

BS EN 16603-20-08:2014



BSI Standards Publication

Space engineering

Part 20-08: Photovoltaic assemblies and components

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National foreword

This British Standard is the UK implementation of EN 16603-20-08:2014.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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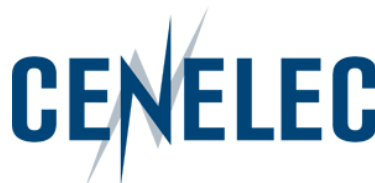
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This European Standard was approved by CEN on 10 February 2014.

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Table of contents

Foreword	10
Introduction.....	11
1 Scope.....	12
2 Normative references	13
3 Terms, definitions and abbreviated terms.....	14
3.1 Terms from other standards.....	14
3.2 Terms specific to the present standard	14
3.3 Abbreviated terms.....	19
4 General	22
4.1 Overview	22
4.1.1 Objective and organization.....	22
4.1.2 Interfaces with other areas	23
4.2 Physical properties	24
4.3 Test and storage.....	25
4.3.1 Test environment	25
4.3.2 Test tolerances and accuracies	25
4.3.3 Margins	26
4.4 Critical materials	26
5 Photovoltaic assemblies.....	27
5.1 Overview	27
5.1.1 Description.....	27
5.1.2 Purpose and objective.....	27
5.2 Conditions and method of test	28
5.3 Photovoltaic assembly design.....	29
5.3.1 Overview	29
5.3.2 Parameters related to parts, materials and processes (PMP).....	29
5.3.3 Parameters related to design	30
5.4 PVA manufacturing.....	34
5.4.1 Process validation	34

5.4.2	Defect acceptability	34
5.4.3	In-process testing	34
5.4.4	Identification and traceability	35
5.4.5	Recording	36
5.5	PVA tests	36
5.5.1	Qualification tests	36
5.5.2	Acceptance tests for qualification coupons	41
5.5.3	Definition of tests and checks	42
5.6	Failure definition	53
5.6.1	Failure criteria	53
5.6.2	Failed qualification coupons	53
5.7	Data documentation	53
5.8	Delivery	54
5.9	Packaging, packing, handling and storage	54
6	Solar cell assemblies	55
6.1	General	55
6.1.1	Testing	55
6.1.2	Conditions and methods of test	55
6.1.3	Deliverable components	55
6.1.4	Identification and traceability	55
6.2	Production control (process identification document)	56
6.3	Acceptance tests	56
6.3.1	General	56
6.3.2	Test methods and conditions	56
6.3.3	Electrical performance acceptance test (EPA)	57
6.4	Qualification tests	57
6.4.1	General	57
6.4.2	Qualification	59
6.4.3	Test methods, conditions and measurements	60
6.5	Failure definition	71
6.5.1	Failure criteria	71
6.5.2	Failed SCAs	72
6.6	Data documentation	72
6.7	Delivery	72
6.8	Packing, dispatching, handling and storage	72
6.8.1	Overview	72
6.8.2	ESD Sensitivity	72

7 Bare solar cells	73
7.1 Testing, deliverable components and marking	73
7.1.1 Testing	73
7.1.2 Deliverable components	74
7.1.3 Marking	74
7.2 Production control (process identification document)	74
7.3 Acceptance tests	75
7.3.1 General	75
7.3.2 Test methods and conditions	76
7.3.3 Documentation	76
7.4 Qualification tests	77
7.4.1 General	77
7.4.2 Qualification	79
7.5 Test methods, conditions and measurements	80
7.5.1 Visual inspection (VI)	80
7.5.2 Dimensions and weight (DW)	82
7.5.3 Electrical performance (EP)	82
7.5.4 Temperature coefficients (TC)	83
7.5.5 Spectral response (SR)	84
7.5.6 Optical properties (OP)	84
7.5.7 Humidity and temperature (HT)	85
7.5.8 Coating adherence (CA)	86
7.5.9 Contact uniformity (CU)	87
7.5.10 Contact thickness (CT)	87
7.5.11 Surface finish (SF)	87
7.5.12 Pull test (PT)	88
7.5.13 Electron irradiation (EI)	88
7.5.14 Proton irradiation (PI)	89
7.5.15 Photon irradiation and temperature annealing (PH)	90
7.5.16 Solar cell reverse bias test (RB)	90
7.5.17 Thermal cycling (CY)	91
7.5.18 Active-passive interface evaluation test (IF)	91
7.5.19 Flatness test (FT)	91
7.6 Failure definition	92
7.6.1 Failure criteria	92
7.6.2 Failed components	92
7.7 Data documentation	92

7.8	Delivery	92
7.9	Packing, dispatching, handling and storage	93
7.9.1	Overview	93
7.9.2	ESD Sensitivity	93
8	Coverglasses	94
8.1	Overview	94
8.1.1	Purpose	94
8.1.2	Description	94
8.2	Interfaces	94
8.3	Testing, deliverable components and marking	95
8.3.1	Testing	95
8.3.2	Deliverable components	95
8.3.3	Marking (coating orientation)	96
8.4	Production control (Process identification document)	96
8.5	Acceptance tests	96
8.5.1	Acceptance test samples	96
8.5.2	Acceptance test sequence	97
8.5.3	Test methods and conditions	97
8.5.4	Documentation	97
8.6	Qualification tests	98
8.6.1	General	98
8.6.2	Qualification	98
8.7	Test methods, conditions and measurements	100
8.7.1	Visual inspection (VI)	100
8.7.2	Transmission into air (TA)	101
8.7.3	Electro-optical properties (EO)	102
8.7.4	Mechanical properties	102
8.7.5	Reflectance properties (OP)	103
8.7.6	Normal emittance (e_N) (NE)	105
8.7.7	Surface resistivity	105
8.7.8	Flatness or bow (FT)	105
8.7.9	Transmission into adhesive (TH)	106
8.7.10	Boiling water test (BW)	106
8.7.11	Humidity and temperature	106
8.7.12	UV exposure (UV)	107
8.7.13	Electron irradiation (EI)	108
8.7.14	Proton irradiation (PI)	108

8.7.15	Breaking strength (BS).....	108
8.7.16	Thermal cycling (CY).....	109
8.7.17	Abrasion resistance (coated surface) (AE)	109
8.7.18	Coating adhesion (TD)	109
8.8	Failure definition	109
8.8.1	Failure criteria	109
8.8.2	Failed components.....	110
8.9	Data documentation.....	110
8.10	Delivery	110
8.11	Packing, dispatching, handling and storage.....	110
9	Solar cell protection diodes.....	111
9.1	Overview	111
9.2	Testing, deliverable components and marking.....	111
9.2.1	Testing.....	111
9.2.2	Deliverable components.....	113
9.2.3	Marking	113
9.3	Production control (process identification document).....	113
9.3.1	Integral protection diodes.....	113
9.3.2	External protection diodes.....	113
9.4	Acceptance tests	114
9.4.1	General	114
9.4.2	Integral protection diodes.....	114
9.4.3	External protection diodes.....	114
9.4.4	External and integral diodes.....	115
9.4.5	Test methods and conditions	115
9.4.6	Documentation.....	116
9.5	Qualification tests	116
9.5.1	General	116
9.5.2	Integral protection diodes.....	116
9.5.3	External protection diodes.....	117
9.5.4	Integral and external protection diodes.....	118
9.6	Test methods, conditions and measurements.....	119
9.6.1	General	119
9.6.2	Visual inspection (VI)	119
9.6.3	Dimensions and weight (DW).....	120
9.6.4	Thermal cycling (CY).....	121
9.6.5	Burn in (BI).....	121

9.6.6	Humidity and temperature (HT).....	122
9.6.7	Contact uniformity (CU).....	122
9.6.8	Contact thickness (CT).....	123
9.6.9	Surface Finish (SF)	123
9.6.10	Contact adherence (CA)	123
9.6.11	Pull test (PT)	124
9.6.12	Electron irradiation (EI)	124
9.6.13	Temperature annealing (TA)	125
9.6.14	Temperature behaviour (TB).....	125
9.6.15	Diode characterization (DC).....	126
9.6.16	Human body ESD (DE)	127
9.6.17	Switching test (DS).....	128
9.6.18	Life test (DL)	130
9.7	Failure definition	132
9.7.1	Failure criteria	132
9.7.2	Failed components.....	133
9.8	Data documentation.....	133
9.9	Delivery	133
9.10	Packing, despatching, handling and storage.....	133
9.10.1	Overview	133
9.10.2	ESD sensitivity	133
10	Sun simulators and calibration procedures.....	134
10.1	Sun simulators.....	134
10.1.1	Spectral distribution.....	134
10.1.2	Irradiance uniformity.....	142
10.1.3	Irradiance stability	142
10.2	Standard cell and Sun simulator calibration	143
10.2.1	Primary standards.....	143
10.2.2	Secondary working standards (SWS).....	144
10.2.3	Standards cells documentation	145
10.2.4	Maintenance of standards	146
10.2.5	Recalibration and intercomparison	146
10.2.6	Sun simulator calibration and maintenance.....	146
11	Capacitance measurement methods	147
11.1	Single junction solar cell capacitance measurement	147
11.1.1	Overview	147
11.1.2	Signal measurement method	148

11.1.3	Measurement procedure	148
11.1.4	Measurement analysis	152
11.1.5	Measurement of the capacitance of a multi-junction cell	155
11.2	Time domain capacitance measurement	155
11.2.1	Overview	155
11.2.2	Measurement procedure	156
Annex A (normative) Source control drawing for photovoltaic assembly (SCD-PVA) - DRD		158
Annex B (normative) Source control drawing for solar cell assembly (SCD-SCA) - DRD		164
Annex C (normative) Source control drawing for bare solar cell (SCD-BSC) - DRD		169
Annex D (normative) Source control drawing for coverglass (SCD-CVG) - DRD		178
Annex E (normative) Source control drawing for External Protection Diodes (SCD-EPD) - DRD		184
Annex F (normative) Process identification document (PID) - DRD		188
Annex G (normative) Data documentation package (DDP) - DRD		190
Bibliography		193
 Figures		
Figure 4-1: Specification hierarchy		23
Figure 6-1: Definition of cell defects		61
Figure 6-2: Test points for electrical performance measurement		63
Figure 7-1: Definition of bare solar cell defects		81
Figure 8-1: Methods of defining coverglass orientation		96
Figure 8-2: Edge chip parameters		101
Figure 8-3: Corner chip parameters		101
Figure 8-4: Coverglass manufacturing tolerance limits		103
Figure 8-5: Schematic for calculating surface resistivity		105
Figure 8-6: Definition of coverglass flatness		106
Figure 9-1: Diode forward and reverse test profile		129
Figure 9-2: Diode switching test profile		130
Figure 11-1: Solar cell impedance measurement equipment		149
Figure 11-2: Channel balancing and reduction of the parasitic inductances		150

Figure 11-3: Measurement of the resistance value of the shunt in the measuring conditions (shunt in parallel with the input of the network analyser).....	151
Figure 11-4: Small signal electrical schema biased with a DC voltage associated impedance	153
Figure C-1 : BSC front side	171
Figure C-2 : BSC rear side	172
Figure C-3 : BSC contact.....	172

Tables

Table 4-1: Test tolerances on temperature	26
Table 5-1: Qualification test plan for PVA	37
Table 5-2: Acceptance test plan	42
Table 6-1: Qualification test plan for SCA.....	58
Table 6-2: Maximum dimensions of corner chips, edge chips and surface nicks	61
Table 7-1: Acceptance test matrix	75
Table 7-2: Qualification test plan for bare solar cells	78
Table 7-3: Maximum dimensions of corner chips, edge chips and surface nicks	81
Table 8-1: Qualification test plan for coverglasses.....	99
Table 9-1: Acceptance test matrix IPD	114
Table 9-2: Acceptance test matrix EPD	114
Table 9-3: Qualification test plan for integral protection diode.....	117
Table 9-4: Qualification test plan for external protection diodes.....	118
Table 9-5: Diode life test parameters.....	132
Table 10-1: AM0 solar spectral irradiance (WRC).....	135
Table 10-2: Classes of single and multi-source solar simulators.....	140
Table 10-3: Classes of solar simulators with respect to nonconformity of irradiance uniformity	142
Table 10-4: Classes of solar simulators with respect to temporal instability of irradiance...	143
Table B-1 : Minimum current requirement for solar assemblies (25 °C or operating temperature)	166
Table C-1 : Electrical performance pass-fail criteria.....	174

Foreword

This document (EN 16603-20-08:2014) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-20-08:2014) originates from ECSS-E-ST-20-08C Rev.1.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by February 2015, and conflicting national standards shall be withdrawn at the latest by February 2015.

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

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

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

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

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, coverglass and protection diodes. This Standard does not outline the requirements for the qualification, procurement, storage and delivery of the solar array subsystem, comprising the solar panels, structural parts and mechanisms.

The general requirements are covered in the main part of this Standard (clauses 5 to 11). Annex A to Annex E specify the contents of the source control drawing of photovoltaic and solar cell assemblies, bare solar cells coverglasses and protection diodes 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 five 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,
- Clause 8 for coverglasses,
- Clause 9 for protection diodes.

Two additional clauses are dedicated to Sun simulators and calibration procedures (clause 10 and capacitance measurement methods (clause 11).

1

Scope

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

This standard does not cover the particular qualification requirements for a specific mission.

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

This standard is limited to crystalline Silicon and single and multi-junction GaAs solar cells with a thickness of more than 50 μm and does not include thin film solar cell technologies and poly-crystalline solar cells.

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

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

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

2

Normative references

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

EN reference	Reference in text	Title
EN 16601-00-01	ECSS-S-ST-00-01	ECSS system – Glossary of terms
EN 16602-60	ECSS-Q-ST-60	Space product assurance – Electrical, electronic and electromechanical (EEE) components
EN 16602-70-06	ECSS-Q-ST-70-06	Space product assurance – Particle and UV radiation testing for space materials
EN 16602-70-09	ECSS-Q-ST-70-09	Space product assurance – Measurements of thermo-optical properties of thermal control materials
	ISO 15387:2005	Space Systems – Single junction space solar cells – Measurement and calibration procedures
	ISO 14644-1:1999	Cleanrooms and associated controlled environments – Part 1: Classification of air cleanliness
	MIL-E-12397B	Eraser, rubber pumice for testing coated optical elements
	IEC 60749-26:2006	Semiconductor devices – Mechanical and climatic test methods - Part 26: Electrostatic discharge (ESD) sensitivity testing – Human body model (HBM)
	ASTM D1193-99	Standard specification for reagent water
	ESCC 23800 Issue 1	Electrostatic Discharge Sensitivity Test Method
	ESCC 24900 Issue 2	Minimum Requirements for Controlling Environmental Contamination of Components
	DIN 53289	Testing of adhesives for metals; floating roller peel test

Terms, definitions and abbreviated terms

3.1 Terms from other standards

For the purpose of this Standard, the terms and definitions from ECSS-S-ST-00-01 apply, in particular for the following terms:

qualification

verification

3.2 Terms specific to the present standard

3.2.1 General

3.2.1.1 blistering

forming of multiple small air bubbles inside the perimeter of a finish layer

3.2.1.2 bubbles

gaseous inclusion in the cell, coverglass or coverglass adhesive

3.2.1.3 chip

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

3.2.1.4 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).

3.2.1.5 delamination

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

3.2.1.6 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

3.2.1.7 dig

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

3.2.1.8 inclusion

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

3.2.1.9 in-process testing

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

3.2.1.10 nick

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

3.2.1.11 peeling

forming of a delamination of a finish layer at the edge of the finished area. A blister at the edge of the surface

3.2.1.12 procurement lot

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

3.2.1.13 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

3.2.1.14 shipment lot

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

3.2.1.15 spatter

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

3.2.1.16 voids

absence of deposited materials

NOTE Examples are absence of cell contact material or anti-reflection coating.

3.2.2 Photovoltaic assemblies

3.2.2.1 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

3.2.2.2 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, formerly also called DVT coupon

3.2.2.3 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.

3.2.3 Solar cell assemblies**3.2.3.1 cladding**

application of a thin layer of material fully covering the surface, For instance silver cladding of an interconnector

3.2.3.2 deformed interconnector

interconnector whose initial conformed shape is modified

3.2.3.3 interconnected cell

solar cell with interconnector without coverglass

3.2.3.4 solar cell assembly

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

3.2.3.5 tearing interconnector

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

3.2.4 Bare solar cells**3.2.4.1 bare solar cell**

photovoltaic component capable to delivering electrical power when illuminated with light

3.2.4.2 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

3.2.4.3 contact vacuum evaporation batch

bare solar cells manufactured in the same contact vacuum evaporation run

3.2.4.4 drops

excess of metallization material on the solar cell contacts

3.2.4.5 remaining Factor

ratio of an electrical performance parameter at EOL to its value at BOL

NOTE E.g. maximum power of a solar cell.

3.2.4.6 solar cell anti-reflection coating

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

3.2.4.7 uncoated area

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

3.2.4.8 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

3.2.5 Coverglasses

3.2.5.1 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.

3.2.5.2 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 clause 3.2.5.1.

3.2.5.3 coverglass

glass substrate and coatings applied to its surfaces

3.2.5.4 coverglass coating lot

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

3.2.5.5 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 conversion efficiency of the SCA.

3.2.5.6 mark

See **stain**

3.2.5.7 multi-layer anti-reflection coating

multiple layer coating which has the effect of increasing the transmission coefficient of the coverglass

3.2.5.8 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 .

3.2.5.9 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

NOTE The term "mark" can be used as a synonymous.

3.2.5.10 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 conversion efficiency of the SCA.

3.2.5.11 uncoated area

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

3.2.6 Verification processes

3.2.6.1 accelerated testing

test in which the life time requirement is verified in an accelerated way by intensifying one parameter of the environment or load.

NOTE The following are examples of accelerated tests:

- UV test done with increased sun intensity in the UV part of the spectrum,
- Electron and proton radiation tests with life time fluences in a limited period of time,
- humidity tests done at higher temperature and humidity,
- bake-out done at higher temperature,
- performance parameter degradation at higher temperature,

- thermal cycling with higher/lower cool-down and heat-up rates and without nominal operating dwell time in between.

3.2.6.2 acceptance test

test to determine that a system, subsystem, component or functional part is capable of meeting performance requirements prescribed in purchase specifications or other documents specifying what constitutes the adequate performance capability for the item and to demonstrate the item is free from manufacturing defects

NOTE In this document acceptance is associated with specified requirements which have a defined acceptance safety factor with respect to requirements corresponding with the actual loads and environments

3.2.6.3 delta qualification

qualification performed on an equipment which has undergone minor design modifications or has been qualified to operate in environments less severe than those specified

3.2.6.4 proto flight test

test requirements which have a defined qualification safety factor with respect to requirements corresponding with the actual loads and environments, but with limited test durations

3.2.6.5 qualification by similarity

process to demonstrate the ability to fulfil specified requirements by comparing a new design specification with a similar proven design specification

3.3 Abbreviated terms

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

Abbreviation	Meaning
ADP	acceptance data package
AOCS	attitude 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
NOTE: U.S. designation of SCA.	

Abbreviation	Meaning
CIDL	configuration item data list
CVCM	collected volatile condensable material
CVG	coverglass
DCR	documentation change request
DJF	design justification file
DRD	document requirements definition
DRB	delivery review board
DVG	direct voltage gradient
DVT	design verification test
EMC	electromagnetic compatibility
EOL	end-of-life
ESD	electrostatic discharge
FIT	failure in time
FMECA	failure modes, effects and criticality analysis
GaAs	gallium arsenide
GEO	geostationary orbit
IC	interconnected cell
I_{imp}	maximum power current
I_{op}	current at operational voltage
IRR	infrared reflector
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
PAD	part approval document
PCDU	power control and distribution unit
PID	process identification document
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

Abbreviation	Meaning
RDC	relative damage coefficients
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
TBD	to be defined
TBS	to be specified
TML	total mass loss
UVR	ultraviolet reflector
V_{mp}	maximum power voltage
V_{oc}	open-circuit voltage
V_{op}	operational voltage
V_{test}	test voltage
WRC	World Radiation Centre in Davos

4

General

4.1 Overview

4.1.1 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 clause describes the organization of the requirements and how they are applied.

The philosophy behind this Standard is two fold in that respect that:

- 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 4-1.

OR

- Qualification of components for a specific application can be achieved at a sub-assembly level at which the qualification is unequivocally demonstrated. This means that certain types of qualification tests do not need to be duplicated at different level of assembly in case of a unique application of a dedicated design

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 design requirements with the objective of demonstrating that the design and manufacturing processes are ready for use on solar panels of a flight application.

For many parameters in this standard the value to be specified as requirement is dependent on the mission concerning duration and environmental conditions or the implemented solar array design. These parameter values are derived from the higher level subsystem specification and reflected in a dedicated

document. In this standard the source control drawing has been selected generically on every level of assembly as an example of a document to reflect the specific requirements. So the source control drawing or equivalent set of documentation is the reference list for physical characteristics, performance requirements and environmental conditions.

Full qualification for an application is not only achieved after successful qualification of the PVA and its components on coupon level. Robustness against some environments can only be demonstrated in the final solar array configuration, that may comprise amongst others full size panel on-station thermal cycling and sine vibration, acoustic noise, and wing deployment testing at subsystem or spacecraft level.

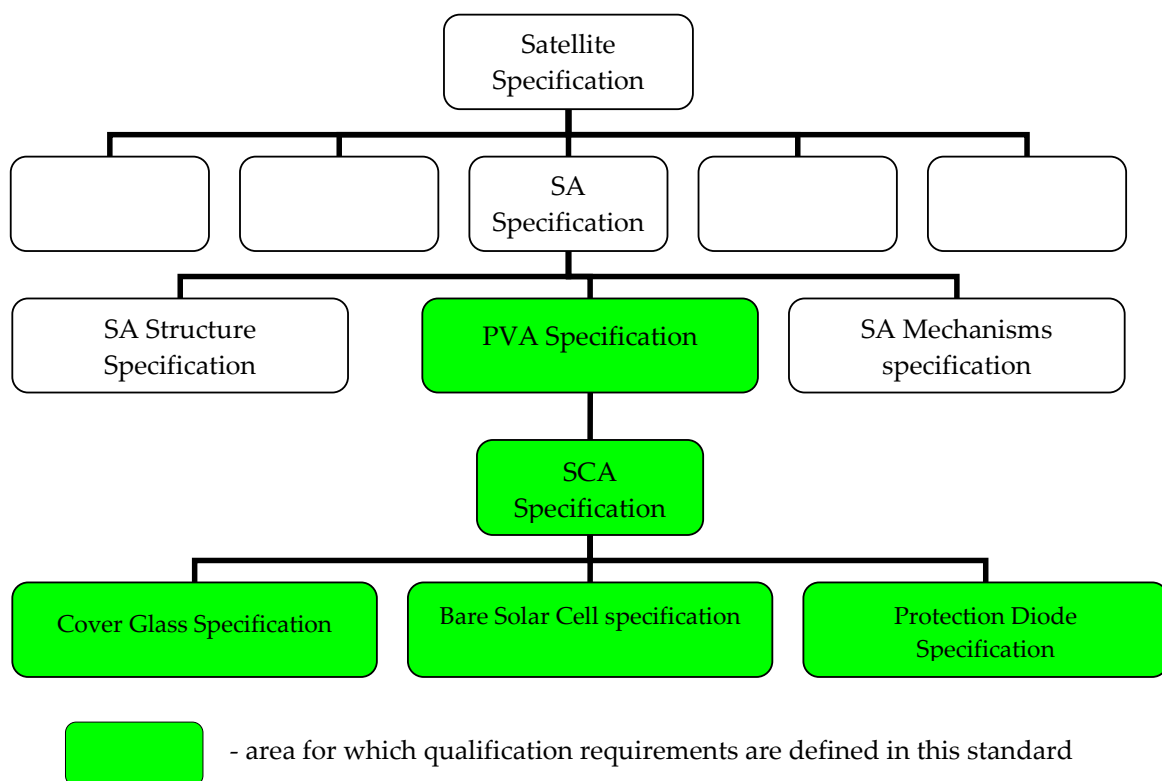


Figure 4-1: Specification hierarchy

4.1.2 Interfaces with other areas

In the specification hierarchy (Figure 4-1) 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. For EEE component specifications, see the ECSS-Q-ST-60 series of standards. For Materials Parts and processes specifications, see the ECSS-Q-ST-70.

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 qualification coupon level).

Non-PVA related 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).

4.2 Physical properties

- a. The following physical properties of the components and materials shall be measured:
 1. coefficient of thermal expansion
 2. heat conductivity
 3. specific heat
 4. Young's modulus and Poisson's ratio
 5. Flex strength

NOTE The objective is to establish the boundaries for the qualification test program over the full range of application by means of analysis.

- b. The data specified in requirement 4.2a shall be determined during the development phase of a new component and need not be repeated during the qualification program.

4.3 Test and storage

4.3.1 Test environment

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

1. Pressure: (1013,25 ± 33) hPa.
2. Temperature: (23 ± 5) °C.
3. Average relative humidity: 40 % - 60 %.

NOTE A pressure of (1013,25 ± 33) hPa is equivalent to (760 ± 25) mmHg.

- b. The room cleanliness level should be airborne particle count: Class 8 ISO 14644-1.
- c. Every deviation from requirements 4.3.1a and 4.3.1b during tests shall be recorded in the data documentation package (DDP).

NOTE 1 For DDP complete contents, refer to Annex G.

NOTE 2 Semiconductor devices (i.e. planar 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.

4.3.2 Test tolerances and accuracies

- a. The accuracy of the instruments and test equipment used to control or measure test parameters shall 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, 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 shall be as given in Table 4-1.
- e. The accuracy of mass measurements shall be better than ±1 % or 0,01 g, whichever is higher.
- f. The test condition tolerances shall be applied to the nominal test values specified.

- g. The accuracy of the electrical performance test on PVA level shall be better than or equal to the calibration loss factor used in the power analysis.

Table 4-1: Test tolerances on temperature

Temperature range (°C)	tolerance (°C)
around - 175	-10 / +0
around - 100	-10 / +0
around + 90	-0 / +10
Around +130	-0 / +10

4.3.3 Margins

- a. The margins to be applied to qualification test conditions shall be as defined in the solar array specification.

4.4 Critical materials

- a. The critical interface information shall be part of the PMP list.

NOTE For PMP, see ECSS-Q-ST-70 Annex B.

- b. Silver cladding shall be annealed and contain a minimum of 99,9 % pure silver.
- c. Pure tin, cadmium and zinc shall not be present in finished space-qualified solar panels.

NOTE Pure tin refers to a tin alloy with less than three atomic percent of an alloying metal, e.g., lead. Pure cadmium and zinc is defined as these metals used or applied in a non-mixed metal or unalloyed state.

- d. Solar panels containing Beryllium Oxide shall be clearly identified with the designation BeO.

5

Photovoltaic assemblies

5.1 Overview

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.

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

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

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

In order to design and verify a solar array, data for the following parameters and characteristics 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.

5.2 Conditions and method of test

- a. The conditions and methods of testing shall conform to the photovoltaic assembly source control drawing (SCD-PVA).

NOTE The PVA specification consists of two parts, the generic specification (this Standard) and the SCD. For the preparation of the SCD-PVA, refer to Annex A.

- b. The SCD-PVA shall be prepared by the supplier, in conformance with Annex A, and provided to the customer for reviewing and agreement.
- c. Any deviation from in-process, acceptance and qualification test shall be justified.
- 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 requirement 5.2c.

5.3 Photovoltaic assembly design

5.3.1 Overview

The objective of this standard at the PVA level is to specify the requirements for the detail design, performance, qualification, manufacture and acceptance testing of coupons equipped with the PVA. The inputs to these requirements are the solar array specification, which is prepared following the requirements of the mission specification, the ground test programme and the spacecraft design. In this clause the steps which influence specific design characteristics of the PVA have been listed. Requirements which merely determine the sizes of the PVA have not been taken into account, like intensity related loss factors and reliability requirements.

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-ST-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.

NOTE The mission specification can specify an absolute limit to the total mass loss and volatile condensable material of the solar array sub-system. The fulfilment of this system requirement can be verified either by analysis using the total amount of the applied materials, the individual material RML and CVCM data, outgassing field of view and temperature distribution, or by test of the representative subsystem and measurement of the outgassing product.

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 conformance with a standard approved by the customer.

5.3.2.3 Flammability

- a. 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

- a. PVA materials shall be capable of tolerating a defined erosion level resulting from spacecraft operation without degradation in the nominal performance of the PVA, in conformance with the PVA specification.

NOTE Example: thruster plumes.

5.3.2.7 Atomic oxygen (ATOX)

- a. PVA materials shall be capable of tolerating a defined level of degradation resulting from an ATOX environment, without degradation in the nominal performance of the PVA, in conformance with the solar array specification.
- b. The ATOX resistivity shall be determined by the individual resistivities of the used materials and components in their configuration.

5.3.3 Parameters related to 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 as to conform to the mission requirements.
- b. The capability for replacement of cracked, broken or damaged SCAs shall be included in the design.
- c. Repair method shall be feasible in horizontal and vertical panel positions.

5.3.3.2 Stringing

- a. 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.
- b. To enable performance measurement at the lowest level of assembly at the coupon level, strings shall be measured individually.
- c. Potential parallel connections shall not prevent performance measurement specified in requirement 5.3.3.2b.
- d. If the dimensions of the coupon enables the accommodation, the full flight string length shall be represented on the qualification coupon.
- e. Coupon layout shall be as defined in a overall assembly drawing as part of the SCD-PVA.

5.3.3.3 Cell interspacing

- a. The cell interspacing shall be compatible, as a minimum, with the following mission requirements:
 1. thermal expansion and contraction within the mission temperature extremes specified in the solar array specification;
 2. panel geometry;
 3. ESD requirements.

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

- a. 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 (including maximum power point tracker when direct energy transfer function is acting at BOL).

5.3.3.6 Insulation

- a. The following items shall be electrically insulated from each other:
 1. Any solar cell circuits to substrate (the grounding reference of the coupon).

2. Solar cell circuits to solar cell circuits (if not connected at the negative ends).
3. Thermal sensor to the solar cell circuits and to the substrate (the grounding reference of the coupon).
4. Conductive coverglass grounding network, if used, to solar cell circuits.

5.3.3.7 Derating

For the derating requirements of components, see ECSS-Q-ST-30-11.

5.3.3.8 Redundancy

For redundancy requirements, see ECSS-Q-ST-30.

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

5.3.3.9 Fault tolerance

- a. A FMECA shall be performed for the design of the solar array.
- b. The design consequences shall be implemented on the qualification coupon, including:
 1. the photovoltaic assembly from solar cell strings to the connector, and

2. redundant bleed resistors and, if any, redundant PVA assemblies or components.

NOTE 1 Examples: Solar cell strings, blocking diodes, temperature sensors.

NOTE 2 For FMECA, see ECSS-Q-ST-30-02.

- c. No single fault shall result in the following:
 1. The loss of integrity of the redundant parts indicated in requirement 5.3.3.9b.2.
 2. The propagation of the fault causing permanent damage or loss of use of the units connected to the PVA.

NOTE Examples: solar array regulator unit, solar array drive mechanism.

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

5.3.3.10 Fatigue resistance

- a. The effects of fatigue shall be verified by analysis or test.
- b. The design of the PVA shall include the result of the verification specified in requirement 5.3.3.10a.

5.3.3.11 Adherence to substrate

5.3.3.11.1 Measurement

- a. The adherence of SCAs to the substrate shall be measured using representative process samples.

5.3.3.11.2 Property

- a. The SCAs shall stay attached to the panel and conform to all requirements during the test campaign and all the phases of the mission.
- b. The adherence shall be such that the SCAs integrated on the substrate can be repaired, removed and replaced.

5.3.3.12 Adhesive uniformity

- 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, in conformance with requirement 5.3.3.12a, shall be guaranteed by a controlled application process demonstrated on separate samples.
- c. The thermal conductance towards the panel substrate shall be such that the specified solar cell and protection diode temperature can be maintained.

5.3.3.13 Electrostatic discharge (ESD)

- a. The solar array design shall be such that it can survive the charging environment and operating conditions defined by the mission.
- b. Requirement 5.3.3.13a 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 Electromagnetic compatibility (EMC)

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

5.3.3.15 Repairability

- a. The capability of repairing, removing and replacing items down to component level shall be provided.

NOTE For example, for single SCAs, diodes, thermal sensors, wires and connectors.

5.4 PVA manufacturing

5.4.1 Process validation

- a. The manufacturing and integration processes shall be validated for all the project specific design configurations and to meet the engineering design requirements.

5.4.2 Defect acceptability

- a. The acceptability of defects at the PVA level shall be:
 - 1. agreed with the customer;
 - 2. defined in a production control document;
 - 3. validated by qualification testing.

5.4.3 In-process testing

5.4.3.1 Overview

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

5.4.3.2 Mass measurement

- a. To determine the add-on mass of the SCA laydown process, the mass of the substrate shall be measured before and after the substrate is equipped with the SCA's and be in conformance 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. Verify continuity between the conductive layer under the insulation to the test connection point.
 - 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. 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.

NOTE For example, for $E_{\text{spec}} = 20$ V/ μm and a (50 ± 10) μm insulation layer, a test voltage of 800 V applies.

- b. The acceptance criteria shall be an insulation larger than 100 M Ω .
- c. In case of a failure, the coupon insulator layer shall be repaired.

5.4.3.4 Adherence to substrate

- a. The adherence of the SCAs to the substrate, shall be performed in parallel to panel laydown.
- b. The adherence to substrate shall be verified by means of one of the following two methods:
 1. Method 1
 - (a) Bond 3 SCAs following identical process to a representative PVA substrate of the following dimensions: 200 x 130 mm.
 - (b) After 1 week at room temperature, perform a pull test, with a pull force equal or larger than 1 N/cm².
 2. Method 2
 - (a) In case no solar cell assemblies and substrate are available, bond together 2 Kapton foils of the same material as used in representative PVA and with dimensions of 250 mm x 150 mm.
 - (b) After 1 week at room temperature, perform a peel test of the foil according to DIN 53289.
 - (c) Use a peel force equal or larger than 1,8 N/cm.
 - (d) Ensure that the separation takes place within the adhesive for an area larger than 50 %.

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 and traceability

- a. Components other than SCAs, bare cells and coverglasses shall be identified in conformance with the traceability requirements of Class 1 components, and PAD DRD of ECSS-Q-ST-60.

NOTE For requirements on the identification and traceability of parts and materials, see clauses 6.1.4,

7.1.3 and 8.3.3 for SCAs, bare cells and coverglass, respectively.

5.4.5 Recording

- a. Before start manufacturing, all processes and process variables related to PVA manufacturing that have impact on the performance of the process, shall be identified by the supplier.
- b. The processes variables specified in requirement 5.4.5a 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. Qualification tests shall be preceded by the acceptance tests as listed in clause 5.5.2, in order to be representative of the life of flight hardware.
- b. All results of the qualification test shall be reported in a qualification test report.
- c. Qualification margins shall not exceed component and material specifications unless agreed between supplier and customer.
- d. The following environmental test shall be performed for qualification of PVAs as applied on solar panels:
 - 1. Fatigue thermal cycling test on the qualification coupon.
 - 2. Humidity test performed on dedicated test sample if not tested on SCA level.
 - 3. ESD test on a dedicated ESD coupon, if specified by the solar array requirement specification.
 - 4. Erosion of materials, due to thruster plume if specified by the solar array requirement specification.

NOTE The tests to be performed for each qualification are listed in Table 5-1 and described in clauses 5.5.2 and 5.5.3.

- e. In cases where the same coupon is used for the fatigue thermal cycling test and the humidity test, in conformance with requirement 5.5.1.2d the humidity test sequence shall precede the fatigue thermal cycling test sequence.

- f. Except in conformance with requirement 5.5.1.2e, each type of test shall be performed on a dedicated qualification coupon built specifically for the test.
- g. 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.
- h. 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.
- i. Each qualification coupon shall be flight representative as far as allowed by the dimensions of the qualification coupon
- j. Facilities shall be available to safely store the qualification hardware (included failed samples) for a minimum of 6 years (equivalent to five years in storage and one year in orbit).

Table 5-1: Qualification test plan for PVA

Check	Fatigue thermal cycling	Humidity test	ESD test
Full visual inspection (5.5.3.2)	1, 6, 9, 14	1, 5	1, 4
Electrical health check and performance (5.5.3.3 and 5.5.3.4)	2, 7, 10, 15	2, 6	2, 5
Capacitance (5.5.3.5)	3, (11), 16		
X-ray photo (5.5.3.9)	4, (12), 17		
Reflectance (5.5.3.8)		3, 7	
Vacuum thermal cycling (5.5.3.11)	5, 13		
Substrate integrity (5.5.3.10)	18		
Fatigue thermal cycling (5.5.1.3)	8		
Humidity (5.5.1.4)		4	
ESD test (5.5.1.5)			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 PVA manufacturer shall demonstrate that lack of continuity is avoided at any time during cycles defined in requirement 5.5.1.3.4g, both on the solar cell and on the protection shunt diode circuits.

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

NOTE For example, acoustic and noise can produce greater stress than thermal cycling in certain missions.

5.5.1.3.3 Qualification coupon

- a. The qualification coupon shall be defined by means of a representative drawing, document or matrix in the SCD-PVA.
- b. The representation of the critical areas of the solar array on the qualification coupon shall be agreed with the customer.

NOTE For 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, but with a minimum of two.

NOTE For example, it can be one blocking diode per string, one shunt diodes per shunt interval, and two bleed resistors per panel, but in accordance with this requirement, in all these cases the minimum number is 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 qualification coupons shall be representative of the full processing of the flight hardware.
- i. At least 3 thermocouples on the front side and 3 on the rearside of each qualification coupon shall be placed for temperature monitoring.
- j. The qualification 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 qualification 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 (at both upper and 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 extremes (both upper and lower qualification temperature limit).
- b. If qualification margin temperature exceeds the brittle point of main elements of the PVA, the option to be used in conformance with requirement 5.5.1.3.4a shall be agreed with the customer.
- c. For a GEO mission, the following cycling profiles shall be used:
 - 1. Define GEO transfer orbit cycles in conformance with the mission profile.
 - 2. all on station representing fatigue cycles are identical".
- d. For a LEO mission, the following cycling profiles shall be used:
 - 1. A temperature profile which envelopes the variation of temperature extremes during the mission.
 - 2. The total profile, divided into a number of equally shaped sub-profiles, where the number of sub-profiles are:
 - (a) equal to the number of years of the mission, and
 - (b) with extreme cycle temperatures derived from the slicing of the temperature profile of the whole mission.
- e. The number of cycles and temperature limits of requirements 5.5.1.3.4a and 5.5.1.3.4b shall be stated in the SCD-PVA.
- f. Monitoring of the insulation between the solar cell circuit and the substrate shall:
 - 1. be performed in conformance with clause 5.5.3.3.3, and
 - 2. take place during the cycles with the maximum temperature limits and for a minimum of two cycles at each test interval.
- g. Monitoring of the continuity of the solar cell circuits shall:
 - 1. be performed in conformance with clause 5.5.3.3.2,
 - 2. take place during cycles for the complete activity,
 - 3. be performed on a regular, at least daily basis for a number of cycles, such that:
 - (a) during 10 % of these cycles of the cell circuit, and

- (b) during 90 % of these cycles on the protection diode network shall be monitored.
- 4. be performed by measuring both cell circuit continuity, at the beginning and at the end of the cycles in conformance to the relevant percentage specified in requirement 5.5.1.3.4g.3.
- h. Insulation and continuity shall not be measured simultaneously.

5.5.1.3.5 Pass-fail criteria

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

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

- a. If there are requirements on specific environmental conditions, they shall be stated in the SCD-PVA.

NOTE For example, chemical vapour requirements.

5.5.1.4.3 Test Sample

- a. The test sample shall be manufactured using the same qualified materials and processes as the flight panels.
- b. The production of the test sample shall be representative of the full processing of the flight hardware.

5.5.1.4.4 Test

- a. The test sample 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 in conformance with ASTM D1193-99, Type I, shall be used.
- g. Water condensation on the surface of the test sample shall be prevented.
- h. If there are requirements on specific environmental conditions, they shall be stated in the SCD-SCA.

NOTE For example, requirements on chemical vapour conditions.

5.5.1.4.5 Pass-fail criteria

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

5.5.1.5 Electrostatic discharge (ESD) test

5.5.1.5.1 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.

Typical rules and a test procedure are described in ECSS-E-ST-20-06.

5.5.1.5.2 Pass-fail criteria

- a. No sustained arc shall occur.
- b. Testing shall demonstrate that the observed primary arcs do not produce any type of damage to the solar array or to the cells.

5.5.1.6 Erosion of materials

- a. 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.

5.5.1.7 EMC

- a. 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 qualification 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

- a. The deliverable documentation shall be agreed with the customer.

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

5.5.2.4 Process

- a. All acceptance tests shall be in conformance with clause 5.2.
b. All results of the acceptance test shall be reported in the data documentation package (DDP).

NOTE For the DDP, see clause 5.7 and Annex G.

- c. The standard sequence of acceptance tests for PVA shall be as presented in Table 5-2.
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 5-2: 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 5.5.2.4d	

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 conformance with the value given the SCD-PVA.

5.5.3.2 Full visual inspection

5.5.3.2.1 Purpose

The full VI is performed to detect imperfections in the complete hardware.

5.5.3.2.2 Process

- a. A full visual inspection shall be performed against the inspection requirements stated in clauses 5.5.3.2.4 to 5.5.3.2.21, 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:

- electroluminescence
- infrared inspection;
- inspection with the naked eye;
- inspection using microscopes;
- any equivalent methods.

- b. Training records of the personnel performing the visual inspection shall be made available to the customer under request.

5.5.3.2.3 General criteria

- a. The PVA supplier shall define the inspection criteria for the PVA components, to be agreed by the customer, and included in the SCD-PVA.

5.5.3.2.4 Visual inspection of dimensions, stay-out zones, and stand-offs

- a. The dimensions shall conform to the qualification coupon assembly drawing.
- b. Cells and components shall not enter the stay-out zones indicated on the qualification coupon assembly drawing.
- c. The stand-off distance of cells and components shall conform to the qualification coupon assembly drawing.

5.5.3.2.5 Visual inspection of the 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.

5.5.3.2.6 Visual inspection of the coverglass

- a. All the coverglass shall be inspected for defects in conformance with requirements 5.5.3.2.6b to 5.5.3.2.6e.

- b. 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 clause 6.4.3.1.4.
 - 2. Cracks on the coverglass, except if they meet the following conditions:
 - (a) no visible separation (in conformance with clause 6.4.3.1.4);
 - (b) no more than three per cover;
 - (c) meeting cracks if they are separated by more than 2 mm at the non-meeting end.
- c. Any defect in conformance with requirement 5.5.3.2.6b, raised after acceptance shall be reported and traced throughout the qualification sequence.
- d. Covers with dirty and contaminated surfaces shall be cleaned.
- e. 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 in conformance with clause 8.3.3.
 - 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 requirement 5.5.3.2.6b.1.
 - 6. Edge chips exceeding the limits specified in clause 6.4.3.1.4.
 - 7. Coverglasses with intersecting cracks exceeding the limits specified clause 6.4.3.1.4.

5.5.3.2.7 Visual inspection of the coverglass adhesive

- a. After coverglass or solar cell repair, there shall be no delamination or discoloration in the adhesive, except in the area opposite rear welds, where discoloration may be present.
- b. After coverglass or solar cell repair, adhesive voids along the cover edge shall not exceed 0,6 mm in depth.
- c. After coverglass or solar cell repair,, the maximum total projected area of additional bubbles shall not exceed 0,2 % of cell area, discounting:
 - 1. bubbles less than 0,02 mm² in the projected area, and

2. bubbles, discolorations and voids located at less than 2 mm from the interconnector edges.

5.5.3.2.8 Visual inspection of the solar cells

- 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 clause 6.4.3.1.4.
- b. Any imperfections listed in requirements 5.5.3.2.8a.1 to 5.5.3.2.8a.3, 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 requirement 5.5.3.2.8a.2.

NOTE Multiple crossing of the same gridline can be present.

2. More cracks than defined in requirement 5.5.3.2.8a.1 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 clause 6.4.3.1.4.
5. Edge chips exceeding the limits specified in clause 6.4.3.1.4.

5.5.3.2.9 Visual inspection of the 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 serpentine may be present.

5.5.3.2.10 Visual inspection of the 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 requirements 5.5.3.2.10a.1 to 5.5.3.2.10a.3, 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.

5.5.3.2.11 Visual inspection of the 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 requirements 5.5.3.2.11a.1 to 5.5.3.2.11a.3, raised after acceptance shall be reported and traced throughout the qualification sequence.
- c. Tarnishing may be present on the end terminations.

5.5.3.2.12 Visual inspection of the 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 requirements 5.5.3.2.12a.1 to 5.5.3.2.12a.5, raised after acceptance shall be reported and traced throughout the qualification sequence.

5.5.3.2.13 Visual inspection of the soldering

- a. Soldering of wires at string terminations and terminals shall be in conformance with a standard agreed with the customer

NOTE For soldering, see for instance ECSS-Q-ST-70-08.

5.5.3.2.14 Visual inspection of the welding

- a. Welding of wires at string terminations and terminals shall be in conformance with the SCD-PVA.

5.5.3.2.15 Visual inspection of the crimping

- a. Crimping of wires shall be in conformance with a standard agreed with the customer.

NOTE For crimping, see for instance ECSS-Q-ST-70-26.

5.5.3.2.16 Visual inspection of the attachment materials

- a. Attachments based on bonding techniques shall be fully cured and not exhibit any tackiness.

5.5.3.2.17 Visual inspection of the feed-throughs

- a. Feed-throughs shall be firmly bonded.
- b. Feed-throughs shall conform to the locations specified on the top assembly drawing.

5.5.3.2.18 Visual inspection of the 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.

5.5.3.2.19 Visual inspection of the hardware

- a. Terminal board locations shall conform to the qualification coupon assembly drawing.
- b. Stand-off of all components shall conform to the qualification coupon assembly drawing.
- c. For mounted components (temperature sensor, resistors and diodes), the following shall be performed:
 - 1. Verify the status of the following items:
 - (a) fixation on the substrate;
 - (b) body aspect and absence of cracks;
 - (c) connections;
 - (d) shrinkage tube.
 - 2. Ensure that conformal coating of the components:
 - (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.

5.5.3.2.20 Visual inspection of the 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.

5.5.3.2.21 Visual inspection of the cleanliness

- a. When visually examined with the unaided eye, the coupon shall appear clean.
- b. There shall be no loose material on the coupon.

5.5.3.3 Electrical health check

5.5.3.3.1 Purpose

All tests specified in this clause 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

- a. 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 conformance 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 be 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 equal to the predicted maximum Voc during the mission.
- b. The reverse current measured shall be negligible with respect to the string current (usually less than 5 mA).