

**DIN EN 16603-20-08**

ICS 49.140

**Raumfahrttechnik –  
Teil 20-08: Fotovoltaische Baugruppen und Komponenten;  
Englische Fassung EN 16603-20-08:2014**

Space engineering –  
Part 20-08: Photovoltaic assemblies and components;  
English version EN 16603-20-08:2014

Ingénierie spatiale –  
Partie 20-08: Ensembles et composants photovoltaïque;  
Version anglaise EN 16603-20-08:2014

Gesamtumfang 203 Seiten

DIN-Normenausschuss Luft- und Raumfahrt (NL)

## **Nationales Vorwort**

Dieses Dokument (EN 16603-20-08:2014) wurde vom Technischen Komitee CEN/CLC/TC 5 „Raumfahrt“ erarbeitet, dessen Sekretariat von DIN (Deutschland) gehalten wird.

Das zuständige deutsche Normungsgremium ist der Arbeitsausschuss NA 131-10-01 AA „Interoperabilität von Informations-, Kommunikations- und Navigationssystemen“ im DIN-Normenausschuss Luft- und Raumfahrt (NL).

Dieses Dokument (EN 16603-20-08:2014) basiert auf ECSS-E-ST-20-08C Rev.1.

Dieses Dokument enthält unter Berücksichtigung des DIN-Präsidialbeschlusses 1/2004 nur die englische Originalfassung von EN 16603-30-08:2014.

Dieses Dokument wurde speziell für die Behandlung von Raumfahrtsystemen erarbeitet und hat daher Vorrang vor jeder anderen EN, die denselben Anwendungsbereich behandelt, allerdings mit erweitertem Bereich der Anwendbarkeit (z. B. Luft- und Raumfahrt).

## Nationaler Anhang NA (informativ)

### Begriffe und Abkürzungen

### 3 Begriffe und Abkürzungen

#### 3.1 Begriffe aus anderen Normen

Für die Anwendung dieser Norm gelten die Begriffe nach ECSS-S-ST-00-01, insbesondere die folgenden Begriffe.

**Qualifikation**

**Verifizierung**

#### 3.2 Für diese Norm spezifische Begriffe

##### 3.2.1 Allgemeines

###### 3.2.1.1

###### **Ausblühung**

Bildung mehrerer kleiner Luftblasen innerhalb einer Deckschicht

###### 3.2.1.2

###### **Blasen**

gasförmige Einschlüsse in der Zelle, dem Deckglas oder dem Deckglasklebstoff

###### 3.2.1.3

###### **Ausbruch**

örtlich begrenztes Fehlen von Werkstoff entlang der Kanten und Ecken eines vollständigen Bauteils, das durch dessen gesamte Dicke verläuft

###### 3.2.1.4

###### **Riss**

Riss im Bauteil, ohne dass sich ein Teil vom Rest getrennt hat

ANMERKUNG Risse können von der Kante des Werkstoffs ausgehen (Kantenrisse) oder zu beiden Seiten im Werkstoff enden (Oberflächenrisse).

###### 3.2.1.5

###### **Delamination**

physikalische Trennung zwischen zwei auslegungsgemäß verbundenen Werkstoffschichten

###### 3.2.1.6

###### **Verfärbung**

örtlich begrenzte Farbabweichung der Antireflexbeschichtung einer Solarzelle aufgrund des Einflusses der Strukturausrichtung der unmittelbar darunter liegenden Schicht der Zelle oder einer Schwankung der Schichtdicke der Antireflexbeschichtung

#### 3.2.1.7

##### **Einkerbung**

Vertiefungen in der Oberfläche eines Bauteils aufgrund von Stoßeinwirkung mit einem spitzen Gegenstand oder Quetschen eines Werkstoffs auf die Oberfläche

#### 3.2.1.8

##### **Einschluss**

Volumen innerhalb des Bauteils, das frei von Untergrundwerkstoff ist

#### 3.2.1.9

##### **fertigungsbegleitende Prüfung**

Prüfungen, die während der Herstellung eines Bauteils oder einer Baugruppe durchgeführt werden, um Fehler oder geringe Leistungen im Voraus festzustellen

#### 3.2.1.10

##### **Kerbe**

örtlich begrenztes Fehlen von Werkstoff auf der Oberfläche eines vollständigen Bauteils, das nicht durch dessen gesamte Dicke verläuft

#### 3.2.1.11

##### **Schälen**

Bilden einer Delamination einer Deckschicht am Rand der beschichteten Fläche; eine Blase an der Kante der Oberfläche

#### 3.2.1.12

##### **Beschaffungslos**

Reihe von Sendungslosen von Solarzellenanordnungen, unverbundenen Solarzellen und Deckgläsern, die mit denselben Prozessen, denselben Werkstoffen sowie identischen Fertigungsstraßen hergestellt wurden und denselben Kaufauftrag erfüllen

#### 3.2.1.13

##### **Kratzer**

lineare Beschädigung eines Bauteils in Form eines Volumens mit fehlendem Untergrundwerkstoff, die nur von einer Oberflächenschicht des Bauteils ausgeht und an keiner Stelle durch die gesamte Dicke des Untergrunds verläuft

#### 3.2.1.14

##### **Sendungslos**

Solarzellenanordnungen, unverbundene Solarzellen und Deckgläser, die mit denselben Prozessen, denselben Werkstoffen sowie identischen Fertigungsstraßen hergestellt wurden und als Teil eines Kaufauftrags an den Kunden ausgeliefert werden

#### 3.2.1.15

##### **Spritzer**

kleine Teile des festen Beschichtungswerkstoffs auf bzw. in der Beschichtung oder dem Untergrundwerkstoff

#### 3.2.1.16

##### **Fehlstellen**

Fehlen aufgebrachtter Werkstoffe

ANMERKUNG Beispiele hierfür sind Fehlen von Kontaktwerkstoffen oder Antireflexbeschichtungen der Zelle.

### 3.2.2 Fotovoltaische Baugruppen

#### 3.2.2.1

##### **fotovoltaische Baugruppe**

energieerzeugendes Netz aus den miteinander verbundenen Solarzellenanordnungen (Stränge und Abschnitte), Nebenschluss- und Sperrdioden, Stromschienen und Sammelschaltpaneelen, Strang-, Abschnitts- und Plattenverdrahtungen, Flügelübertragungsleitungen, Steckverbindern, Ableitwiderständen und Thermistoren

**3.2.2.2****Qualifikationsprüfstück**

nicht für den Flug repräsentatives Prüfstück von Fluginstrumententafeln, gebaut mit Flugprozessen aus für die Fertigung von Fluginstrumententafeln repräsentativen Werkstoffen und Bauteilen, früher auch als DVT-Prüfstück bezeichnet

**3.2.2.3****Aufteilung****Slicing**

Verfahren für die gleichmäßige Verteilung der Gesamtanzahl von Temperaturzyklen über Temperaturbereiche, angepasst an die Temperaturkurve in einer Umlaufhöhe statt an die Temperatur-Hüllkurve der gesamten Mission

ANMERKUNG Gebräuchlich bei LEO-Missionen.

**3.2.3 Solarzellenanordnungen****3.2.3.1****Abdeckung**

Aufbringen einer dünnen Werkstoffschicht, die die gesamte Oberfläche bedeckt, z. B. Silberabdeckung auf einer Verbindungsleitung

**3.2.3.2****verformte Verbindungsleitung**

Verbindungsleitung, deren ursprüngliche zugelassene Form verändert ist

**3.2.3.3****verbundene Zelle**

Solarzelle mit Verbindungsleitung ohne Deckglas

**3.2.3.4****Solarzellenanordnung**

Solarzelle gemeinsam mit Verbindungsleitung, Deckglas und, sofern vorhanden, Bypass-Diode

**3.2.3.5****getrennte Verbindungsleitung**

physikalisch von der Zelle aufgrund von Versagen der Schweiß- oder Lötverbindung getrennte Verbindungsleitung

**3.2.4 Unverbundene Solarzellen****3.2.4.1****unverbundene Solarzelle**

fotovoltaisches Bauteil, das bei Belichtung elektrische Energie liefern kann

**3.2.4.2****nicht mit Bauteilen verbundene Solarzelle**

speziell hergestellte Solarzelle mit nur einem aktiven Anschluss und derselben Spektralempfindlichkeit wie eine Teilzelle einer mehrfach verbundenen Solarzelle

**3.2.4.3****Kontaktvakuumverdampfungs-Charge**

in demselben Kontaktvakuumverdampfungsverfahren hergestellte, unverbundene Solarzellen

**3.2.4.4****Tropfen**

überschüssiger Metallisierungswerkstoff auf den Solarzellenkontakten

### 3.2.4.5

#### **Restfaktor**

Verhältnis zwischen einem Parameter der elektrischen Leistung bei EOL und dessen Wert bei BOL

ANMERKUNG Beispielsweise maximale Leistung einer Solarzelle.

### 3.2.4.6

#### **Antireflexbeschichtung der Solarzelle**

ein- oder mehrschichtiger Überzug zur Verringerung des Reflexionskoeffizienten der einfallenden Sonnenstrahlung

### 3.2.4.7

#### **unbeschichteter Bereich**

Bereich der Solarzelle, in dem die unverbundene Solarzelle ohne jeglichen Überzug freiliegt

### 3.2.4.8

#### **wurmförmige Wölbung**

hervorstehender Kontaktwerkstoff in Form von unregelmäßigen Linien oder einzelnen Punkten mit örtlich begrenzter Delamination zwischen Kontaktwerkstoff und unmittelbar darunter liegender Schicht

## 3.2.5 Deckgläser

### 3.2.5.1

#### **Überzug**

dielektrischer oder leitfähiger Werkstoff, der auf den Glasuntergrund durch Vakuumbeschichtung aufgebracht wird

ANMERKUNG Auf die Außenfläche des Deckglases aufgetragene Überzüge werden als „Vorderseitenüberzug“ bezeichnet. Überzüge, die auf die Innenfläche des Glasuntergrunds aufgebracht werden, welche mit der Solarzelle verbunden sind, werden als „Rückseitenüberzug“ bezeichnet. Allgemein gebräuchliche Überzüge umfassen:

- Einschicht-Antireflexbeschichtung;
- Mehrschicht-Antireflexbeschichtung;
- Reflektor für ultraviolette Strahlung;
- Reflektor für Infrarotstrahlung; und
- leitfähiger Überzug.

### 3.2.5.2

#### **leitfähiger Überzug**

transparenter Überzug zur Verhinderung der Aufladung der freiliegenden Oberfläche und somit zum Schutz der Solarzelle gegenüber den Auswirkungen elektrostatischer Entladung

ANMERKUNG Das Deckglas besteht gewöhnlich aus einem geeigneten Glasuntergrund und einer oder mehreren Kombination(en) der in der Anmerkung zu 3.2.5.1 angegebenen Überzüge.

### 3.2.5.3

#### **Deckglas**

Glasuntergrund und die auf dessen Oberfläche aufgetragenen Überzüge

### 3.2.5.4

#### **Deckglasüberzuglos**

Zusammenfassung von Glasuntergründen, die dem-/denselben Überzugverfahren (bei Deckgläsern mit mehr als einem Überzug) unterzogen wurden

**3.2.5.5****Reflektor für Infrarotstrahlung**

mehrschichtiger dielektrischer Überzug mit einem hohen Reflexionsgrad im Infrarotbereich des Sonnenspektrums

ANMERKUNG Der Reflektor für Infrarotstrahlung dient dem Reflektieren von Licht, das nicht zur Umwandlung in elektrische Energie durch die Solarzelle nutzbar ist, wodurch die Betriebstemperatur verringert und der Wirkungsgrad der SCA erhöht wird.

**3.2.5.6****Marke**

siehe Fleck

**3.2.5.7****Mehrschicht-Antireflexbeschichtung**

mehrschichtiger Überzug, der den Durchlässigkeitsfaktor des Deckglases erhöht

**3.2.5.8****Einschicht-Antireflexbeschichtung**

einfachste Art des Überzugs aus einer einzelnen Schicht gering dielektrischen Werkstoffs, der den Reflexionsgrad der einfallenden Sonnenstrahlung minimiert und somit den Durchlässigkeitsfaktor des Deckglases erhöht

ANMERKUNG Die einzelne Schicht gering dielektrischen Werkstoffs besteht gewöhnlich aus  $\text{MgF}_2$ .

**3.2.5.9****Fleck**

Bereich, der unter Prüfbedingungen eindeutig als optisch nicht homogen mit dem Werkstoff feststellbar und nicht als Einschluss, Kratzer, Riss, Ausbruch, Einkerbung, Fehlstelle oder Delamination des Überzugs identifizierbar ist

ANMERKUNG Der Begriff „Marke“ kann als Synonym verwendet werden.

**3.2.5.10****Reflektor für ultraviolette Strahlung**

mehrschichtiger dielektrischer Überzug mit einem hohen Reflexionsgrad im UV-Bereich des Sonnenspektrums

ANMERKUNG Der Reflektor für ultraviolette Strahlung dient dem Schutz der darunter liegenden Klebstoffschicht und dem Reflektieren von Licht, das nicht zur Umwandlung in elektrische Energie durch die Solarzelle nutzbar ist, wodurch die Betriebstemperatur der Solarzelle verringert und der Wirkungsgrad der SCA erhöht wird.

**3.2.5.11****unbeschichteter Bereich**

Bereich des Deckglases, in dem der bloße Deckglasuntergrund ohne jeglichen Überzug freiliegt

**3.2.6 Verifizierungsprozesse****3.2.6.1****beschleunigte Prüfung**

Prüfung, in der die Anforderung an die Lebensdauer mittels Verstärkung eines umgebungs- oder lastbezogenen Parameters auf beschleunigte Art verifiziert wird

ANMERKUNG Folgendes sind Beispiele für beschleunigte Prüfungen:

- UV-Prüfung bei erhöhter Sonnenintensität im UV-Bereich des Spektrums;
- Elektronen- und Protonenstrahlungsprüfungen mit Lebensdauerfluenzen innerhalb eines begrenzten Zeitraums;
- Feuchteprüfungen bei erhöhter Temperatur und Feuchte;

- Ausheizen bei erhöhter Temperatur;
- Verschlechterung der Leistungsparameter bei erhöhter Temperatur;
- Temperaturwechselbeanspruchung mit höherer/niedrigerer Abkühl- und Aufheizgeschwindigkeit sowie ohne die dazwischen liegende Nennbetriebshaltezeit.

### **3.2.6.2**

#### **Abnahmeprüfung**

Prüfung zur Feststellung, dass ein System, Untersystem, Bauteil oder Funktionselement die Leistungsanforderungen erfüllen kann, die in Auftragspezifikationen oder anderen Dokumenten festgelegt sind, welche die angemessene Funktionsfähigkeit des Gegenstands festlegen, sowie zum Nachweis, dass der Gegenstand frei von Herstellungsfehlern ist

**ANMERKUNG** In diesem Dokument steht die Abnahme in Zusammenhang mit festgelegten Anforderungen, die einen festgelegten Abnahmesicherheitsbeiwert bezüglich der Anforderungen für die tatsächlichen Lasten und Umgebungen beinhalten.

### **3.2.6.3**

#### **Delta-Qualifikation**

Qualifikation eines Geräts, das geringfügigen Veränderungen der Auslegung unterzogen oder für weniger strenge als die festgelegten Betriebsumgebungen qualifiziert wurde

### **3.2.6.4**

#### **Erstflug-Prüfung**

Prüfanforderungen mit einem festgelegten Sicherheitsbeiwert für die Qualifikation in Zusammenhang mit Anforderungen hinsichtlich der tatsächlichen Lasten und Umgebungen, aber begrenzter Prüfdauer

### **3.2.6.5**

#### **Qualifikation durch Vergleich**

Prozess zum Nachweis, dass festgelegte Anforderungen erfüllt werden können, durch Vergleich einer neuen mit einer vergleichbaren zugelassenen Auslegungsspezifikation

## **3.3 Abkürzungen**

Für die Anwendung dieser Norm gelten die Abkürzungen nach ECSS-S-ST-00-01 und die folgenden Abkürzungen.

|      |                                                                                          |
|------|------------------------------------------------------------------------------------------|
| ADP  | Annahme-Datenpaket (en: acceptance data package)                                         |
| AOCS | Lage- und Bahnregelungssystem (en: attitude and orbit control system)                    |
| AM0  | Luftmasse 0 (Null) [en: air mass 0 (zero)]                                               |
| APTC | Temperaturwechselbeanspruchung bei Umgebungsdruck (en: ambient pressure thermal cycling) |
| AR   | Antireflex- (en: anti-reflection)                                                        |
| ARC  | Antireflexbeschichtung (en: anti-reflection coating)                                     |
| ATOX | atomarer Sauerstoff (en: atomic oxygen)                                                  |
| BOL  | Missionsbeginn (en: beginning-of-life)                                                   |
| BSC  | unverbundene Solarzelle (en: bare solar cell)                                            |
| BSR  | Rückseitenreflektor (en: back surface reflector)                                         |
| CIC  | Zelle mit eingebautem Steckverbinder (en: connector integrated cell)                     |

ANMERKUNG US-Amerikanische Bezeichnung für SCA.

|          |                                                                                                                   |
|----------|-------------------------------------------------------------------------------------------------------------------|
| CIDL     | Konfigurationsdatenliste (en: configuration item data list)                                                       |
| CVCM     | aufgefangenes flüchtiges kondensierbares Material (en: collected volatile condensable material)                   |
| CVG      | Deckglas (en: coverglass)                                                                                         |
| DCR      | Dokumentationsänderungsanforderung (en: documentation change request)                                             |
| DJF      | Auslegungsbegründungsakte (en: design justification file)                                                         |
| DRD      | Definition der Anforderungen an Dokumente (en: document requirements definition)                                  |
| DRB      | Lieferungs-Untersuchungsausschuss (en: delivery review board)                                                     |
| DVG      | direkter Spannungsgradient (en: direct voltage gradient)                                                          |
| DVT      | Auslegungsverifizierungsprüfung (en: design verification test)                                                    |
| EMV      | elektromagnetische Verträglichkeit (EMC, en: electromagnetic compatibility)                                       |
| EOL      | Missionsende (en: end-of-life)                                                                                    |
| ESD      | elektrostatische Entladung (en: electrostatic discharge)                                                          |
| FIT      | Ausfallrate (en: failure in time)                                                                                 |
| FMECA    | Analyse der Arten, Einflüsse und Kritikalität von Ausfällen (en: failure modes, effects and criticality analysis) |
| GaAs     | Galliumarsenid (en: gallium arsenide)                                                                             |
| GEO      | geostationäre Erdumlaufbahn (en: geostationary Earth orbit)                                                       |
| IC       | verbundene Zelle (en: interconnected cell)                                                                        |
| $I_{mp}$ | Strom bei maximaler Leistung (en: maximum power current)                                                          |
| $I_{op}$ | Strom bei Betriebsspannung (en: current at operational voltage)                                                   |
| IRR      | Reflektor für Infrarotstrahlung (en: infrared reflector)                                                          |
| $I_{sc}$ | Kurzschlussstrom (en: short-circuit current)                                                                      |
| IVG      | invertierter Spannungsgradient (en: inverted voltage gradient)                                                    |
| LEO      | erdnahe Umlaufbahn (en: low Earth orbit)                                                                          |
| LVDT     | Linearspannungswegaufnehmer (en: linear voltage displacement transducer)                                          |
| MLAR     | Mehrschicht-Antireflexbeschichtung (en: multi-layer anti-reflection coating)                                      |
| NCR      | Fehler-Bericht (en: nonconformance report)                                                                        |
| NRB      | Fehler-Untersuchungsausschuss (en: nonconformance review board)                                                   |
| OSTC     | Temperaturwechselbeanspruchung während des Einsatzes (en: on station thermal cycling)                             |

|                   |                                                                                                                                  |
|-------------------|----------------------------------------------------------------------------------------------------------------------------------|
| PAD               | Teilezulassungsdokument (en: part approval document)                                                                             |
| PCDU              | Energiekontroll- und -verteilungsgerät (en: power control and distribution unit)                                                 |
| PID               | Prozessidentifikationsdokument (en: process identification document)                                                             |
| $P_{\max}$        | maximale Leistung (en: maximum power)                                                                                            |
| PMCF              | Produktherstellungs- und -kontrollunterlagen (en: product manufacturing and control file)                                        |
| PMP               | Teile, Werkstoffe und Prozesse (en: parts, materials and processes)                                                              |
| PTH               | Leistungstransfer-Kabelbaum (en: power transfer harness)                                                                         |
| PVA               | fotovoltaische Baugruppen (en: photovoltaic assemblies)                                                                          |
| r.m.s.            | Effektivwert (en: root mean square)                                                                                              |
| RAMS              | Funktionsfähigkeit, Verfügbarkeit, Instandhaltbarkeit und Sicherheit (en: reliability, availability, maintainability and safety) |
| RDC               | relative Schadenskoeffizienten (en: relative damage coefficients)                                                                |
| RML               | Masseverlust ohne Wasser (en: recovered mass loss)                                                                               |
| S.C.              | Solarkonstante (en: solar constant)                                                                                              |
| S.C. (AM0)        | Solarkonstante bei Luftmasse 0 (en: solar constant at air mass 0)                                                                |
| SCA               | Solarzellenanordnung (en: solar cell assembly)                                                                                   |
| SCD               | Quellenkontrollzeichnung (en: source control drawing)                                                                            |
| SLAR              | Einschicht-Antireflexbeschichtung (en: single layer anti-reflection coating)                                                     |
| SWS               | Sekundär-Arbeitsnormal (en: secondary working standard)                                                                          |
| TAT               | Eignungsprüfung (en: type approval test)                                                                                         |
| TBD               | zu definieren (en: to be defined)                                                                                                |
| TBS               | festzulegen (en: to be specified)                                                                                                |
| TML               | Gesamt-Masseverlust (en: total mass loss)                                                                                        |
| UVR               | Reflektor für ultraviolette Strahlung (en: ultraviolet reflector)                                                                |
| $V_{\text{mp}}$   | Spannung bei maximaler Leistung (en: maximum power voltage)                                                                      |
| $V_{\text{oc}}$   | Trennspannung (en: open-circuit voltage)                                                                                         |
| $V_{\text{op}}$   | Betriebsspannung (en: operational voltage)                                                                                       |
| $V_{\text{test}}$ | Prüfspannung (en: test voltage)                                                                                                  |
| WRC               | Weltstrahlungszentrum in Davos (en: World Radiation Centre in Davos)                                                             |

English version

## Space engineering - Part 20-08: Photovoltaic assemblies and components

Ingénierie spatiale - Partie 20-08: Ensembles et composants photovoltaïque

Raumfahrttechnik - Teil 20-08: Fotovoltaische Baugruppen und Komponenten

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

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## Foreword

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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 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  $\mu\text{m}$  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  $\text{MgF}_2$ .

### **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. |                                   |

| <b>Abbreviation</b> | <b>Meaning</b>                                        |
|---------------------|-------------------------------------------------------|
| 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                                   |
| $I_{\text{imp}}$    | maximum power current                                 |
| $I_{\text{op}}$     | current at operational voltage                        |
| IRR                 | infrared reflector                                    |
| $I_{\text{sc}}$     | 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                       |
| $P_{\text{max}}$    | 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 |

| <b>Abbreviation</b>          | <b>Meaning</b>                       |
|------------------------------|--------------------------------------|
| <b>RDC</b>                   | relative damage coefficients         |
| <b>RML</b>                   | recovered mass loss                  |
| <b>S.C.</b>                  | solar constant                       |
| <b>S.C. (AM0)</b>            | solar constant at air mass 0         |
| <b>SCA</b>                   | solar cell assembly                  |
| <b>SCD</b>                   | source control drawing               |
| <b>SLAR</b>                  | single layer anti-reflection coating |
| <b>SWS</b>                   | secondary working standard           |
| <b>TAT</b>                   | type approval test                   |
| <b>TBD</b>                   | to be defined                        |
| <b>TBS</b>                   | to be specified                      |
| <b>TML</b>                   | total mass loss                      |
| <b>UVR</b>                   | ultraviolet reflector                |
| <b><math>V_{mp}</math></b>   | maximum power voltage                |
| <b><math>V_{oc}</math></b>   | open-circuit voltage                 |
| <b><math>V_{op}</math></b>   | operational voltage                  |
| <b><math>V_{test}</math></b> | test voltage                         |
| <b>WRC</b>                   | World Radiation Centre in Davos      |

# 4

## General

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### 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.

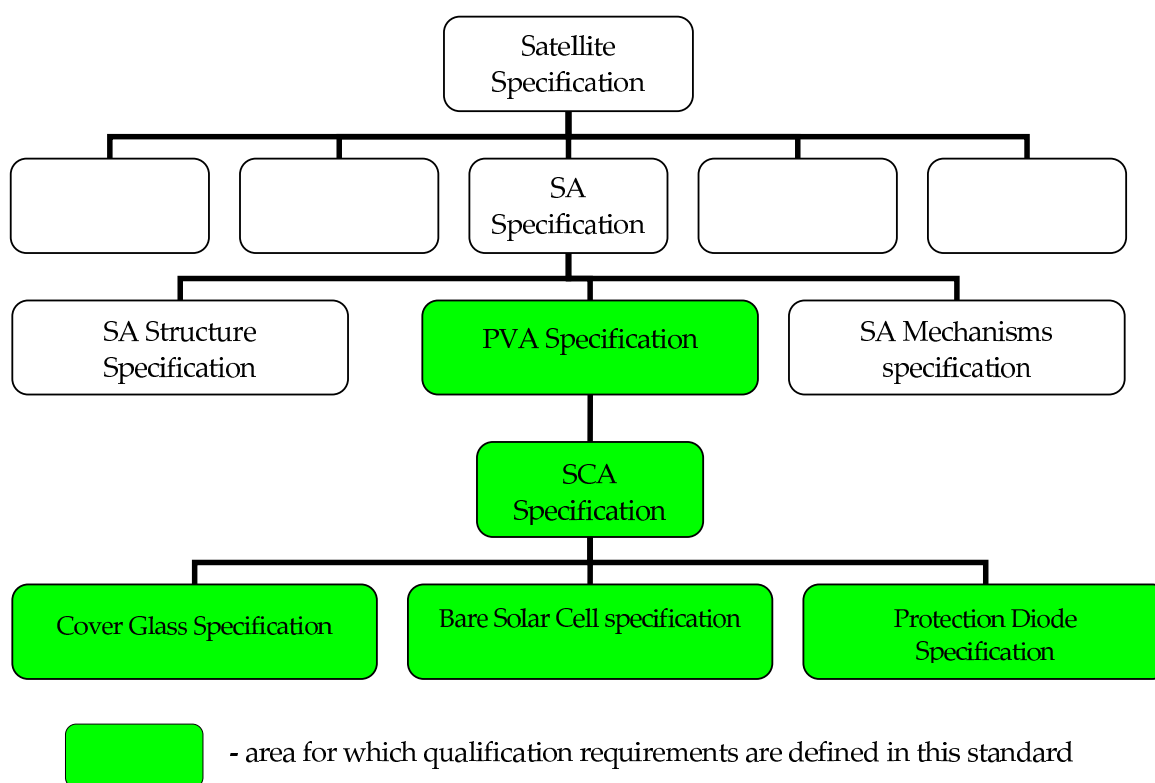


**Figure 4-1: Specification hierarchy**

## 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.

# 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 ( $E_{\text{spec}}$  V/ $\mu\text{m}$ ) times the minimum guaranteed thickness.

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

- b. The acceptance criteria shall be an insulation larger than 100 M $\Omega$ .
- 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/cm<sup>2</sup>.
  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.