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ICS 49.140

Einsprüche bis 2022-10-19
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DIN EN 16603-20-08:2014-11

Entwurf

Raumfahrttechnik – Fotovoltaische Baugruppen und Komponenten; Englische Fassung prEN 16603-20-08:2022

Space engineering –
Photovoltaic assemblies and components;
English version prEN 16603-20-08:2022

Ingéniérie spatiale –
Ensembles et composants photovoltaïque;
Version anglaise prEN 16603-20-08:2022

Anwendungswarnvermerk

Dieser Norm-Entwurf mit Erscheinungsdatum 2022-08-19 wird der Öffentlichkeit zur Prüfung und Stellungnahme vorgelegt.

Weil die beabsichtigte Norm von der vorliegenden Fassung abweichen kann, ist die Anwendung dieses Entwurfs besonders zu vereinbaren.

Stellungnahmen werden erbeten

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Gesamtumfang 240 Seiten

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Nationales Vorwort

Dieses Dokument (prEN 16603-20-08:2022) wurde vom Technischen Komitee CEN/CLC/TC 5 „Raumfahrt“ erarbeitet, dessen Sekretariat von DIN (Deutschland) gehalten wird.

Das zuständige nationale Normungsgremium ist der Arbeitsausschuss NA 131-06-02 AA „Interoperabilität von Informations-, Kommunikations- und Navigationssystemen“ im DIN-Normenausschuss Luft- und Raumfahrt (NL).

Dieses Dokument (prEN 16603-20-08:2022) basiert auf ECSS-E-ST-20-08C Rev.2 DIR1.

Dieses Dokument enthält unter Berücksichtigung des Präsidialbeschlusses 1/2004 nur die englische Originalfassung von prEN 16603-20-08:2022.

Der Bedarf für eine Deutsche Fassung wird derzeit beraten.

Dieses Dokument wurde speziell zur Behandlung von Raumfahrtsystemen erarbeitet und hat daher Vorrang vor jeder anderen EN-Norm, die denselben Anwendungsbereich abdeckt, aber einen breiter gefassten Geltungsbereich besitzt (z. B. Luft- und Raumfahrt).

Für die in diesem Dokument zitierten Dokumente wird im Folgenden auf die entsprechenden deutschen Dokumente hingewiesen:

ISO 2859 (all parts)	siehe	DIN ISO 2859 (alle Teile)
ISO 9211-4	siehe	DIN ISO 9211-4

Aktuelle Informationen zu diesem Dokument können über die Internetseiten von DIN (www.din.de) durch eine Suche nach der Dokumentennummer aufgerufen werden.

Änderungen

Gegenüber DIN EN 16603-20-08:2014-11 wurden folgende Änderungen vorgenommen:

a) technische Überarbeitung;

b) redaktionelle Überarbeitung;

c) detaillierte Angaben zu Änderungen werden zur Veröffentlichung hinzugefügt.

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Nationaler Anhang NA
(informativ)

Begriffe und Abkürzungen

Reihenfolge und Inhalt der folgenden Begriffe sind identisch mit denen in Abschnitt Begriffe der englischen Fassung.

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.

Qualifizierung

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

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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 aufgebrachter Werkstoffe

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

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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, 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 mit oder ohne Bypass-Diode

3.2.3.5
getrennte Verbindungsleitung
physikalisch von der Zelle aufgrund von Versagen der Schweiß- oder Lötverbindung getrennte Verbindungsleitung

3.2.3.6
Flachstecker für Verbindungsleitung
Teil der Verbindungsleitung, der z. B. durch Schweißen, Löten oder Ultraschall mit dem Kontaktpad von Solarzellen oder dem Rückseitenkontakt von Solarzellen verbunden ist

ANMERKUNG Flachstecker werden auch als Stifte bezeichnet, und Verbindungsleitungen können aus mehreren Flachsteckern oder Stiften bestehen.

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3.2.4 Unverbundene Solarzellen

3.2.4.1
unverbundene Solarzelle
fotovoltaisches Bauteil, das bei Belichtung elektrische Energie liefern kann

3.2.4.2
Nenngröße der Zellen
Zellenmaße des Beschaffungsloses von Solarzellen

3.2.4.3
nicht mit Bauteilen verbundene Solarzelle
speziell hergestellte Solarzelle mit nur einem aktiven Anschluss und derselben Spektralempfindlichkeit wie eine Teilzelle einer mehrfach verbundenen Solarzelle

3.2.4.4
Kontaktvakuumverdampfungs-Charge
in demselben Kontaktvakuumverdampfungsverfahren hergestellte, unverbundene Solarzellen

3.2.4.5
Tropfen
überschüssiger Metallisierungswerkstoff auf den Solarzellenkontakten

3.2.4.6
Restfaktor
Verhältnis zwischen einem Parameter der elektrischen Leistung bei EOL und dessen Wert bei BOL

ANMERKUNG Beispielsweise maximale Leistung einer Solarzelle.

3.2.4.7
Antireflexbeschichtung der Solarzelle
ein- oder mehrschichtiger Überzug zur Verringerung des Reflexionskoeffizienten der einfallenden Sonnenstrahlung

3.2.4.8
unbeschichteter Bereich
Bereich der Solarzelle, in dem die unverbundene Solarzelle ohne jeglichen Überzug freiliegt

3.2.4.9
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 aufgebrachte Überzüge werden als „Vorderseitenüberzug“ bezeichnet. Überzüge die auf die Innenfläche des Glasuntergrunds aufgebracht werden, welche mit der Solarzelle verbunden wird, werden als „Rückseitenüberzug“ bezeichnet. Allgemein gebräuchliche Überzüge umfassen:

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

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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 aufgebrachten 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 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.

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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 Auftragsspezifikationen 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 umfassen.

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

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3.3 Abkürzungen

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

Abkürzung	Bedeutung
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
BSR	Rückseitenreflektor (en: back surface reflector)
CIBD	im Steckverbinder integrierte Sperrdiode (en: connector integrated blocking diode)
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
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)
EMC	elektromagnetische Verträglichkeit (en: Electromagnetic Compatibility)
EOL	Missionsende (en: end-of-life)
EPD	externe Schutzdiode (en: external protection diode)
ESD	elektrostatische Entladung (en: electrostatic discharge)
FIT	Ausfallrate (en: failure in time)
FMECA	Fehlermöglichkeits-, Einfluss- und Kritikalitäts-Analyse (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)
$\mathbf{I_{fw}}$	Strom in Durchlassrichtung der Diode (en: current in forward direction of the diode)
$\mathbf{I_{mp}}$	Strom bei maximaler Leistung (en: maximum power current)

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Abkürzung	Bedeutung
I_{op}	Strom bei Betriebsspannung (en: current at operational voltage)
I_{rev}	Strom in Sperrrichtung der Diode (en: current in reverse direction of the diode)
IPD	eingebaute Schutzdiode (en: integral protection diode)
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	Nichtkonformitäten/Fehler-Bericht (en: Nonconformance Report)
NRB	Nichtkonformitäten-Prüfausschuss (en: Nonconformance Review Board)
OSTC	Temperaturwechselbeanspruchung während des Einsatzes (en: on station thermal cycling)
PAD	Teilezulassungsdokument (en: part approval document)
PBD	planare Sperrdiode (en: planar blocking diode)
PCDU	Energiekontroll- und -verteilungsgerät (en: power control and distribution unit)
PID	Prozessidentifikations-Dokument (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)
PSA	Dauerlichtbogen (en: permanent sustained arc)
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)
SMM	spektraler Korrekturfaktor (en: spectral mismatch factor)
SWS	Sekundär-Arbeitsnormal (en: secondary working standard)
T_{amb}	Raumtemperatur (en: ambient temperature)
TAT	Eignungsprüfung (en: type approval test)
TBD	zu definieren (en: to be defined)

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Abkürzung	Bedeutung
TBS	festzulegen (en: to be specified)
TML	Gesamt-Masseverlust (en: total mass loss)
TQCM	thermische Quarzkristall-Mikrowaage (en: thermal quartz crystal microbalance)
UVR	Reflektor für ultraviolette Strahlung (en: ultraviolet reflector)
$\mathbf{V_{fw}}$	Spannung in Durchlassrichtung der Diode (en: voltage in forward direction of the diode)
$\mathbf{V_{mp}}$	Spannung bei maximaler Leistung (en: maximum power voltage)
$\mathbf{V_{oc}}$	Trennspannung (en: open-circuit voltage)
$\mathbf{V_{op}}$	Betriebsspannung (en: operational voltage)
$\mathbf{V_{rev}}$	Spannung in Sperrrichtung der Diode (en: voltage in reverse direction of the diode)
$\mathbf{V_{test}}$	Prüfspannung (en: test voltage)
WRC	Weltstrahlungszentrum in Davos (en: World Radiation Centre in Davos)
Φe	Äquivalentfluenz für die Elektronenbestrahlung (en: equivalent fluence used for electron irradiation)

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Nationaler Anhang NB
(informativ)

Literaturhinweise

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– Entwurf –

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NORME EUROPÉENNE

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English version

Space engineering - Photovoltaic assemblies and components

Ingéniérie spatiale - Ensembles et composants photovoltaïque

Raumfahrttechnik - Fotovoltaische Baugruppen und Komponenten

This draft European Standard is submitted to CEN members for enquiry. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

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European Foreword

This document (prEN 16603-20-08:2022) has been prepared by Technical Committee CEN/CLC/TC 5 “Space”, the secretariat of which is held by DIN (Germany).

This document (prEN 16603-20-08:2022) originates from ECSS-E-ST-20-08C Rev.2 DIR1.

This document is currently submitted to the ENQUIRY.

This document will supersede EN 16603-20-08:2014.

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

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Introduction

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

This Standard outlines the requirements for the qualification, procurement, storage and delivery of the main assemblies and components of the space solar array electrical layout: photovoltaic assemblies, solar cell assemblies, bare solar cells, 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 6for solar cell assemblies,
- Clause 7 for bare solar cells,
- Clause 8for 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).

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1 Scope

This Standard specifies the general requirements for the qualification, procurement, storage and delivery of photovoltaic assemblies, solar cell assemblies, bare solar cells, 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 crystaline 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-crystaline 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 constrains of a space project in conformance with ECSS-S-ST-00.

Qualification is a process to confirm compliance with requirements that have been established with reference to foregoing characterization and engineering test programs. Guidelines for characterization and engineering tests and for relaxation of qualification tests due to similarity with earlier performed qualification are defined in the handbook ECSS-E-HB-20-08. Those clauses in this standard, for which the Handbook gives additional information, will refer to the Handbook.

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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
	Gueymard, C., 2018	Gueymard, C., Revised composite extraterrestrial spectrum based on recent solar irradiance observations. Solar Energy, Volume 169, 2018, Pages 434-440, ISSN 0038-092X, https://doi.org/10.1016/j.solener.2018.04.067. (https://www.sciencedirect.com/science/article/pii/S0038092X1830433X)

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3 Terms, definitions and abbreviated terms

3.1 Terms from other standards

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

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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, also called DVT coupon

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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 with or without 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

3.2.3.6 interconnector tab

part of the interconnector that is joined, e.g. welded, soldered, ultrasonic, with the solar cell contact pad or the solar cell rear side contact

NOTE Tabs are also known as fingers and interconnectors can be composed of several tabs or fingers.

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 cells nominal size

cell dimensions of the solar cell procurement lot

3.2.4.3 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

3.2.4.4 contact vacuum evaporation batch

bare solar cells manufactured in the same contact vacuum evaporation run

3.2.4.5 drops

excess of metallization material on the solar cell contacts

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3.2.4.6 remaining Factor

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

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

3.2.4.7 solar cell anti–reflection coating

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

3.2.4.8 uncoated area

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

3.2.4.9 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

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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,

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- 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

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Abbreviation	Meaning
BOL	beginning-of-life
BSC	bare solar cell
BSR	back surface reflector
CIBD	connector integrated blocking diode
CIC	connector integrated cell NOTE: U.S. designation of SCA.
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
EPD	external protection diode
ESD	electrostatic discharge
FIT	failure in time
FMECA	failure modes, effects and criticality analysis
GaAs	gallium arsenide
GEO	geostationary orbit
IC	interconnected cell
I_{fw}	current in forward direction of the diode
I_{mp}	maximum power current
I_{op}	current at operational voltage
I_{rev}	current in reverse direction of the diode
IPD	integral protection diode
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

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Abbreviation	Meaning
PAD	part approval document
PBD	planar blocking diode
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
PSA	permanent sustained arc
PTH	power transfer harness
PVA	photovoltaic assemblies
r.m.s.	root mean square
RAMS	reliability, availability, maintainability and safety
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
SMM	spectral mismatch factor
SWS	secondary working standard
T_{amb}	ambient temperature
TAT	type approval test
TBD	to be defined
TBS	to be specified
TML	total mass loss
TQCM	thermal quartz crystal microbalance

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Abbreviation	Meaning
UVR	ultraviolet reflector
V_{fw}	voltage in forward direction of the diode
V_{mp}	maximum power voltage
V_{oc}	open-circuit voltage
V_{op}	operational voltage
V_{rev}	voltage in reverse direction of the diode
V_{test}	test voltage
WRC	World Radiation Centre in Davos
Φe	equivalent fluence used for electron irradiation

3.4 Nomenclature

The following nomenclature applies throughout this document:

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

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

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

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

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

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

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

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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 higher level specifications.
- To define the set of requirements from component level up to solar panel level consisting of photovoltaic assemblies (PVA) and solar panel substrate (rigid or flexible) to achieve generic qualification for each level of assembly for about 90 % of the solar arrays within a given application domain; for example, deployable solar arrays for GEO or LEO applications.

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 (generically) qualified at lower levels. The specification tree, of which panel substrates, photovoltaic assemblies (PVA) and their components form part 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 lower 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, assemblies and up to and including PVA on Design Verification Test (DVT) coupons. Components, assemblies and coupons are built according to component, assemblies and PVA design requirements and are being qualified with the objective of demonstrating that the design and manufacturing processes are approved and verified for use on solar panels of a flight application.

Together with the PVA qualification on a specific substrate, the material database for this substrate shall be fully established.

NOTE For a sandwich CFRP type of substrate the material mechanical performance database shall complete

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ECSS-E-ST-32-08 Clause 4.6 and ECSS-E-HB-32-20_Part 1A, including stiffness and strength data for CFRP sandwich structures that can be obtained by substrate elementary tests such as

- 4-point bending and/or edgewise compression stiffness and strength tests
- shear and/or skin +-45° tensile stiffness and strength tests
- sandwich flatwise tensile strength tests,
- inserts in-plane and out-of-plane strength tests,
- kapton peel strength test.

For any other type of substrate, additional or different tests might be needed.

NOTE NOTE: By having this material data base upfront, potential failures in the substrate design at a late stage or incompatibilities of the design can be avoided.

Generally, with the substrate elementary tests and the solar array mechanical tests, a solar panel substrate is deemed to be mechanically qualified, up to the point of deployment.

In order to qualify a solar panel in view of thermal life time cycling, it is needed to perform a DVT coupon campaign (see clause 5) for qualifying the substrate, PVA and their combination.

The elementary substrate tests will need to be repeated after thermal cycling only if the solar array is subjected to substantial mechanical loading long after deployment, e.g. as a result of main engine firings, docking/undocking manoeuvres, etc.

Minor design modifications as described in the ECSS-E-HB-20-08 do not require the repetition of the DVT thermal life cycling. In the Handbook rules are defined with which so-called qualification by similarity or delta qualification can be justified as acceptable for specific cases.

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 of an application is not achieved after successful qualification of the solar panel substrate, PVA and its components at coupon level only. Robustness against certain 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.

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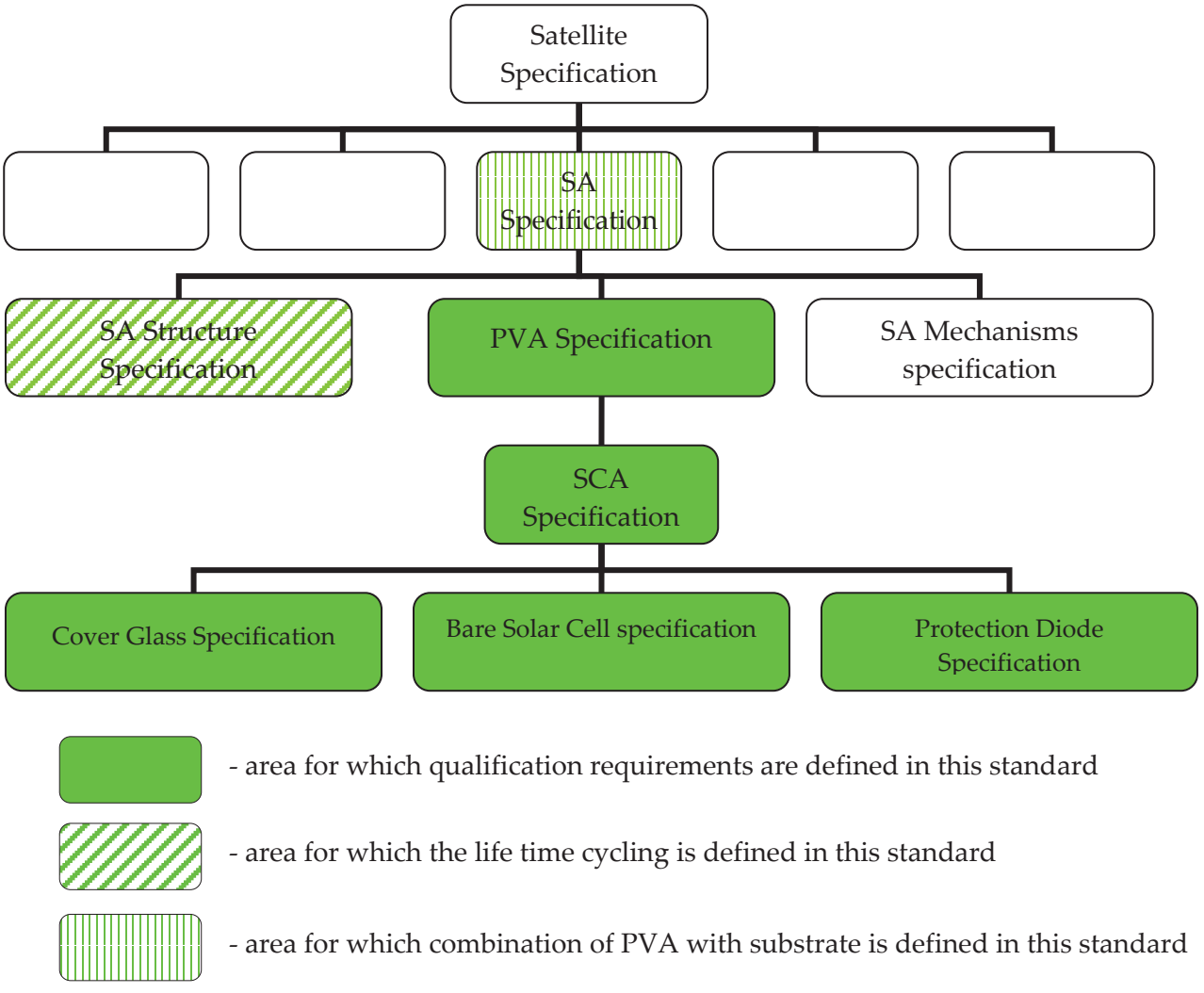

Figure 4-1: Specification hierarchy

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.

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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 shorter than 6 months shall be as follows:

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1. Pressure: (1 013,25 ± 33) hPa.
2. Temperature: (23 ± 5) °C.
3. Average relative humidity: 55 +/- 10 %.

NOTE A pressure of (1 013,25 ± 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.

d. For long term storage longer than 6 months, qualification coupons shall be kept in the dark in a dry nitrogen environment.

NOTE It is good practice to use light tight coverage during periods shorter than 6 months.

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.

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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 <deleted>

a. <<deleted>>

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.

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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).

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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;
- inputs to describe radiation degradation such as relative damage coefficient and electron-proton equivalence or non-ionising energy loss, according to the approach used;
- 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.

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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 on the relevant substrate representing all design specifics (e.g. undisturbed area, re-enforced area, edge members, Holddowns etc.). To cover all the aspects of the solar array, more than one coupon might be needed.

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.

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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.

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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).

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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.

NOTE For fulfilment of reliable insulation (also known as "double insulation") requirements reference is made to ECSS-E-ST-20.

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 test as specified in 5.5.1.3.

b. The design of the PVA shall include the result of the verification specified in requirement 5.3.3.10a.

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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.

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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 or prevent 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_{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 MΩ.

c. In case of a failure, the coupon insulator layer shall be repaired.

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