

DIN EN 16603-20-06

ICS 49.140

**Raumfahrttechnik –
Aufladung von Raumfahrzeugen;
Englische Fassung EN 16603-20-06:2014**

Space engineering –
Spacecraft charging;
English version EN 16603-20-06:2014

Ingénierie spatiale –
Charges électrostatique des véhicules spatiales;
Version anglaise EN 16603-20-06:2014

Gesamtumfang 125 Seiten

DIN-Normenausschuss Luft- und Raumfahrt (NL)

Nationales Vorwort

Dieses Dokument (EN 16603-20-06:2014) wurde vom Technischen Komitee CEN/CLC/TC 5 „Space“ erarbeitet, dessen Sekretariat vom 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 basiert auf ECSS-E-ST-20-06C.

Dieses Dokument wurde speziell zur Behandlung von Raumfahrtssystemen erarbeitet und hat daher Vorrang vor jeglicher Europäischer Norm, da es denselben Anwendungsbereich hat, jedoch über einen größeren Geltungsbereich (z. B. Luft- und Raumfahrt) verfügt.

Nationaler Anhang NA (informativ)

Begriffe

3 Begriffe und Abkürzungen

3.1 In anderen Normen definierte Begriffe

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

3.2 Für diese Norm spezifische Begriffe

3.2.1

Aluminium-Äquivalentdicke

Dicke von Aluminium mit einer Massendichte je Flächeneinheit, die der des beschriebenen Werkstoffs entspricht

ANMERKUNG Die Massendichte wird gewöhnlich in ($\text{g} \cdot \text{cm}^{-2}$) gemessen.

3.2.2

Polarlichtzone

Gebiet zwischen dem 60. und 70. Grad nördlicher oder südlicher Breite, in dem Polarlichter auftreten

3.2.3

dielektrische Tiefenaufladung

elektrische Aufladung innerhalb der Masse eines außen oder innen liegenden Werkstoffs

3.2.4

Dielektrikum

ein Medium, in dem ein elektrisches Feld aufrechterhalten werden kann

ANMERKUNG In Abhängigkeit von ihrem spezifischen Widerstand können dielektrische Werkstoffe als isolierend, antistatisch, schwach leitfähig oder leitfähig beschrieben werden. Folgendes ist ein klassisches Beispiel der Klassifikation nach spezifischem Widerstand:

- über $10^9 \Omega \text{ m}$: isolierend
- zwischen $10^2 \Omega \text{ m}$ und $10^9 \Omega \text{ m}$: antistatisch
- zwischen $10^3 \Omega \text{ m}$ und $10^6 \Omega \text{ m}$: statisch ableitend
- zwischen $10^{-2} \Omega \text{ m}$ und $10^2 \Omega \text{ m}$: schwach leitfähig
- unterhalb $10^{-2} \Omega \text{ m}$: leitfähig

3.2.5

Dosis

örtlich aufgenommene Energie je Masseneinheit aufgrund von Strahlungswirkung

3.2.6

Abströmseite

(bezogen auf einen Gegenstand in relativer Bewegung gegenüber einem Plasma) die Seite eines Gegenstands in Richtung des Plasmageschwindigkeitsvektors

3.2.7

elektrostatistisch

bezogen auf statische Elektrizität oder Elektrizität im Ruhezustand

3.2.8

elektrostatischer Funken

Versagen der isolierenden Eigenschaften eines Dielektrikums, das zu einer plötzlichen Entladung und einem Risiko der Beschädigung des betreffenden Dielektrikums führt

3.2.9

elektrostatische Entladung

schnelle, spontane Übertragung elektrischer Ladung, induziert durch ein starkes elektrostatisches Feld

3.2.10

äußere Aufladung

elektrische Aufladung von außen liegenden Werkstoffen

3.2.11

Fluenz

zeitliches Integral der Flussdichte

3.2.12

Isolator

isolierendes Dielektrikum

3.2.13

innere Aufladung

elektrische Aufladung von innen liegenden Werkstoffen, die zumindest von der Hülle des Raumfahrzeugs abgeschirmt sind, aufgrund des Eindringens geladener Teilchen aus dem umgebenden Medium

ANMERKUNG Werkstoffe können Leiter oder Dielektrika sein.

3.2.14

innere dielektrische Aufladung

innere Aufladung dielektrischer Werkstoffe

3.2.15

Ionentriebwerk

Antriebssystem, das durch den Ausstoß von Ionen mit hohen Geschwindigkeiten arbeitet

3.2.16

***L*-Schale**

Parameter des Erdmagnetfelds

ANMERKUNG 1 Sie wird auch mit L bezeichnet und als Koordinate zur Lagebeschreibung im erdnahen Weltraum verwendet.

ANMERKUNG 2 Die Ableitung von L oder L -Schale ist kompliziert und beruht auf einer Invarianz der Bewegung geladener Teilchen im Erdmagnetfeld. Allerdings unterstützt dies die Definition von Plasmaregimen innerhalb der Magnetosphäre, da es bei einem Dipolmagnetfeld gleich der geozentrischen Höhenlage in Erdradien der örtlichen Magnetfeldlinie bei Querung des Äquators ist.

3.2.17

ungerichtete Flussdichte

skalares Integral der Flussdichte über alle Richtungen

ANMERKUNG Dies besagt, dass die Richtungsverteilung, die auch nicht-isotrop sein kann, nicht berücksichtigt wird. Die Flussdichte an einem Punkt ist die Anzahl der Teilchen, die eine Kugel mit Querschnittsflächeneinheit (d. h. Radius) durchdringen. Eine ungerichtete Flussdichte darf nicht mit einer isotropen Flussdichte verwechselt werden.

3.2.18

Ausgasrate

Masse einer Molekülspezies, die von einem Material je Zeiteinheit und je Flächeneinheit ausgeht

ANMERKUNG Die Einheit der Ausgasrate ist $\text{g} \cdot \text{cm}^{-2} \cdot \text{s}^{-1}$. Sie kann auch in anderen Einheiten angegeben werden, wie z. B. in relativer Masseneinheit je Zeiteinheit ($\text{g} \cdot \text{s}^{-1}$), ($\% \cdot \text{s}^{-1}$) oder ($\% \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$).

3.2.19**Plasma**

teilweise oder vollständig ionisiertes Gas, dessen Teilchen ein gemeinsames Verhalten in dessen elektromagnetischem Feld aufweisen

3.2.20**Primärentladung**

erste elektrostatische Entladung, die durch Erzeugung einer vorübergehenden Leiterbahn zu einem Sekundärbogen führen kann

3.2.21**Strahlung**

Energieübertragung durch Teilchen (einschließlich Photonen)

ANMERKUNG Im Sinne dieser Norm wird elektromagnetische Strahlung unterhalb des UV-Bereiches nicht behandelt. Somit werden sichtbare, Wärme-, Mikrowellen- und Radiowellenstrahlung nicht behandelt.

3.2.22**Strahlungsgürtel**

Bereich gebundener oder quasigebundener energiereicher Teilchen im Erdmagnetfeld

3.2.23**Staustrahl**

Volumen in unmittelbarer Umgebung und in Bewegungsrichtung des Raumfahrzeugs, in dem Veränderungen von Oberfläche oder Plasma aufgrund des Durchgangs eines Raumfahrzeugs durch das Medium auftreten können

3.2.24**Sekundärbogen**

Durchgang eines Stroms von einer äußeren Quelle, wie einer Solaranlage, durch eine ursprünglich von einer Primärentladung erzeugten Leiterbahn

3.2.25**Oberflächenaufladung**

elektrische Aufladung der Oberfläche von außen oder innen liegendem Werkstoff

3.2.26**Verbindungsanordnung**

flexibles leitfähiges oder nicht leitendes Kabel, das zwei Raumfahrzeuge oder zwei Teile desselben Raumfahrzeugs ohne jede weitere mechanische Befestigung miteinander verbindet

3.2.27**Schubdüse**

Einrichtung zur Änderung der Fluglage oder Umlaufbahn eines Raumfahrzeugs im Weltraum nach dem Reaktionsprinzip

ANMERKUNG Beispielsweise Rakete, Kaltgas-Emitter und elektrischer Antrieb.

3.2.28**Tripelpunkt**

(bezogen auf den Beginn elektrostatischer Entladung) Punkt des Aufeinandertreffens von Dielektrikum, Metall und Vakuum

3.2.29**Zuströmseite**

(bezogen auf einen Gegenstand in relativer Bewegung gegenüber einem Plasma) die Seite eines Gegenstands in entgegengesetzter Richtung des Plasmageschwindigkeitsvektors

3.2.30**Wirbelschleppe**

Volumen in unmittelbarer Umgebung und entgegengesetzt der Bewegungsrichtung des Raumfahrzeugs, in dem Veränderungen des umgebenden Plasmas aufgrund des Durchgangs eines Raumfahrzeugs durch das Medium auftreten können

3.3 Abkürzungen

In dieser Norm werden die folgenden Abkürzungen definiert und verwendet.

AOCS	Lage- und Bahnregelungssystem (en: attitude and orbital control system)
DGD	Entladung mit direktem Gradienten (en: direct gradient discharge)
EMV	elektromagnetische Verträglichkeit (EMC, en: electromagnetic compatibility)
emf	elektromotorische Kraft (en: electro-motive force)
EP	elektrischer Antrieb (en: electric propulsion)
ESD	elektrostatische Entladung (en: electrostatic discharge)
ETFE	Ethylen-Tetrafluorethylen-Copolymer (en: ethylene-tetrafluoroethylene copolymer)
eV	Elektronvolt (en: electron volt) (auch keV, MeV)
FEED	Feldemissionselektroantrieb (en: field emission electric propulsion)
FEP	Fluorethylenpropylen (en: fluoroethylene-propylene)
GEO	geostationäre Erdumlaufbahn (en: geostationary Earth orbit)
HEO	hochexzentrische Umlaufbahn (en: highly eccentric orbit)
ISS	Internationale Raumstation (en: International Space Station)
IVG	invertierter Spannungsgradient (en: inverted voltage gradient)
IVGD	Entladung mit invertiertem Spannungsgradienten (en: inverted voltage gradient discharge)
LEO	erdnahe Umlaufbahn (en: low Earth orbit)
MEMS	mikroelektromechanische(s) System(e) [en: micro-electromechanical system(s)]
MEO	mittlere Erdumlaufbahn [en: medium (altitude) Earth orbit]
MLI	Mehrschichtisolierung (en: multi-layer insulation)
MLT	magnetische Ortszeit (en: magnetic local time)
NASA	Nationale Luft- und Raumfahrtbehörde (en: National Aeronautics and Space Administration)
NGD	Entladung mit normalem Gradienten (en: normal gradient discharge)
PCB	Leiterplatte (en: printed circuit board)
PEO	polare Erdumlaufbahn (en: polar Earth orbit)
PTFE	Polytetrafluorethylen (en: poly-tetrafluoroethylene)
PVA	photovoltaische Baugruppe (en: photo-voltaic assembly)
r.m.s.	Effektivwert (en: root-mean-square)
SAS	Solaranlagensimulator (en: solar array simulator)
SPT	Antrieb mit breitem Beschleunigungskanal (en: stationary plasma thruster)
SSM	rückseitig beschichteter Spiegel (en: second surface mirror)
UV	ultraviolettes Licht (en: ultra-violet light)

English version

Space engineering - Spacecraft charging

Ingénierie spatiale - Charges électrostatique des véhicules spatiales

Raumfahrttechnik - Aufladung von Raumfahrzeugen

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

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**CEN-CENELEC Management Centre:
Avenue Marnix 17, B-1000 Brussels**

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Foreword

This document (EN 16603-20-06:2014) has been prepared by Technical Committee CEN/CLC/TC 5 "Space", the secretariat of which is held by DIN.

This standard (EN 16603-20-06:2014) originates from ECSS-E-ST-20-06C.

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 January 2015, and conflicting national standards shall be withdrawn at the latest by January 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 subject of spacecraft plasma interactions has been part of the spacecraft design process since spacecraft surface charging was first encountered as a problem in the earliest geostationary spacecraft. However, spacecraft surface charging is only one of the ways in which the space environment can adversely affect the electrical state of spacecraft and satellite technology has evolved over the years.

A need was identified for a standard that is up to date and comprehensive in its treatment of all the main environment-induced plasma and charging processes that can affect the performance of satellites in geostationary and medium and low Earth orbits. This standard is intended to be used by a number of users, with their own design rules, and therefore it has been done to be compatible with different alternative approaches.

This document aims to satisfy these needs and provides a consistent standard that can be used in design specifications. The requirements are based on the best current understanding of the processes involved and are not radical, building on existing de-facto standards in many cases.

As well as providing requirements, it aims to provide a straightforward brief explanation of the main effects so that interested parties at all stages of the design chain can have a common understanding of the problems faced and the meaning of the terms used. Guide for tailoring of the provisions for specific mission types are described in Annex B. Further description of the main processes are given in Annex C. Some techniques of simulation, testing and measurement are described in Annex D and Annex E.

Electrical interactions between the space environment and a spacecraft can arise from a number of external sources including the ambient plasma, radiation, electrical and magnetic fields and sunlight. The nature of these interactions and the environment itself can be modified by emissions from the spacecraft itself, e.g. electric propulsion, plasma contactors, secondary emission and photoemission. The consequences, in terms of hazards to spacecraft systems depend strongly on the sensitivity of electronic systems and the potential for coupling between sources of electrical transients and fields and electronic components.

Proper assessment of the effects of these processes is part of the system engineering process as defined in ECSS-E-ST-20. General assessments are performed in the early phases of a mission when consideration is given to e.g. orbit selection, mass budget, thermal protection, and materials and component selection policy. Further into the design of a spacecraft, careful consideration is given to material selection, coatings, radiation shielding and electronics protection.

This standard begins with an overview of the electrical effects occurring in space (Clause 4). The requirements, in terms of spacecraft testing, analysis and design that arise from these processes (Clause 5 to Clause 11) form the core of this document. Annex B holds a discussion of types of orbits and how to tailor the requirements according to the mission. Annex C discusses the quantitative assessment of the physical processes behind these main effects. Annex D describes computer simulations and Annex E describes testing and measurement.

1

Scope

This standard is a standard within the ECSS hierarchy. It forms part of the electrical and electronic engineering discipline (ECSS-E-ST-20) of the engineering branch of the ECSS system (ECSS-E). It provides clear and consistent provisions to the application of measures to assess, in order to avoid and minimize hazardous effects arising from spacecraft charging and other environmental effects on a spacecraft's electrical behaviour.

This standard is applicable to any type of spacecraft including launchers, when above the atmosphere.

Although spacecraft systems are clearly subject to electrical interactions while still on Earth (e.g. lightning and static electricity from handling), these aspects are not covered, since they are common to terrestrial systems and covered elsewhere. Instead this standard covers electrical effects occurring in space (i.e. from the ionosphere upwards).

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

Terms, definitions and abbreviated terms

3.1 Terms defined in other standards

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

3.2 Terms specific to the present standard

3.2.1 aluminium equivalent thickness

thickness of aluminium with a mass density per unit area equal to that of the material being described

NOTE The mass density is normally measured in (g cm^{-2}).

3.2.2 auroral zone

region at a latitude between 60 and 70 degrees north or south where aurorae are formed

3.2.3 deep-dielectric charging

electrical charge deposition within the bulk of an external or internal material

3.2.4 dielectric

pertaining to a medium in which an electric field can be maintained

NOTE Depending on their resistivity, dielectric materials can be described as insulating, antistatic, moderately conductive or conductive. The following gives a classic example of classification according to the resistivity:

- more than $10^9 \Omega \text{ m}$: insulating
- between $10^2 \Omega \text{ m}$ and $10^9 \Omega \text{ m}$: antistatic
- between $10^3 \Omega \text{ m}$ and $10^6 \Omega \text{ m}$: static dissipative
- between $10^{-2} \Omega \text{ m}$ and $10^2 \Omega \text{ m}$: moderately conductive
- less than $10^{-2} \Omega \text{ m}$: conductive

3.2.5 dose

energy absorbed locally per unit mass as a result of **radiation** exposure

3.2.6 downstream

<relating to an object at relative motion with respect to a **plasma**>
on side of an object in the same direction as the **plasma** velocity vector

3.2.7 electrostatic

pertaining to static electricity or electricity at rest

3.2.8 electrostatic breakdown

failure of the insulation properties of a **dielectric**, resulting in a sudden release of charge and risk of damage to the **dielectric** concerned

3.2.9 electrostatic discharge

rapid, spontaneous transfer of electrical charge induced by a high **electrostatic** field

3.2.10 external charging

electric charge deposition on external materials

3.2.11 fluence

time-integration of the flux

3.2.12 insulator

insulating **dielectric**

3.2.13 internal charging

electrical charge deposition on internal materials shielded at least by the spacecraft skin due to penetration of charged particles from the ambient medium

NOTE Materials can be conductors or dielectrics.

3.2.14 internal dielectric charging

internal charging of **dielectric** materials

3.2.15 ion engine

propulsion system which operates by expelling ions at high velocities

3.2.16 L shell

parameter of the geomagnetic field

NOTE 1 It is also referred as L_r and is used as a co-ordinate to describe positions in near-Earth space.

NOTE 2 L or L shell has a complicated derivation based on an invariant of the motion of charged particles in the terrestrial magnetic field. However, it is useful in defining plasma regimes within the

magnetosphere because, for a dipole magnetic field, it is equal to the geocentric altitude in Earth-radii of the local magnetic field line where it crosses the equator.

3.2.17 omnidirectional flux

scalar integral of the flux over all directions

NOTE This implies that no consideration is taken of the directional distribution of the particles which can be non-isotropic. The flux at a point is the number of particles crossing a sphere of unit cross-sectional surface area (i.e. of radius). An omnidirectional flux is not to be confused with an isotropic flux.

3.2.18 outgassing rate

mass of molecular species evolving from a material per unit time and unit surface area

NOTE The units of outgassing rates are $\text{g cm}^{-2} \text{s}^{-1}$. It can also be given in other units, such as in relative mass unit per time unit: (g s^{-1}), ($\% \text{s}^{-1}$) or ($\% \text{s}^{-1} \text{cm}^{-2}$).

3.2.19 plasma

partly or wholly ionized gas whose particles exhibit collective behaviour through its electromagnetic field

3.2.20 primary discharge

initial electrostatic discharge which, by creating a temporary conductive path, can lead to a secondary arc

3.2.21 radiation

transfer of energy by means of a particle (including photons)

NOTE In the context of this Standard, electromagnetic radiation below the UV band is excluded. This therefore excludes visible, thermal, microwave and radio-wave radiation.

3.2.22 radiation belt

area of trapped or quasi-trapped energetic particles, contained by the Earth's magnetic field

3.2.23 ram

volume adjacent to the spacecraft and located in the same direction of the spacecraft motion where modification to the surface or **plasma** can occur due to the passage of the spacecraft through the medium

3.2.24 secondary arc

passage of current from an external source, such as a solar array, through a conductive path initially generated by a **primary discharge**

3.2.25 surface charging

electrical charge deposition on the surface of an external or internal material

3.2.26 tether

flexible conductive or non-conductive cable linking two spacecraft or two parts of the same spacecraft not mechanically attached in any other way

3.2.27 thruster

device for altering the attitude or orbit of a spacecraft in space through reaction

NOTE E.g. rocket, cold-gas emitter, and electric propulsion.

3.2.28 triple point

<relating to onset of electrostatic discharge>
point where **dielectric**, metal and vacuum meet

3.2.29 upstream

<relating to an object at relative motion with respect to a **plasma**>
on the side of the object in the opposite direction to the **plasma** velocity vector

3.2.30 wake

volume adjacent to a spacecraft and located in the opposite direction to the spacecraft motion where the ambient **plasma** is modified by the passage of the spacecraft through the medium

3.3 Abbreviated terms

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

Abbreviation	Meaning
AOCS	attitude and orbital control system
DGD	direct gradient discharge
EMC	electromagnetic compatibility
emf	electro-motive force
EP	electric propulsion
ESD	electrostatic discharge
ETFE	ethylene-tetrafluoroethylene copolymer
eV	electron volt (also keV, MeV)
FEED	field emission electric propulsion
FEP	fluoroethylene-propylene
GEO	geostationary Earth orbit
HEO	highly eccentric orbit
ISS	International Space Station

IVG	inverted voltage gradient
IVGD	inverted voltage gradient discharge
LEO	low Earth orbit
MEMS	micro-electromechanical system(s)
MEO	medium (altitude) Earth orbit
MLI	multi-layer insulation
MLT	magnetic local time
NASA	National Aeronautics and Space Administration
NGD	normal gradient discharge
PCB	printed circuit board
PEO	polar Earth orbit
PTFE	poly-tetrafluoroethylene
PVA	photo-voltaic assembly
r.m.s.	root-mean-square
SAS	solar array simulator
SPT	stationary plasma thruster
SSM	second surface mirror
UV	ultra-violet light

4

Overview

4.1 Plasma interaction effects

4.1.1 Presentation

Most spacecraft engineers have come across the term space plasma because of the potential risk it represents in leading to high-level spacecraft charging and related electrostatic discharges. Such a phenomenon is a critical environment hazards for satellites, especially in high altitude orbits (including in geostationary orbit). However, there are numerous other plasma interaction effects of which it is also important to be aware, in order to improve engineering design and to optimize the behaviour of space systems in the space plasma environment. Not all spacecraft-plasma interactions are adverse. For example, electrodynamic tethers use current collection from the plasma to complete their electrical circuit and generate power or thrust. Scientific instruments may exploit spacecraft plasma interactions to make plasma measurements, and a magnetospheric propulsion system has been proposed to use plasma interactions with an artificial magnetic field as a propulsion system.

This clause briefly introduces the various effects covered by this standard. The most common engineering issues are first briefly described in clause 4.1.2 while a short overview of the physical mechanisms involved is given in the second of this section.

4.1.2 Most common engineering concerns

The following are the most common engineering concerns related to electrical charging of a spacecraft:

- **Surface charging** due to charge accumulation on spacecraft surface is a potential cause of spacecraft anomalies. High levels of differential potential may lead to ESDs which may couple to spacecraft electronics and damage electronic components. Initial ESDs may also trigger the generation of secondary arcs on high voltage systems. Several occurrences of permanent solar array power loss in space are believed to be related to such phenomena.
- **Internal charging** due to penetrating electrons is another cause of spacecraft anomalies. ESDs may be generated within the spacecraft Faraday cage and in close proximity to vulnerable components.

- **Current leakage** affects exposed high voltage systems which can experience significant power loss due to current leakage sustained by freely moving particles (from the plasma or photo-electrons).
- **Environment modification** occurs as a bi-product of surface charging and/or particle emission by surfaces. Electric charge and plasma density are affected in a volume that can extend very far from the spacecraft (many times its typical dimension). This is usually a critical problem for scientific plasma measurements that cannot retrieve the natural parameters to be measured without taking these alterations into account.
- **Electric propulsion** actively modifies the local environment and creates a local plasma population and modifies the current balance of the satellite that otherwise can occur. It can affect other spacecraft systems, e.g. by increased contamination.
- **Electrostatic tethers** make use of current collection from the ambient medium to allow a current to pass. These also change the currents passing through the system and can lead to high potentials.

Table 4-1 contains a more complete list of the various effects in which space plasma plays an important role.

A quantitative description of the most important processes in spacecraft-plasma interactions is given in Annex C but a brief qualitative overview follows here.

4.1.3 Overview of physical mechanisms

Surface charging occurs because electric charges (electrons and ions) of the plasma are free to move and eventually get trapped on material surfaces when they hit them. Electrons and ions provide negative and positive current respectively. Both electrons and ions can also expel electrons when they hit the surface, providing an additional positive current. UV and soft X-ray photons coming from the Sun also have enough energy to expel electrons from materials, thereby providing a positive current. The accumulation of charge (positive or negative) leads to the creation of a potential that eventually prevents further charge accumulation by repelling charges of a given polarity and attracting charges of opposite polarity. Different surfaces on the same spacecraft can charge to very different potentials, resulting in strong local electric fields. Photo-emission and secondary yield are important factors in determining occurrence of high level differential charging. Charging effect is highly dynamic as the plasma populations can change rapidly.

Internal charging occurs because higher energy electrons are able to penetrate thin surfaces and deposit charge in or on materials within the spacecraft. Internal charging involves lower currents but potentials can build up over longer periods on materials with low resistivity because current through the structure is the only mechanism by which charge can be removed. Strong electric fields again are the result.

An important hazard related to charging (surface and internal) is sudden electrostatic discharge (ESD). ESDs are most likely initiated by field effect emission and avalanche process at so-called 'triple-points', where metal, dielectric and vacuum are found together. This can eventually result in the injection of high current electrical transients into the spacecraft electrical

system. This can cause transient state changes in electronics or permanent damage of material coating or electronic components. In the vicinity of high potential differences, plasma released in an ESD can trigger a secondary discharge or even a sustained arc if the potential is maintained e.g. by the solar array.

Table 4-1: List of electrostatic and other plasma interaction effects on space systems

Spacecraft reference potential change (e.g. so-called spacecraft high voltage charging)
Differential surface charging
Internal surface charging
Deep-dielectric charging
Surface charging effects on e.g. plasma instruments
Charging interactions with thruster plumes
Charging induced sputtering
Charging induced contamination
Dust charging and sticking
Electrostatic sticking (SA, inflatables, solar sails, dusts)
Charging differences in docking procedures and EVA
Material modifications (e.g. electric field induced conductivity, plasma-contaminant modifications, cracking e.g. of ITO)
Tether systems and $\mathbf{v} \times \mathbf{B}$ induced voltages and currents
Interference induced by electrostatic sheath and induced plasma on EM systems
Spontaneous discharges
Triggered discharges: <ul style="list-style-type: none"> - Thruster-triggered - Low voltage discharges (e.g. Paschen and secondaries) - Sunlit/shadow triggered discharges - triggered by micro particles - triggered by natural high density plasma
Synergistic secondary low-voltage discharges (e.g. on solar array)
Power loss and current flow from exposed elevated voltage systems
Photoelectron cloud induced charging and disturbance of plasma sensors
Plasma perturbation from microparticle impacts (e.g. antennas)
Active plasma sources (e.g. emitters, thrusters, contactors)

If a surface is maintained at high potential, it draws a current from the plasma, particularly in the dense LEO environment. This is an issue with exposed solar array interconnects because this leakage current drains power from the array. In addition the floating potential of the spacecraft can be altered as a result.

The magnitude of spacecraft plasma interaction effects varies greatly with the changes in the ambient plasma from one type of Earth orbit to another. Also the plasma environment can exhibit temporal changes along the orbit and as a result of so-called 'Space Weather'. In addition, the spacecraft itself can modify the plasma environment e.g. via thruster firings, active experiments, or debris impacts. Other aspects of the space environment besides plasma can also influence the plasma interaction e.g. radiation, contamination, and temperature.

In any case, it is important to have access to a good quantitative description of the space environment. Suitable descriptions and models of the space environment, including aspects that control charging effects, can be found in ECSS-E-ST-10-04.

4.2 Relationship with other standards

This standard is a standard within the engineering branch. It relies on the following ECSS standards:

ECSS-E-ST-10 "Space engineering – System engineering general requirements"

ECSS-E-ST-20 "Space engineering - Electrical and electronic"

A number of ECSS standards are related to this Standard:

- The environment, defined by ECSS-E-ST-10-04 "Space engineering - Space environment", is an input to the analysis of charging and related effects described in this document.
- Radiation transport as described in ECSS-E-ST-10-12 "Space engineering - Method for the calculation of radiation received and its effects, and a policy for design margins" has relevance to internal charging effects described in this document.
- Secondary electron emission is a feature of surface charging effects described in this document and in multipaction as described in ECSS-E-ST-20-01 "Space engineering – Multipaction design and test".
- Testing of electrostatic behaviour shares many techniques with general electromagnetic cleanliness. Hence ECSS-E-ST-20-07 "Space engineering – Electromagnetic compatibility" interfaces with this standard.
- Charging of solar arrays is an important charging hazard. Hence ECSS-E-ST-20-08 "Space engineering – Photovoltaic assemblies and components" interfaces with this standard.
- This standard specifies the selection of materials and components according to their electrical behaviour, in order to avoid hazardous effects. Electrical properties are not the only consideration and ECSS-Q-ST-70-71 "Space product assurance - Data for selection of space materials and processes" describe complementary information.
- ECSS-E-ST-10-02 "Space engineering – Verification" specifies the concepts behind verification processes in general, the criteria for defining a verification strategy and rules for its implementation. It includes a description of the documentation associated to the verification process, and provisions on specific aspects of the verification process.

- ECSS-E-ST-10-03 “Space engineering – Testing” gives standard environmental and performance test requirements for a space system and its constituents. It defines the general test requirements for products and systems that are generally applicable to all projects. It also defines the documentation associated with testing activities.

5

Protection programme

- a. For any spacecraft, the supplier shall establish, at the start of the project, a plan for the assessment and mitigation of hazards associated with electrical interactions with the environment in conformance with Annex A.
- b. The compliance of the design with the design requirements shall be verified through measurement, inspection and testing.

6

Surface material requirements

6.1 Overview

6.1.1 Description and applicability

The phenomenon of surface charging leads to requirements to control the electrical behaviour of materials directly in contact with the ambient plasma. These materials can become the source of electrostatic discharges whose principal hazardous effect is to cause damage to electronic systems elsewhere on the spacecraft and of undesired electric fields, whose principal effect is to interfere with measurements of the ambient medium. The components affected include any spacecraft material on the outer surface of the spacecraft, e.g. thermal blankets, solar cell cover glass, sensor optics, exposed cables.

In addition, thin films, e.g. thermal blankets, sometimes do not shield underlying materials from the electrons mainly responsible for high level surface charging (~ 10 keV to 50 keV). Hence components affected include any spacecraft material covered by only a thin film, with thickness equivalent to less than 100 micro-meters Aluminium ($0,03 \text{ g/cm}^2$), including multi-layer insulation. The requirements in this clause also apply to surfaces partly exposed to space through small apertures (e.g., venting holes), although holes can be designed so as to avoid direct exposure.

Another factor influencing charging levels is the conduction path from each surface to ground and to other parts on the spacecraft. Hence these requirements cover all components concerned with the grounding and electrical continuity of the spacecraft structure, subsystems and electronics.

In addition to considering components that affect the build-up of charge, the effects of any resulting electrostatic discharges, i.e. coupling to sensitive devices, are controlled in order to prevent discharges causing damage and interference to systems elsewhere. This is an EMC issue that is common to electrical transients, however generated. Because this is part of general EMC design, specific requirements are not included here but standard EMC procedures are applied to control the transmission of transients.

These requirements also cover solar arrays and there are additional specific requirements for these due to the possibility of secondary discharges, fed by the power of the array itself, in clause 7.

6.1.2 Purpose common to all spacecraft

The main purpose of the requirements in this clause is to reduce differential charging and therefore the risk of electrostatic discharge or its power below an acceptable level. This is achieved principally by effective grounding throughout the spacecraft.

6.1.3 A special case: scientific spacecraft with plasma measurement instruments

Scientific spacecraft, which have the measurement of ambient electric field or of low energy particles as part of their mission, have more stringent requirements in terms of differential charging, absolute spacecraft potentials and contamination by spacecraft generated particles. For this reason, clause 6.7 provides specific requirements for this case.

Since quantitative requirements are often mission specific, the requirements in clause 6.7 are not intended to be exhaustive, but to cover the common aspects that can be expected in most of the scientific missions.

6.2 General requirements

6.2.1 Maximum permitted voltage

- a. In order to avoid electrostatic discharge, the following critical voltages and electric fields shall be used.
 - 1. To avoid an electrostatic discharge in normal potential gradient (i.e. between a dielectric and a conductor at a more positive potential), a maximum differential voltage between a dielectric and an adjacent conductor of -1000 V.
 - 2. To avoid electrostatic discharges, a maximum electric field within the dielectric of 10^7 V/m.
 - 3. To avoid an electrostatic discharge in inverted voltage gradient (i.e. between a dielectric and a conductor at a more negative potential), a maximum differential voltage between a dielectric and an adjacent conductor exposed to the vacuum of +100 V.

NOTE Maximum permitted voltages specified for scientific missions including field or plasma measurement can be lower than the limits above to limit contamination of environmental measurements.

- b. If the limits specified in 6.2.1a are not met, the assembly shall be submitted to charging tests as described in clause 6.6.

6.2.2 Maximum resistivity

- a. In order to limit differential voltage, a maximum current density of $J = 10 \text{ nA/cm}^2$ through the dielectric shall be used to calculate the maximum resistivity of dielectric materials.

NOTE This current is a recommended upper bound of the current through dielectric material to other parts on Earth orbiting spacecraft. It is not the electron irradiation current used for testing.. For example, a small sunlit area of aluminium coupled to a larger area of material in eclipse can lead to a current flow through a dielectric beneath the aluminium as large as the photocurrents ($\sim 4 \text{ nA/cm}^2$ for aluminium) plus any difference in secondary emission current.

- b. The method used for resistivity measurement shall be justified.

NOTE Some methods are described in Annex D.3.

6.3 Electrical continuity, including surfaces and structural and mechanical parts

6.3.1 Grounding of surface metallic parts

- a. All structural and mechanical parts shall be electrically bonded to each other, ensuring that, in order to control differential charging, there is a resistance of less than $10^6 \Omega$ at each bond.

NOTE 1 For example, for electrical boxes.

NOTE 2 EMC requirements can be more restrictive than this.

For EMC requirements, see ECSS-E-ST-20-07.

- b. Ground shall be carried across an articulating joint or hinge using a ground strap.
- c. Where structural ground is carried across slip-rings on a rotating joint, at least two slip-rings shall be dedicated to the structural ground path, some at each end of the slip-ring set.

NOTE This is to provide redundancy.

- d. Floating surface conductors shall not be used unless they are less than 1 cm^2 and 10 pF and not part of a multi-conductor elements structure.

NOTE Multi-conductor structures exist where at least two conductive elements are separated by a dielectric surface of less than 100 cm^2 .

- e. A risk assessment of the potential discharges due to sharp edges and tips shall be performed

- f. Circuits and conductive elements shall remain grounded in all possible situations

NOTE E.g. contacts and cables in switched circuits and moveable conductors.

- g. The grounding of surface conductors shall be implemented in one of the following two ways:

- Make the grounding to the main spacecraft of external and internal metallic parts and intrinsically conductive parts (like carbon) by a resistance as defined in ECSS-E-ST-20 clause 6.6.3a.
- Select the resistance to spacecraft ground not to be exceeded, such that it ensures that metal parts do not float by over V_{MAX} absolute potential with respect to spacecraft ground.

NOTE This normally leads to a requirement that the product of the resistance R and the area exposed to the environment A , is such that

$$R \cdot A \leq \frac{V_{MAX}}{J}$$

For a V_{MAX} of 100 V and $J = 10 \text{ nA cm}^{-2}$,

$$RA \leq 1 \times 10^6 \text{ } \Omega \text{ m}^2$$

For example:

- For a one square metre MLI, the maximum resistance is $5 \text{ M}\Omega$
- For a scientific mission where $V_{MAX}=10 \text{ V}$,
 $RA \leq 10^5 \text{ } \Omega \text{ m}^2$

6.3.2 Exceptions

- a. Except in the case specified in 6.3.2c, floating conductive parts may be used if they have an area less than 1 cm^2 and have a total capacitance less than 10 pF with respect to the structure.

NOTE This is to limit the energy available to discharge.

- b. The configuration shall be such that energy involved in any possible discharge is less than one corresponding to a discharge of a capacitance of 10 pF under $6 \times 10^3 \text{ V}$.

- c. In case of multiple elements (in which case the empirical rule in 6.3.2a does not apply), tests shall be performed.

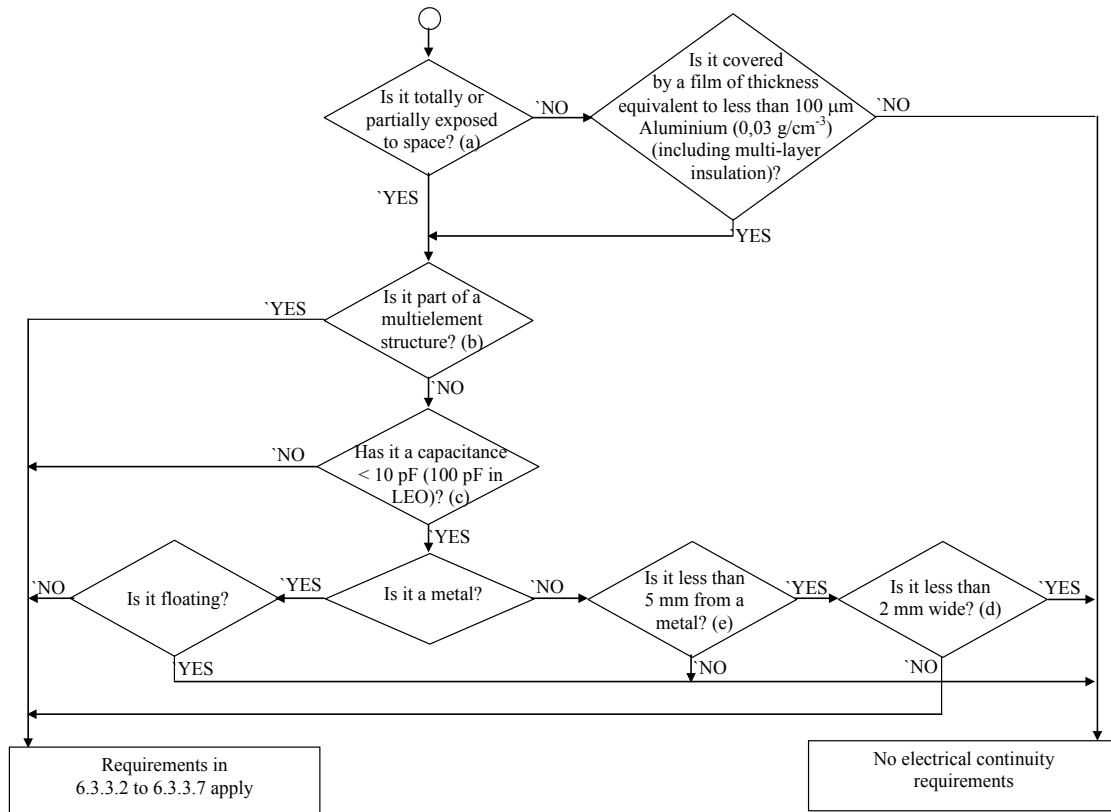
NOTE 1 Examples are patched antenna and solar arrays are multiple elements.

NOTE 2 See 6.3.1d NOTE for definition of a multi-conductor structures.

6.3.3 Electrical continuity for surface materials

6.3.3.1 Applicability

- a. The applicability of the electrical continuity requirements shall be established in accordance with the diagram in Figure 6-1.



- (a) Surfaces partially exposed include those exposed through small apertures such as venting holes.
- (b) Multi-conductor structures exist where at least two conductive elements are separated by a dielectric surface of less than 100 cm².
- (c) A capacitance of less than 10 pF is typically the case where the surface area is less than 1cm². Keeping the capacitance low limits the size of any discharge. In LEO the short charging time as the spacecraft crosses the aurora limits the size of discharge even with a capacitor up to 100 pF.
- (d) Two dielectric patches within a 100 cm² area are considered as one single dielectric for area or width estimates.
- (e) This forms a triple point. For the definition of triple point, see 3.2.28. An example where this is important is the spot of non-conductive glue used to stick wires near the ends of an array string from the bare ends.

Figure 6-1: Applicability of electrical continuity requirements

6.3.3.2 General

- a. All spacecraft surface materials shall be conductive to the extent that they lead to surface voltage below the maximum voltage specified in clause 6.2.1.
- b. If a surface material is used which is not conductive, to the extent specified in 6.3.3.2a, then it shall be tested to verify if hazardous ESD can occur or submitted to the customer.
- c. The determination of dc resistance of the surface material shall include the change over the service life of the bond in the environmental conditions which it is expected to experience including vacuum, temperature and mechanical stress.

6.3.3.3 Blankets

- a. All external and internal metallic layers of a thermal blanket shall be grounded to the structure with at least 2 bonding straps directly to ground (no daisy chain configuration).
- b. Any point on a blanket shall be within 1 m of a bonding strap.
- c. Adjacent blankets greater than 100 cm² in area shall be separately grounded to structure.

6.3.3.4 Material assemblies

- a. Material assemblies composed of different materials that are not separately grounded, shall be tested in their entirety.

NOTE An example is optical solar reflectors.

- b. Metallic layers within material assemblies shall not be exposed to the plasma.

6.3.3.5 Conductive coatings

- a. The thickness of conductive coatings shall be such that there is no degradation of their performance as a conductor when exposed to the expected erosion due to sputtering and atomic oxygen.

6.3.3.6 Dielectric materials

- a. The following materials shall be avoided:
 - 1. Perforated metallized FEP or ETFE (SSM)
 - 2. Polyimide material with thickness above 50 µm if no ESD conductive coating is used on the space-exposed side
 - 3. FEP, ETFE, C₂F₄
 - 4. Epoxy glass
 - 5. Silica cloth

NOTE The reason is that they have a known association with ESD risks.

- b. For dielectric materials, laid on top of a more conductive material, the resistivity of the dielectric shall be such that the electric field anywhere within the dielectric does not exceed $E_{MAX}=10^7$ V/m.

NOTE Normally, this is fulfilled through the requirement that the resistivity is less than the ratio of E_{MAX} by the current density J .

$$r \leq \frac{E_{MAX}}{J}$$

For a J of 10 nA cm⁻², $r \leq 10^{11}$ Ω m.

- c. For a dielectric material, adjacent to a more conductive material and both exposed to vacuum, hereby constituting a triple point, the resistivity of the dielectric shall be such that the dielectric does not charge at any location to more than 1 kV negative or to more than 100 V positive with respect to the adjacent conductor.

NOTE 1 Normally, for a slab geometry, this is fulfilled through the requirement that the resistivity r is such that

$$r \leq \frac{1}{t} \frac{V_{MAX}}{J}$$

or

$$r \leq \frac{t}{d^2} \frac{V_{MAX}}{J}$$

where t is the material thickness and d is the minimum distance at the surface of the dielectric to the adjacent grounded conductor.

or

$$\rho \leq \frac{V_{MAX}}{J} \frac{2}{d^2}$$

where ρ is surface resistivity in Ω/square.

NOTE 2 The first equation in NOTE 1 is when the main conduction path is through the thickness of the material, e.g., to an underlying conductor while the second and third equations are when the main conduction path is parallel to the surface, e.g. to an adjacent conductor.

For a V_{MAX} of 100 V and J of 10 nA cm⁻², $V_{MAX} / J = 10^6$ Ω m².

For example, a 100 μm thickness dielectric must have a resistivity of less than 10¹⁰ Ω.m if on top of a conductor and a resistivity of less than 10⁶ Ω.m if on top of a very resistive material and grounded every 1 cm.

For a scientific mission where, say $V_{MAX}=10$ V, $V_{MAX} / J = 10^4$ Ω m² usually implies that all surface materials must be good conductors.

NOTE 3 No margin is included in the values in NOTE 2.

6.4 Surface charging analysis

- a. A surface charging analysis shall be performed, including:
 - 1. A systematic inventory of all surface materials, their resistivity, area and thickness.
 - 2. A systematic inventory of triple-points, floating conductors and multiple-conductor element components.
- b. In the event that some dielectric surfaces are left more insulating than specified in 6.3.3.6, requirements in 6.3.3.2 shall be verified by computational analysis, test or similarity.
- c. Computational modelling and laboratory testing shall model the effects of the phenomenon related to surface particle emission (secondary emission and photo-emission), conduction and collection processes.

NOTE 1 Annex D describes some charging codes that can form part of this analysis.

NOTE 2 Many materials suitable for space use are found in ECSS-Q-ST-70-71.

6.5 Deliberate potentials

- a. The perturbation of surface electrostatic potential arising from potentials that are deliberately maintained on a surface shall be analysed.

NOTE This can for example be the case where a scientific experiment has a deliberately exposed surface held at a potential. Recessing and shielding of the potential surface are strategies for reducing such perturbations.

6.6 Testing of materials and assemblies

6.6.1 General

- a. If the requirements of 6.3.3 and 6.4 are not satisfied, tests in accordance with 6.6.1b shall be performed on a representative sample of the concerned surface material or assembly.
- b. The rationale behind the test, the details of the procedure and the test results shall be submitted to the customer for approval.
- c. The tests shall either:
 - reproduce the physical process of concern, i.e. charging, in a worst-case environment, or
 - yield electrostatic material properties enabling the materials response to such an environment to be assessed.
- d. The tests shall be performed under vacuum (i.e. < 1 mPa) and electron irradiation.