment.

f. Thermal cycling

The SCD-CVG shall include the same provisions as for the thermal cycling for qualification tests (see E.2.2<8> p.).

<8> Qualification tests

a. Qualification test samples

As specified in 8.5.2.2, the SCD-CVG shall include the number of the first production batches from which the coverglass qualification set is obtained.

b. Visual inspection

As specified in 8.6.1.2, the SCD-CVG shall include:

1. The maximum dimensions, in mm, of scratches and digs.
2. The maximum number of corner chips per coverglass.

c. Transmission into air

1. Average transmission before the test

   The SCD-CVG shall include the transmission values shown in Table E-1.

2. Maximum average transmission deviations after test

   The SCD-CVG shall include the transmission values shown in Table E-2.

Table E-1: Average transmission into air before test (%)

Discrete wavelength (nm)				Wavelength range (nm)				
400	**450**	**500**	**600**	**300-320**	**400 - 450**	**600 - 800**	**450 - 1 100**	**900 - 1 800**
[Insert value]	[Insert value]	[Insert value]	[Insert value]	[Insert value]	[Insert value]	[Insert value]	[Insert value]	[Insert value]

Table E-2: Maximum average deviation of transmission into air after test (%)

	Discrete Wavelength (nm)				Wavelength Range (nm)				
Environmental	400	450	500	600	300 - 320	400 - 450	600 - 800	450 - 1 100	900- 1 800
Boiling water	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]
Humidity and temperature HT1	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]
Thermal cycling	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]
UV exposure	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]
Electron irradiation	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]
Proton irradiation	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]	[insert value]

d. Physical properties

As specified in 8.6.3, the SCD-CVG shall include a figure showing the nominal values and tolerances for the following physical properties:

1. density;

2. thermal expansion coefficient (including the temperature range);
3. Young's modulus and Poisson's ratio;
4. bulk resistivity and surface resistivity;
5. refractive index.

e. Mechanical properties

As specified in 8.6.4, the SCD-CVG shall include a figure showing the nominal values and tolerances of the following mechanical properties:

1. dimensions (A: length, B: width);
2. weight (average per shipping lot);
3. thickness;
4. edge parallelism;
5. perpendicularity of sides.

NOTE This figure can be the same as in E.2.2 <8>d.

f. Reflectance properties

As specified in 8.6.5, the SCD-CVG shall include a figure showing the nominal values and tolerances of the following reflectance properties:

1. reflectance (including wavelength);
2. reflectance cut-on;
3. reflectance cut-off;
4. reflectance bandwidth.

NOTE This figure can be the same as in E.2.2 <8>d.

g. Normal emittance

As specified in 8.6.6, the SCD-CVG shall include the minimum value of the normal emittance, as a percentage (%) and the equipment used to measure the normal emittance.

h. Surface resistivity

As specified in 8.6.7, the SCD-CVG shall include the minimum value of the surface resistivity, in Ω/cm^2, and the equipment used to measure the resistivity.

i. Flatness or bow

As specified in 8.6.8, the SCD-CVG shall include:

1. The minimum value of the flatness or bow, as a maximum deviation, in mm.
2. The maximum value of coverglass displacement, from an optically flat surface over a specified distance in mm, for localized flatness deformations, in mm.

j. Transmission into adhesive

As specified in 8.6.9, the SCD-CVG shall include:

1. The values as shown in Table E-1.
2. The Fresnel's equation used for the correction of the transmission for reflectance losses including all parameters.

k. HT1 humidity and temperature

As specified in 8.6.11.1, the SCD-CVG shall state the chemical contents (type and percentage (%) in the mist) of the humid environment when there are specific requirements on the contents of the environment.

l. UV exposure

As specified in 8.6.12.2, the SCD-CVG shall include the value of the acceleration factor of the UV irradiation.

m. Electron irradiation

As specified in 8.6.13.2, the SCD-CVG shall state the value of the nominal dose of the electron irradiation, in $e^- \ cm^{-2}$, and maximum rate, in $e^- \ cm^{-2} \ s^{-1}$.

n. Proton irradiation

As specified in 8.6.14.2, the SCD-CVG shall state the value of the nominal dose of the proton irradiation in $p^+ \ cm^{-2}$ and maximum rate, in $p^+ \ cm^{-2} \ s^{-1}$.

o. Breaking strength

As specified in 8.6.15, the SCD-CVG shall state the method to be used to test for the breaking strength and the limits of the breaking strength, in N

p. Thermal cycling

As specified in 8.6.16, the SCD-CVG shall state the number of thermal cycles to be performed before contact adhesion and their extreme temperatures.

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Annex F (informative)

PVA manufacturing flow chart

Figure F-1 shows an example of PVA manufacturing chart.

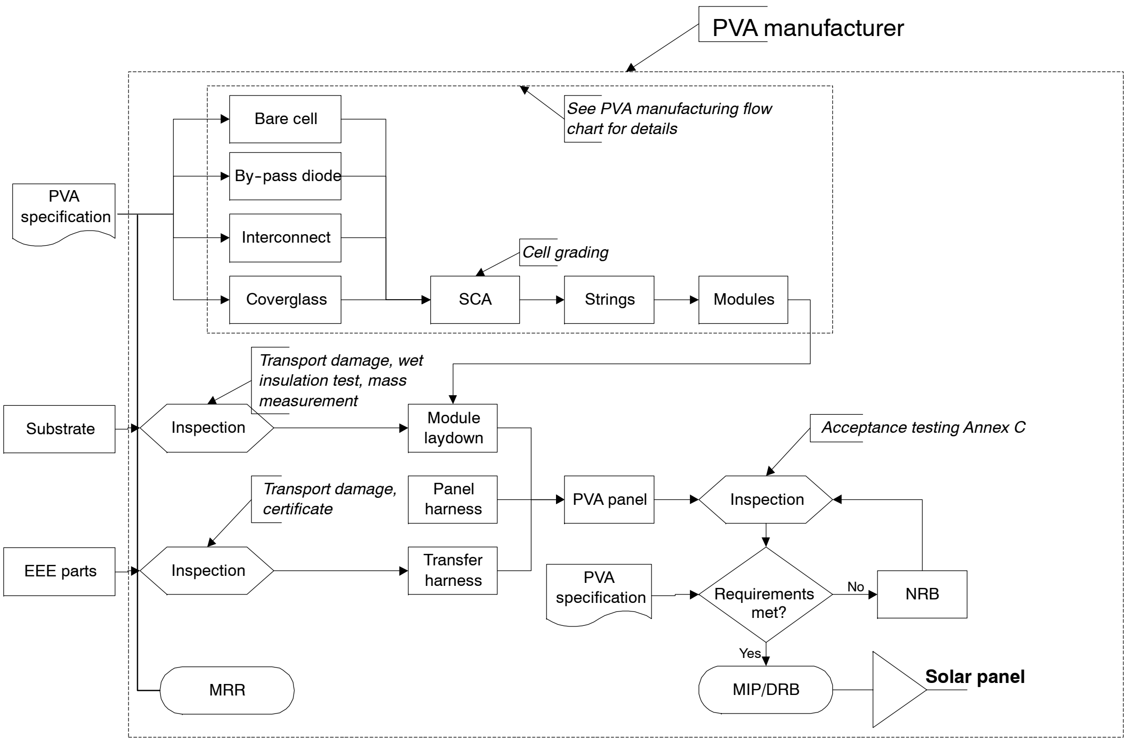

Figure F-1: Example of PVA manufacturing chart

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Annex G (normative)

Full visual inspection criteria for PVA

G.1 Dimensions, stay-out zones, and stand-offs

a. The dimensions shall conform to the coupon assembly drawing.

b. Cells and components shall not enter the stay-out zones indicated on the SCD-PVA coupon.

c. The stand-off distance of cells and components shall conform to the SCD-PVA coupon.

G.2 Substrate

a. Substrates shall be inspected for any damage due to coupon assembly, handling and testing.

b. The insulator material shall show no evidence of delamination.

NOTE The insulator material is usually kapton.

c. The integrity of the substrate shall not deviate from the coupon assembly drawing.

G.3 Coverglass

G.3.1 General

All the coverglass shall be inspected for defects as specified in G.3.2.

G.3.2 Process

a. No more than 5 % of the total number of coverglasses shall exhibit any of the following defects on the coupon, due to assembly, handling and acceptance:

1. For 100 % covered cells, or cells where the unprotected solar cell surface is covered with the coverglass adhesive up to a maximum of 5 % of the cell area, chips and nicks in the coverglass with the characteristics specified in 6.4.3.2.4.

2. Hairline cracks on the coverglass, except if they meet the following conditions:
   (a) no visible separation (see 6.4.3.2.4);
   (b) no more than three per cover;
   (c) meeting hairline cracks if they are separated by more than 2 mm at the non-meeting end.

b. Any defect as specified in a. above, raised after acceptance shall be reported and traced throughout the qualification sequence.

c. Covers with dirty and contaminated surfaces shall be cleaned.

d. Coverglasses with any of the following defects shall be rejected at the end of acceptance:
   1. Coverglasses installed upside down as indicated by improper location of the coating orientation mark as specified in 8.2.3.
   2. Coverglass which is not flush with or overhanging all four cell edges.
   3. Coverglasses with dirty and contaminated surface if they cannot be cleaned.
   4. Loose coverglasses.
   5. Corner chip exceeding the limits specified in a.1 above.
   6. Edge chips exceeding the limits specified in 6.4.3.2.4.
   7. Coverglasses with intersecting cracks exceeding the limits specified 6.4.3.2.4.

G.4 Coverglass adhesive

After coverglass or solar cell repair, the following criteria apply:

a. There shall be no delamination or discoloration in the adhesive, except in the area opposite rear welds, where discoloration may be present.

b. Adhesive voids along the cover edge shall not exceed 0,6 mm in depth.

c. The maximum total projected area of additional bubbles shall not exceed 0,2 % of cell area, discounting:
   1. bubbles less than 0,02 mm^2 in the projected area, and
   2. bubbles, discolorations and voids located at less than 2 mm from the interconnector edges.

G.5 Solar cells

G.5.1 General

Solar cells shall be inspected for defects as denoted in G.5.2.

G.5.2 Process

a. No more than 2 % of the total quantity of solar cells or one cell, whichever is larger, per coupon shall exhibit any of the following defects:
   1. More than the number of cracks per cell specified in the SCD-PVA.
   2. Cracks crossing more than the number of different gridlines specified in the SCD-PVA.
   3. Corner chips and edge chips greater than those specified in 6.4.3.2.4.

b. Any imperfections listed in a.1 to a.3 above, raised after acceptance shall be reported and traced throughout the qualification sequence.

c. Solar cells with any of the following defects shall be rejected at the end of acceptance:
   1. Cracks crossing more gridlines than defined in a.2. above.

      NOTE Multiple crossing of the same gridline may be present.
   2. More cracks than defined in a.1. above on a single cell.
   3. Cracks between the cell edges parallel to the gridlines and the outermost edges of the interconnectors.
   4. Corner chip exceeding the limits specified in 6.4.3.2.4.
   5. Edge chips exceeding the limits specified in 6.4.3.2.4.

G.6 Solar cell bypass diodes

a. Cracks in the body of the diode, causing separation of the material, shall not be present.

b. Tarnishing of the diode body or attachment serpentines may be present.

G.7 Interconnectors

a. No more than 2 % of the total number of interconnectors and no more than one interconnector per cell shall exhibit any of the following defects at the end of acceptance testing:
   1. Deformation.
   2. Solder or adhesive blocking, bridging, plugging or otherwise impeding the flexure of the stress relief loop.
   3. Foreign matter or contamination on the interconnector or within the interconnector weld or solder joint or within the stress relief loop.

b. Any imperfections listed in a.1. to a.3. above, raised after acceptance shall be reported and traced throughout the qualification sequence.

c. None of the interconnectors shall exhibit lifting tears, breaks or cracks.

d. Interconnectors may be tarnished.

G.8 Bus bars

a. None of the bus bars shall exhibit any of the following defects at the end of acceptance testing:
   1. Solder or adhesive blocking, bridging, plugging or otherwise impede the flexure of stress relief loops between solar cell strings.
   2. Foreign matter, or contamination on the interconnector, within the interconnector weld or solder joint, or within the stress relief loop.
   3. Tears, breaks or cracks.

b. Any defect listed in a.1. to a.3. above, raised after acceptance shall be reported and traced throughout the qualification sequence.

c. Tarnishing may be present on the end terminations.

G.9 Wiring

a. None of the wiring shall exhibit any of the following defects at the end of acceptance testing:
   1. Sharp bends, sharp twists, sharp buckles or creases in the wire.
   2. Delamination or looseness of the wire attachment.
   3. Chafing or abrasion of the wire insulation.
   4. Cracks, breaks or nicks in the wire insulation or conductor.
   5. Exposed shields on shielded wires.

b. Any defects listed in a.1 to a.5 above, raised after acceptance shall be reported and traced throughout the qualification sequence.

G.10 Soldering

Soldering of wires at string terminations and terminals shall be in accordance with a standard agreed with the customer

NOTE For soldering, see ECSS-Q-70-08.

G.11 Welding

Welding of wires at string terminations and terminals shall be in accordance with the SCD-PVA.

G.12 Crimping

Crimping of wires shall be in accordance with a standard agreed with the customer.

NOTE For crimping, see ECSS-Q-70-26.

G.13 Attachment materials

Attachments based on bonding techniques shall be fully cured and not exhibit any tackiness.

G.14 Feed-throughs

a. Feed-throughs shall be firmly bonded.

b. Feed-throughs shall conform to the locations specified on the top assembly drawing.

G.15 Marking

a. All identification markings specified by the customer shall be firmly adhered to the locations identified on the assembly drawing.

b. Identification markings shall be clearly legible.

G.16 Hardware

a. Terminal board locations shall conform to the SCD-PVA coupon.

b. Stand-off of all components shall conform to the SCD-PVA coupon.

c. For mounted components (temperature sensor, resistors and diodes):

1. The status of the following items shall be verified:
   - (a) fixation on the substrate;
   - (b) body aspect and absence of cracks;
   - (c) connections;
   - (d) shrinkage tube.
2. Conformal coating of the components, as specified by the program schedule, shall:
   - (a) consist of a uniform layer of the specified adhesive, and
   - (b) encapsulate the components.

d. For the connectors, the status of the following items shall be verified:

1. fixing on the substrate;
2. absence of cracks;
3. connections;
4. shrinkage tube.

G.17 Bonding integrity

a. 100 % of the solar cells shall be inspected for bond integrity.

b. Any loose cells shall not be used unless an engineering disposition, specifying that it can be used, is issued.

G.18 Cleanliness

a. When visually examined with the unaided eye, the coupon shall appear clean.

b. There shall be no loose material on the coupon.

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Annex H (normative)

Single junction solar cell capacitance measurement

H.1 Introduction

H.1.1 Overview

This method is included as a recommendation to be used for the measurement of capacitance of bare solar cells and solar cell assemblies, and as an outline for PVA coupons.

H.1.2 Description

This annex describes a method of measuring the dynamic properties of a single junction solar cell, using the small signal method. This consists of measurement of the cell impedance in darkness for several bias voltages.

The measurement is performed between 0 V and the bias voltage corresponding to a current of 200 mA. The frequencies are between 10 Hz and 10 MHz.

These measurements enable the cell capacitance for each bias voltage to be estimated and, subsequently, to build a model of the capacitance according to the cell voltage and current.

The following parameters and values are used

a. The minimum number of frequencies is N_f = 26 with logarithmic steps

b. The minimum number of voltage biases is N_p= 6

c. V_1= 0 V

d. V_2= V_3 / 2

e. V_3= bias voltage corresponding to a current of 1 mA

f. V_4= bias voltage corresponding to a current of 10 mA

g. V_5= bias voltage corresponding to a current of 100 mA

h. V_6= bias voltage corresponding to a current of 200 mA

H.1.3 Signal measurement method

The signal measurement method that should be used is the shunt method.

H.2 Measurement procedure

H.2.1 Preparation of the measurement equipment

The following process should be used to prepare the measurement equipment:

a. Prepare the test bay according to Figure H-1 and the following equipment list:
   1. One DC power supply.
   2. Two precision voltmeters.
   3. One 4-points ohmmeter (or one of the 2 voltmeters if they are multi-meters).
   4. One network analyser.
   5. The measuring head containing one non-inductive shunt (1 Ω) and connections for BNC cables and the voltmeters, with the following:
      (a) The hot terminal of the shunt to the voltmeters connected to the voltmeters via an air coil inductance higher than 45 μH.
      (b) A resonance frequency higher than 10 MHz and damped by a 270 Ω resistor in parallel.

      NOTE This device is used to suppress the influence of the harness and the parasitic capacitances of the voltmeters on the shunt in the measuring bandwidth.

      (c) The coil made with a 10 mm diameter Teflon mandrel of roughly 125 jointed turns of a 2/10 mm wire.
   6. The injection elements with the following properties:
      (a) Direct current: 200 Ω resistor, power 10 W, stable with regard to the temperature.
      (b) Alternative current: electrochemical capacitance of 1 000 μF and four common mode cores T22 FT40.
      (c) One 50 Ω cable for injection passing through the 4 common mode cores.
   7. A ground braid between the analyser ground and the measuring head.
   8. Two 50 Ω cables of same length for measurement.
   9. Two twisted unshielded cables for voltmeter connection with a maximum length of 1,50 m.
   10. One male BNC adapter.

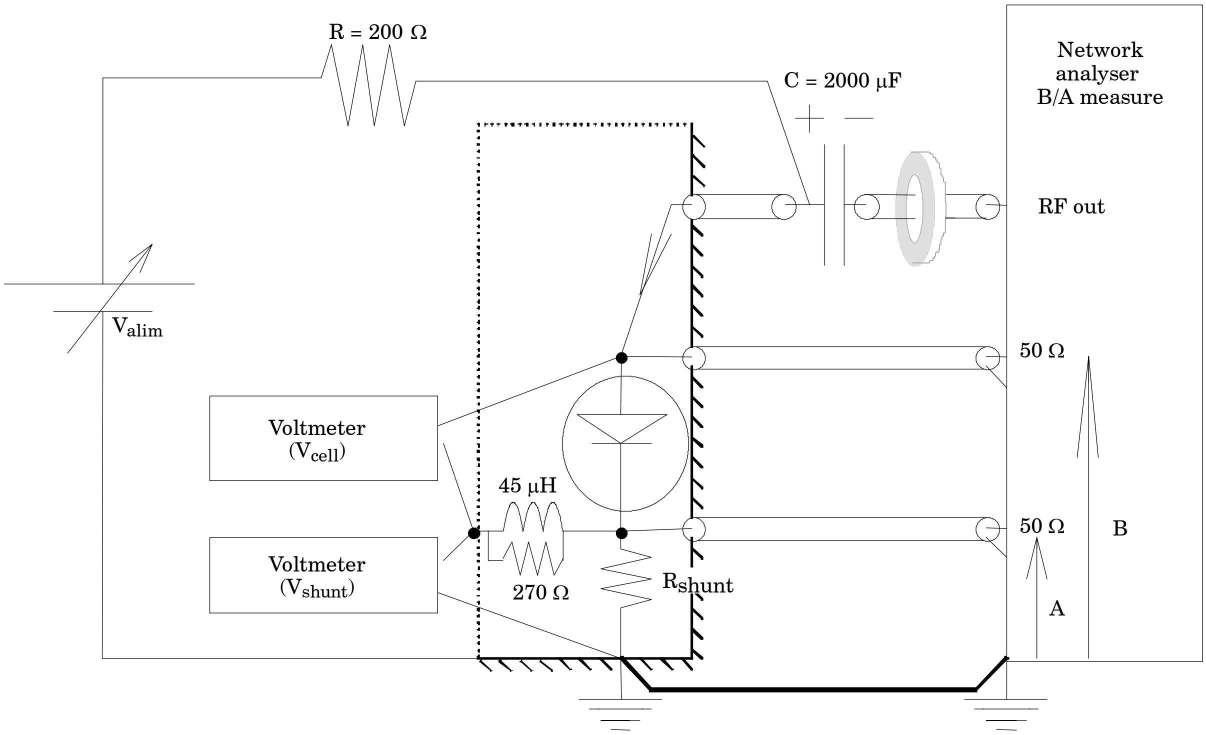


Figure H-1: Solar cell impedance measurement equipment

b. Adjust the parameters of the network analyser using the network analyser in the B/A mode (B/A= $(V_{cell}+V_{shunt})/V_{shunt}$), ensuring that the channels are not inverted, as follows:

1. frequency range: 10 Hz to 10 MHz;
2. number of frequencies N_f: at least 26;
3. step type: logarithmic;
4. bandwidth: automatic or otherwise limited to few Hz in order to limit the noise at low frequency;
5. injection level: default value of the network analyser;
6. program the network analyser to record the B/A values in the complex form X+j × Y; or in the amplitude $|B/A|$ and phase φ (B/A).

H.2.2 Calibration of the test equipment

The following process should be used to calibrate the test equipment:

a. Verify the balancing of the channels at low frequency, and the influence of the parasitic inductance between the two measuring points, A and B, once before the measurements, by replacing the solar cell with a short-circuit according to Figure H-2.

b. Ensure that the B/A ratio between 10 Hz and 10 MHz conforms to the following provisions:

1. At low frequency: equal to (1 ± 2) % (or equal to (0 ± 2) dB).
2. At 10 MHz: lower than 1,6 (or 4 dB).

NOTE It is considered that the shunt has no inductance; this means that the inductance of the short-circuit is lower than 20 nH. A ratio lower than 1 (or < 0dB) means that the A and B channels are inverted.

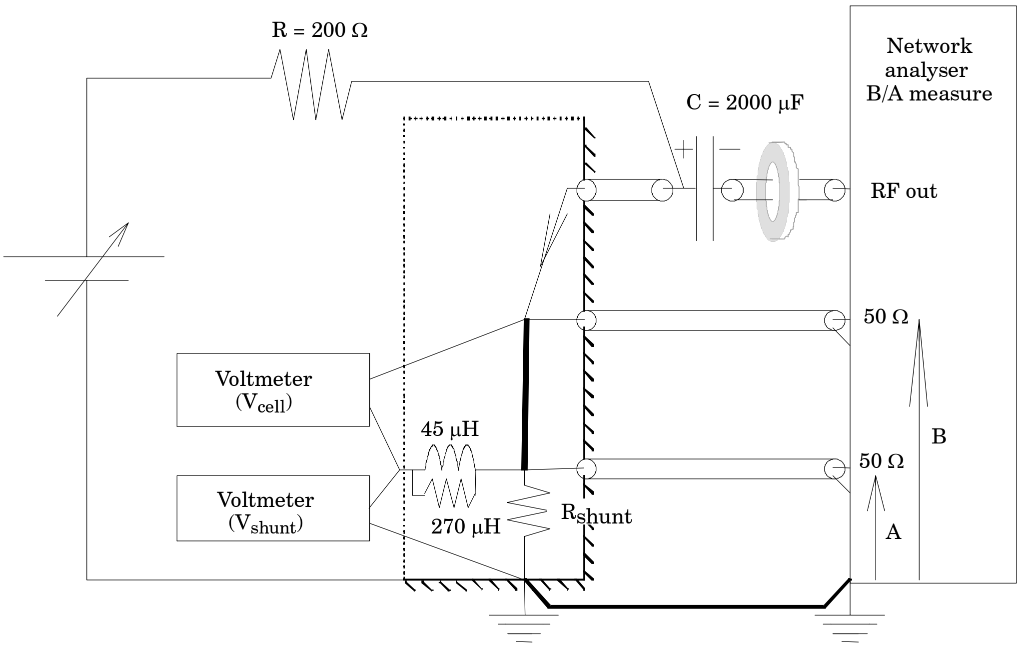


Figure H‑2: Channel balancing and reduction of the parasitic inductances

c. Measure the ohmic value of the shunt associated with the cabling and at the network analyser, at room temperature using one of the following two methods:

1. Calculation

   To be used if the certified calibrated value of the shunt, of the cable and of the 50 Ω input are known.

   In this case:

$$R_{shunt\ measured} = \frac{1}{1/R_{shunt} + 1/\left(R_{50\,\Omega\ input} + R_{cable}\right)}$$

2. Direct measurement

   Measure $R_{shunt\ measured}$ with the cell short‑circuited, the channel A plugged on the network analyser, all the other cables unplugged (Figure H‑3), and a 4‑wire setting, as follows:

   (a) unplug the injection cable (RF channel);

   (b) unplug the V_{cell} measuring cable and keep it insulated;

   (c) unplug the cable on channel B of the network analyser and plug it into the input “input” of the ohmmeter with a BNC adaptor, paying attention to the polarities;

   (d) unplug the measuring cable V_{shunt} and plug it in the input “sense” of the ohmmeter, paying attention to the polarities;

   (e) monitor the calculated or measured value.

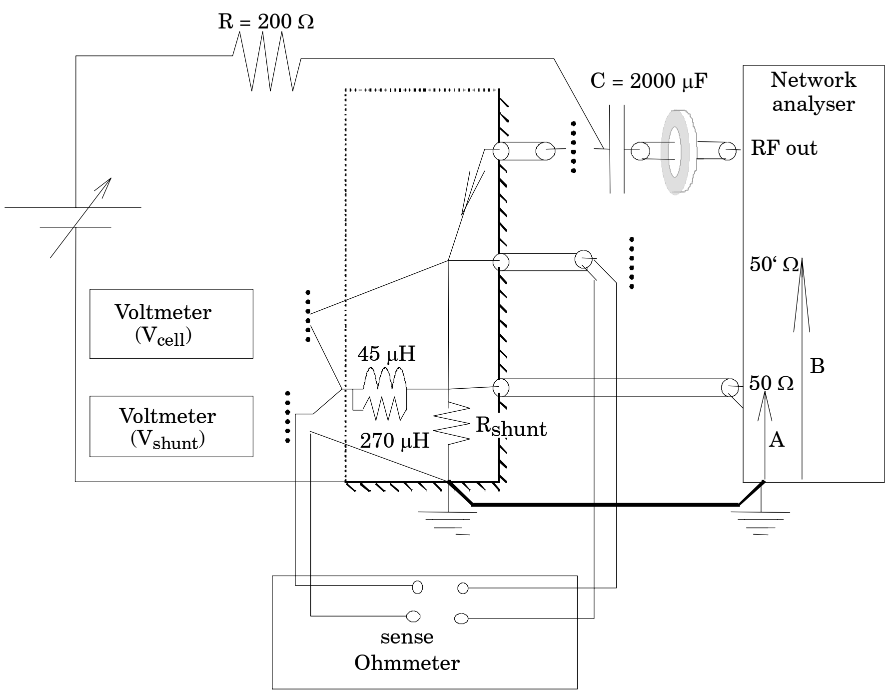


Figure H-3: Measurement of the resistance value of the shunt in the measuring conditions (shunt in parallel with the input of the network analyser)

d. Adjust the injection level of the network analyser as follows:

1. Connect the cell in place of the short-circuit and keep the voltage supply at 0 V.

   NOTE The injection level is selected low enough so as not to generate a variation of the impedance curves when the level changes.

2. Begin at 0 dB and lower the signal with 3 dB steps until there is no change at low frequency (variation lower than 0,1 dB).
3. Monitor the selected injection level.

H.2.3 Measurement of the cell with the network analyser

The cell should be measured with the network analyser as follows:

a. If the measurement is performed at several temperatures in a thermostatic chamber:

1. Wait for thermal equilibrium.
2. Determine the resistance value of the shunt at each temperature (H.2.2.c.).

b. Determine and record the voltage of the power supply to obtain the bias voltages defined in H.1.1 and set the power supply to 0 V at the end.

c. Measure the B/A ratios for the chosen bias voltages, as follows. For each bias voltage:

1. Adjust the power supply voltage to the determined value.
2. Note the cell and the shunt voltages.
3. Measure the B/A ratios in the complex form $X+j \times Y$; or in the amplitude $|B/A|$ and phase $\varphi(B/A)$ from 10 Hz to 10 MHz, and store the data file in the network analyser.

4. Note or record the cell voltage change (to detect a temperature increase of the cell).
5. Set the power supply voltage to 0 V.
6. Record the stored data file.

H.3 Measurement analysis

H.3.1 Correction of the measurement with respect to the actual impedance of the shunt (impedance values from the *B/A* measurements)

For a 1 Ω shunt, the value given by the analyser is the impedance of the cell in series with the 1 Ω resistor, where the cell impedance should be determined using the following calculation:

a. If B/A is given in amplitude $|B/A|$ and phase φ (B/A), the cell impedance is:

$$Z_{cell} = R_{shunt\ measured} \times \left[1 + |B/A|^2 - 2\cos(\varphi)|B/A|\right]^{½}$$

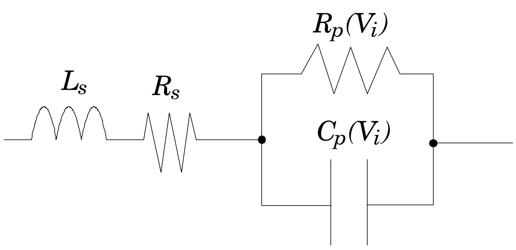
b. If B/A is given in the complex form X+j × Y

$$Z_{cell} = R_{shunt\ measured} \times \left[1 + X^2 + Y^2 - 2X\right]^{½}$$

H.3.2 Modelization

H.3.2.1 Calculation of the items of the equivalent network using the impedance values

The small signal electrical model parameters (Figure H-4) should be calculated for each bias voltage $V_{cell,i}$ and bias current $I_{cell,i}$ with respect to the frequency, as follows:



$$Z_{theo}(L_s, R_s, C_p, R_p, f) = \left[\left(R_s + \frac{R_p}{1 + 4\pi^2 R_p^2 C_p^2 f^2}\right)^2 + 4\pi^2 f^2 \left(L_s - \frac{R_p^2 C_p}{1 + 4\pi^2 R_p^2 C_p^2 f^2}\right)^2\right]^{½}$$

Figure H-4: Small signal electrical schema biased with a DC voltage associated impedance

a. Minimize the relative error of the theoretical impedance $Z_{theo}(L_s, R_s, C_p, R_p, f)$ with the measured values (regression by least square method).

NOTE As the $\mathbf{N_f}$ impedance measurements

$$\begin{bmatrix} Z_{cell,1} \\ Z_{cell,2} \\ \dots \\ Z_{cell,Nf} \end{bmatrix}$$

are associated to the frequencies

$$\begin{bmatrix} f_1 \\ f_2 \\ \dots \\ f_{Nf} \end{bmatrix},$$

the function to minimize is

$$\sum_{j=1}^{N_f} = \left[1 - \frac{Z_{theo}(L_s, R_s, C_p, R_p, f_j)}{Z_{cellj}}\right]^2,$$

which is a function of L_s, R_s, C_p and R_p.

b. Calculate each parameter R_p, C_p, L_s and R_s by successive iterative optimization, one after the other, using the following initial parameters:

$R_p0 = Z(f_{MIN})$,

$C_p0 = 1/\ (2 \times \pi \times f_{MIN}\ Z(f_{MIN}))$,

$L_s0 = Z(f_{MAX})\ /(2 \times \pi \times f_{MAX})$,

R_s0 = minimum value of $Z(f)$.

H.3.2.2 Determination of the capacitance model

From the capacitance measurements at several bias voltages, the parameters of the model of capacitance with respect to the cell junction voltage and temperatures:

- C_0 (capacitance at 0 V),
- C_1 (diffusion parameter), and
- Φ (voltage barrier at measurement temperature),

should be determined as follows:

a. Use the capacitance model based on the following expression:

$$C(v) = \frac{C_0}{\sqrt{1 - v/\Phi}} + C_1 \exp\left(\frac{v}{v_0}\right)$$

where

$$v_0 = \frac{kT}{q}$$

T = measurement temperature

$k = 1{,}38 \times 10^{-23}$ J/K

$q = 1{,}602 \times 10^{-19}$ C

NOTE For measurement in darkness and low currents, the cell voltage V_i and the junction voltage v_i are the same (the error is 4 mV for a bias current of 200 mA and a cell serial resistance of 20 mΩ).

b. Minimize the relative error between the theoretical capacitance $C(C_0, \Phi, C_1, v)$ and the previously calculated capacitances (regression by least square method).

NOTE As the $\mathbf{N_p}$ impedance measurements

$$\begin{bmatrix} C(V_1) \\ C(V_2) \\ \dots \\ C(V_{Np}) \end{bmatrix}$$

are associated to the voltages

$$\begin{bmatrix} V_1 \\ V_2 \\ \dots \\ V_{Np} \end{bmatrix},$$

the function to minimize is $\sum_{j=1}^{N_f} = \left[1 - \frac{C(V_j, C_0, \Phi, C_1)}{C(V_j)}\right]^2$,

which is the function of C_0, Φ and C_1.

c. Calculate each parameter C_0, C_1 and Φ by successive iterative optimization one after the other, where the initial parameters are as follows:

$C_0 = C(V_1)$

$C_{1=} \exp\left(-\frac{v}{v_0}\right) C(V_{Np})$

Φ - 1, 5 V_{Np}

H.4 Measurement of the capacitance of a multi-junction cell

The cell capacitance measurement method cannot be directly applied to multi-junction solar cells because it assumes that the photo-currents of each junction of the cell were perfectly matched.

For real cells, this matching is not realized and the voltage profile through the different junctions of the cell is different when the cell is illuminated and when it is in darkness. The measurement in darkness enables the order of magnitude of the capacitance to be evaluated.

In order to obtain a higher precision, these measurements are added to measurements under illumination with the right spectral irradiance.

NOTE 1 Some measurements have been performed and the capacitance has been observed to be higher than the values measured in darkness, even at low bias voltage. This is under experimentation and currently there is not a lot of information available.

NOTE 2 This is the fundamental difference between single junction and multi-junction cells: measurements done in darkness are sufficient to characterize the dynamic behaviour of single junction cells in darkness and under illumination.

NOTE 3 Measurements done in darkness are not sufficient to characterize the dynamic behaviour of multi-junction cells under illumination.

Annex I (normative)

Time domain capacitance measurement

I.1 Introduction

I.1.1 Overview

This method is included as a recommendation to be used for the measurement of the capacitance of SCAs and PVA coupons that are part of power subsystems that use sequential switching shunt regulators.

I.1.2 Description

This Annex describes a method for measuring the dynamic properties of a solar cell or PVA coupon, using the time domain method while operating in the current region (to the left of the maximum power point on the curve).

The capacitance of the solar cell or PVA coupon, when switching between two different voltage operational points with the assumptions that

- the capacitance is constant between the two points, and
- the current is constant in the two points,

is obtained with the expression:

$$C = \frac{I \times \Delta t}{\Delta V},$$

where

I is the measured current at the two points;

Δt is the time increment;

ΔV is the voltage increment.

The measurements are performed at 1 S.C (AM0) illumination and at constant temperature.

The capacitance that is derived from the short-circuit current point and the operational voltage of the solar cell or PVA coupon is used to derive the requirements for the design of sequential switching shunt regulators specified in ECSS-E-20.

I.2 Measurement procedure

I.2.1 Measurement equipment set-up

a. The time domain capacitance measurement test set-up, should comprise the following test equipment:

1. A continuous or pulsed solar simulator according to the requirements specified in Annex A.
2. A solar array capacity tester which supplies a synchronizable fast switch to perform a controlled short-circuit release at the open circuit condition of the PVA coupon or SCA under test.
3. A digital-analog oscilloscope to capture the voltage-current transient during the short-circuit release at the open circuit condition.
4. A twisted harness of short length to reduce the parasitic inductance of the harness from the test specimen to the capacity tester.

b. The voltage should be measured at the test specimen terminals.

c. For PVA coupons with multiple strings, each particular string voltage should be measured not including the string blocking diode (see 5.5.1.3.3.f.).

d. External parallel capacitors to derive the capacitance of the PVA coupon or SCA should not be used because this parameter depends on the rate of change of the transient.

I.2.2 Calibration of the measurement equipment

The continuous or pulsed solar simulator should be calibrated according to the requirements specified in Annex A.2.

I.2.3 Performance measurement

a. The short-circuit release at the open circuit condition of the SCA or PVA coupon should be performed under the illumination conditions specified in I.2.2 and at constant temperature.

b. The voltage curve vs time and the current curve vs time of the test specimen should be recorded during the release.

I.2.4 Data processing

a. Since the voltage of the test specimen at the moment of the short-circuit release is difficult to measure (due to the high frequency oscillations created by the parasitic harness inductance), one of the following two methods should be used to determine the voltage:

- mathematical analysis to find a curve without oscillation that fits the voltage curve measured;
- calculation of the intersection of two voltage curves (for example, the first voltage curve at the test specimen terminals and the second voltage curve at the capacity tester terminal (+) and test specimen terminal (-)).

b. The voltage determined in a. should be used to calculate the capacitance according to the expression and conditions specified in I.1.2.

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ECSS-Q-30-02	Space product assurance — Failure modes, effect and criticality analysis (FMECA)
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1) To be published.

MIL‐PRF 13830	General specification governing the manufacture, assembly and inspection of optical components for fire control instruments

ECSS Document Improvement Proposal

1. Document I.D.	2. Document date	3. Document title
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4. Recommended improvement (identify clauses, subclauses and include modified text or graphic, attach pages as necessary)

5. Reason for recommendation

6. Originator of recommendation		
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Address:	Phone: Fax: e-mail:	**7. Date of submission:**

8. Send to ECSS Secretariat		
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