

### Table of contents

---

<b>European Forward</b> .....	<b>9</b>
<b>Introduction</b> .....	<b>11</b>
<b>1 Scope</b> .....	<b>13</b>
<b>2 Normative references</b> .....	<b>14</b>
<b>3 Terms, definitions and abbreviated terms</b> .....	<b>15</b>
3.1 Terms defined in other standards .....	15
3.2 Terms specific to the present standard .....	15
3.3 Abbreviated terms.....	18
3.4 Nomenclature .....	19
<b>4 Overview</b> .....	<b>21</b>
4.1 Plasma interaction effects.....	21
4.1.1 Presentation.....	21
4.1.2 Most common engineering concerns.....	21
4.1.3 Overview of physical mechanisms .....	22
4.2 Relationship with other standards .....	24
<b>5 Protection programme</b> .....	<b>26</b>
<b>6 Surface material requirements</b> .....	<b>27</b>
6.1 Overview .....	27
6.1.1 Description and applicability.....	27
6.1.2 Purpose common to all spacecraft .....	28
6.1.3 A special case: scientific spacecraft with plasma measurement instruments .....	28
6.2 General requirements .....	28
6.2.1 Maximum permitted voltage .....	28
6.2.2 Maximum resistivity.....	29
6.3 Electrical continuity, including surfaces and structural and mechanical parts.....	29
6.3.1 Grounding of surface metallic parts.....	29
6.3.2 Exceptions .....	30

6.3.3	Electrical continuity for surface materials .....	31
6.4	Surface charging analysis.....	35
6.5	Deliberate potentials.....	35
6.6	Testing of materials and assemblies.....	35
6.6.1	General.....	35
6.6.2	Material characterization tests.....	37
6.6.3	Material and assembly qualification.....	37
6.7	Scientific spacecraft with plasma measurement instruments .....	38
6.8	Verification.....	38
6.8.1	Grounding .....	38
6.8.2	Material selection .....	39
6.8.3	Environmental effects.....	39
6.8.4	Computer modelling .....	39
6.9	Triggering of ESD .....	40
<b>7</b>	<b>Secondary arc requirements .....</b>	<b>41</b>
7.1	Description and applicability .....	41
7.2	Solar arrays .....	42
7.2.1	Overview.....	42
7.2.2	General requirement .....	42
7.2.3	Testing of solar arrays.....	43
7.3	Other exposed parts of the power system including solar array drive mechanisms .....	47
<b>8</b>	<b>High voltage system requirements .....</b>	<b>48</b>
8.1	Description .....	48
8.2	Requirements .....	48
8.3	Validation.....	48
<b>9</b>	<b>Internal parts and materials requirements .....</b>	<b>49</b>
9.1	Description .....	49
9.2	General.....	49
9.2.1	Internal charging and discharge effects.....	49
9.2.2	Grounding and connectivity.....	49
9.2.3	Dielectric electric fields and voltages.....	50
9.3	Validation.....	51
<b>10</b>	<b>Tether requirements .....</b>	<b>55</b>
10.1	Description .....	55
10.2	General.....	55

10.2.1	Hazards arising on tethered spacecraft due to voltages generated by conductive tethers .....	55
10.2.2	Current collection and resulting problems .....	55
10.2.3	Hazards arising from high currents flowing through the tether and spacecraft structures .....	56
10.2.4	Continuity of insulation .....	56
10.2.5	Hazards from undesired conductive paths .....	56
10.2.6	Hazards from electro-dynamic tether oscillations .....	56
10.2.7	Other effects .....	56
10.3	Validation .....	57
<b>11</b>	<b>Electric propulsion requirements .....</b>	<b>58</b>
11.1	Overview .....	58
11.1.1	Description .....	58
11.1.2	Coverage of the requirements .....	58
11.2	General .....	60
11.2.1	Spacecraft neutralization .....	60
11.2.2	Beam neutralization .....	61
11.2.3	Contamination .....	62
11.2.4	Sputtering .....	62
11.2.5	Neutral gas effects .....	62
11.3	Validation .....	63
11.3.1	Ground testing .....	63
11.3.2	Computer modelling characteristics .....	63
11.3.3	In-flight monitoring .....	63
11.3.4	Sputtering .....	63
11.3.5	Neutral gas effects .....	64
<b>Annex A</b>	<b>(normative) Electrical hazard mitigation plan - DRD .....</b>	<b>65</b>
A.1	DRD identification .....	65
A.1.1	Requirement identification and source document .....	65
A.1.2	Purpose and objective .....	65
A.2	Expected response .....	65
A.2.1	Scope and content .....	65
A.2.2	Special remarks .....	66
<b>Annex B</b>	<b>(informative) Tailoring guidelines .....</b>	<b>67</b>
B.1	Overview .....	67
B.2	LEO .....	67
B.2.1	General .....	67

B.2.2	LEO orbits with high inclination .....	68
B.3	MEO and GEO orbits.....	68
B.4	Spacecraft with onboard plasma detectors .....	68
B.5	Tethered spacecraft.....	69
B.6	Active spacecraft .....	69
B.7	Solar Wind.....	69
B.8	Other planetary magnetospheres.....	69
<b>Annex C (informative) Physical background to the requirements .....</b>		<b>70</b>
C.1	Introduction.....	70
C.2	Definition of symbols.....	70
C.3	Electrostatic sheaths.....	70
C.3.1	Introduction .....	70
C.3.2	The electrostatic potential .....	71
C.3.3	The Debye length.....	71
C.3.4	Presheath .....	72
C.3.5	Models of current through the sheath.....	73
C.3.6	Thin sheath – space-charge-limited model.....	73
C.3.7	Thick sheath – orbit motion limited (OML) model .....	74
C.3.8	General case.....	75
C.3.9	Magnetic field modification of charging currents.....	75
C.4	Current collection and grounding to the plasma .....	75
C.5	External surface charging .....	76
C.5.1	Definition.....	76
C.5.2	Processes .....	76
C.5.3	Effects.....	77
C.5.4	Surface emission processes .....	77
C.5.5	Floating potential.....	78
C.5.6	Conductivity and resistivity .....	79
C.5.7	Time scales.....	81
C.6	Spacecraft motion effects .....	81
C.6.1	Wakes.....	81
C.6.2	Motion across the magnetic field .....	84
C.7	Induced plasmas .....	85
C.7.1	Definition.....	85
C.7.2	Electric propulsion thrusters.....	86
C.7.3	Induced plasma characteristics .....	86
C.7.4	Charge-exchange effects .....	87

C.7.5	Neutral particle effects .....	88
C.7.6	Effect on floating potential .....	88
C.8	Internal and deep-dielectric charging .....	88
C.8.1	Definition .....	88
C.8.2	Relationship to surface charging .....	89
C.8.3	Charge deposition .....	90
C.8.4	Material conductivity .....	90
C.8.5	Time dependence .....	93
C.8.6	Geometric considerations .....	93
C.8.7	Isolated internal conductors .....	94
C.8.8	Electric field sensitive systems .....	94
C.9	Discharges and transients .....	95
C.9.1	General definition .....	95
C.9.2	Review of the process .....	95
C.9.3	Dielectric material discharge .....	96
C.9.4	Metallic discharge .....	98
C.9.5	Internal dielectric discharge .....	99
C.9.6	Secondary powered discharge .....	100
C.9.7	Discharge thresholds .....	100
<b>Annex D (informative)</b>	<b>Charging simulation .....</b>	<b>102</b>
D.1	Surface charging codes .....	102
D.1.1	Introduction .....	102
D.2	Internal charging codes .....	104
D.2.1	DICTAT .....	104
D.2.2	ESADDC .....	104
D.2.3	GEANT-4 .....	105
D.2.4	NOVICE .....	105
D.3	Environment model for internal charging .....	105
D.3.1	FLUMIC .....	105
D.3.2	Worst case GEO spectrum .....	105
<b>Annex E (informative)</b>	<b>Testing and measurement. ....</b>	<b>106</b>
E.1	Definition of symbols .....	106
E.2	Solar array testing .....	106
E.2.1	Solar cell sample .....	106
E.2.2	Pre-testing of the solar array simulator (SAS) .....	107
E.2.3	Solar array test procedure .....	109
E.2.4	Other elements .....	113

E.2.5	The solar panel simulation device .....	114
E.3	Measurement of conductivity and resistivity .....	116
E.3.1	Determination of intrinsic bulk conductivity by direct measurement .....	116
E.3.2	Determination of radiation-induced conductivity coefficients by direct measurement .....	117
E.3.3	Determination of conductivity and radiation-induced conductivity by electron irradiation.....	118
E.3.4	The ASTM method for measurement of surface resistivity and its adaptation for space used materials.....	118

**References ..... 120**

**Bibliography..... 124**

**Figures**

Figure 6-1:	Applicability of electrical continuity requirements .....	32
Figure 7-1:	Solar array test set-up .....	45
Figure C-1 :	Schematic diagram of potential variation through sheath and pre-sheath. ....	72
Figure C-2 :	Example secondary yield curve .....	78
Figure C-3 :	Schematic diagram of wake structure around an object at relative motion with respect to a plasma.....	82
Figure C-4 :	Schematic diagram of void region .....	83
Figure C-5 :	Schematic diagram of internal charging in a planar dielectric.....	89
Figure C-6 :	Dielectric discharge mechanism. ....	97
Figure C-7 :	Shape of the current in relation to discharge starting point.....	97
Figure C-8 :	Example of discharge on pierced aluminized Teflon® irradiated by electrons with energies ranging from 0 to 220 keV. ....	98
Figure C-9 :	Schematic diagram of discharge at a triple point in the inverted voltage gradient configuration with potential contours indicated by colour scale. ....	99
Figure E-1 :	Photograph of solar cells sample – Front face & Rear face (Stentor Sample. Picture from Denis Payan - CNES®).....	107
Figure E-2 :	Schematic diagram of power supply test circuit.....	108
Figure E-3 :	Example of a measured power source switch response.....	108
Figure E-4 :	Example solar array simulator.....	109
Figure E-5 :	Absolute capacitance of the satellite .....	110
Figure E-6 :	Junction capacitance of a cell versus to voltage.....	112
Figure E-7 :	The shortened solar array sample and the missing capacitances .....	113
Figure E-8 :	Discharging circuit oscillations .....	114
Figure E-9 :	Effect of an added resistance in the discharging circuit (SAS + resistance) ....	114
Figure E-10 :	Setup simulating the satellite including flashover current .....	115

Figure E-11 : Basic arrangement of apparatus for measuring dielectric conductivity in planar samples.....	116
Figure E-12 : Arrangement for measuring cable dielectric conductivity and cross-section through co-axial cable.....	116
Figure E-13 : Arrangement for carrying out conductivity tests on planar samples under irradiation .....	118
Figure E-14 : Basic experimental set up for surface conductivity .....	119

## Tables

Table 4-1: List of electrostatic and other plasma interaction effects on space systems.....	23
Table 7-1: Tested voltage-current combinations.....	42
Table 7-2: Typical inductance per unit length for cables .....	46
Table C-1 : Parameters in different regions in space .....	72
Table C-2 : Typical plasma parameters for LEO and GEO .....	83
Table C-3 : Plasma conditions on exit plane of several electric propulsion thrusters .....	87
Table C-4 : Emission versus backflow current magnitudes for several electric propulsion thrusters.....	87
Table C-5 : Value of $E_a$ for several materials .....	91