

| | | |
|------------|--|--|
| TNI | Kozmická technika Príručka na posudzovanie najhoršieho prípadu nabíjania vo vesmíre | TNI CEN/TR 17603-20-06 31 0540 |
|------------|--|--|

Space engineering - Assessment of space worst case charging handbook

Táto technická normalizačná informácia obsahuje anglickú verziu CEN/TR 17603-20-06:2022.
This Technical standard information includes the English version of CEN/TR 17603-20-06:2022.

Táto technická normalizačná informácia bola oznámená vo Vestníku ÚNMS SR č. 04/22

134696



TECHNICAL REPORT
RAPPORT TECHNIQUE
TECHNISCHER BERICHT

CEN/TR 17603-20-06

January 2022

ICS 49.140

English version

**Space engineering - Assessment of space worst case
charging handbook**

Ingénierie spatiale - Guide sur les techniques de
durcissement des ASICs et FPGAs vis-à-vis des effets
des radiations

Raumfahrtproduktsicherung - Handbuch zu
Minderungsmethoden von Strahlungseffekten auf
ASICs und FPGA

This Technical Report was approved by CEN on 29 November 2021. It has been drawn up by the Technical Committee CEN/CLC/JTC 5.

CEN and CENELEC members are the national standards bodies and national electrotechnical committees of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey and United Kingdom.



**CEN-CENELEC Management Centre:
Rue de la Science 23, B-1040 Brussels**

Table of contents

| | |
|--|-----------|
| European Foreword | 6 |
| Introduction | 7 |
| 1 Scope | 8 |
| 2 References | 9 |
| 3 Terms, definitions and abbreviated terms | 13 |
| 3.1 Terms from other documents..... | 13 |
| 3.2 Abbreviated terms..... | 13 |
| 4 Surface charging | 15 |
| 4.1 Fundamentals..... | 15 |
| 4.2 General methodology of surface charging analyses..... | 17 |
| 4.2.1 Introduction | 17 |
| 4.2.2 Necessity of 3D surface charging analyses | 17 |
| 4.2.3 Simulation process..... | 18 |
| 4.2.4 Assessment of simulation results | 19 |
| 4.3 Electrostatic discharge..... | 20 |
| 4.3.1 ESD types..... | 20 |
| 4.3.2 Thresholds for ESD occurrence | 20 |
| 4.3.3 Quantitative characterization of ESD electrical transients..... | 21 |
| 4.3.4 Interpretation of results | 25 |
| 4.4 Critical aspects with respect to worst case surface charging analyses..... | 25 |
| 4.4.1 Orbit..... | 25 |
| 4.4.2 Material properties | 26 |
| 4.4.3 Sunlit/Eclipse | 26 |
| 4.4.4 Protons | 27 |
| 4.4.5 Electric propulsion..... | 27 |
| 4.5 How to set up a simulation..... | 27 |
| 4.5.1 Charging environment parameters | 27 |
| 4.5.2 Modelling requirements for surface charging analyses..... | 27 |
| 4.5.3 Spacecraft geometry modelling..... | 28 |

CEN/TR 17603-20-06:2022 (E)

| | | |
|----------------|--|-----------|
| 4.5.4 | Gmsh – The CAD interface to SPIS | 29 |
| 4.5.5 | Physical groups and surface materials definition | 33 |
| 4.5.6 | Basic electrical circuit of the satellite | 36 |
| 4.5.7 | Plasma models | 37 |
| 4.5.8 | Global parameters..... | 37 |
| 4.5.9 | Consistency checks | 38 |
| 5 | Internal Charging..... | 40 |
| 5.1 | Fundamentals..... | 40 |
| 5.1.1 | Introduction | 40 |
| 5.1.2 | Floating metals..... | 40 |
| 5.1.3 | Insulators | 40 |
| 5.1.4 | Charge Deposition | 41 |
| 5.1.5 | Conductivity | 41 |
| 5.1.6 | Time-dependence | 43 |
| 5.2 | General methodology | 43 |
| 5.2.1 | Introduction | 43 |
| 5.2.2 | Internal charging analyses | 44 |
| 5.2.3 | Critical aspects with respect to worst case internal charging analysis | 45 |
| 5.2.4 | Modelling aspects for internal charging analyses | 49 |
| 5.2.5 | Environment..... | 50 |
| 5.2.6 | Geometry | 50 |
| 5.2.7 | Materials parameters | 51 |
| 5.2.8 | Simulation tools in 1D and 3D | 51 |
| 5.2.9 | Scenarios..... | 52 |
| 5.2.10 | Important Outputs | 52 |
| 6 | General aspects of surface and internal charging analysis | 53 |
| 6.1 | Material characterization aspects..... | 53 |
| 6.2 | Charging analyses and project phases | 53 |
| 6.2.1 | Phase 0: Mission analysis | 53 |
| 6.2.2 | Phase A: Feasibility..... | 53 |
| 6.2.3 | Phase B: Preliminary definition | 53 |
| 6.2.4 | Phase C: Detailed definition | 54 |
| 6.2.5 | Phase D: Production | 54 |
| 6.2.6 | Phase E: Utilisation..... | 54 |
| Annex A | Orbit plasma environment..... | 55 |
| A.1 | Plasma environment for different Earth orbits | 55 |

CEN/TR 17603-20-06:2022 (E)

| | | |
|-------|-----------------------------------|----|
| A.2 | GEO worst case environments | 56 |
| A.2.1 | Introduction | 56 |
| A.2.2 | ECSS | 56 |
| A.2.3 | NASA | 56 |
| A.2.4 | ONERA/CNES | 58 |
| A.3 | LEO/Polar | 58 |

Figures

| | | |
|--------------|--|----|
| Figure 4-1: | Current contributions influencing the surface charging of a body in space plasma | 16 |
| Figure 4-2: | Flowchart showing the steps needed to determine the necessity of a 3D surface charging analysis | 18 |
| Figure 4-3: | Flow diagram of the typical process of a 3D charging analysis | 19 |
| Figure 4-4: | Charged surface with area A showing the geometrical meaning and the range for the parameter R | 23 |
| Figure 4-5: | Two-dimensional meshing of a solar array (from Sarrailh et al 2013 0) | 24 |
| Figure 4-6: | Examples of 2 discharges | 24 |
| Figure 4-7: | Definition of nodes and lines with Gmsh | 30 |
| Figure 4-8: | Definition of surfaces and volume with Gmsh | 31 |
| Figure 4-9: | Top: Surface meshes of the spacecraft and boundary. Bottom: Volume mesh of the computational space | 32 |
| Figure 4-10: | Definition of surface materials through the SPIS group editor | 33 |
| Figure 4-11: | Example of material properties list used by SPIS | 35 |
| Figure 4-12: | SPIS configuration of satellite electrical connections | 36 |
| Figure 4-13: | SPIS plasma parameters settings for the ECSS-E-ST-10-04 GEO worst case environment for surface charging | 37 |
| Figure 5-1: | Mulassis 0 simulation of net flux (forward minus backward travelling) due to a 5 MeV incident beam in a planar sample of Aluminium. CSDA range is approximately 11,4 mm | 41 |
| Figure 5-2: | Decision flow diagram for performing an internal charging analysis | 44 |
| Figure 5-3: | Current density v shielding depth curve for a geostationary orbit with longitude 195deg East with nominal date 21/09/1994 according to the FLUMIC model as calculated by the Mulassis tool in SPENVIS. The FLUMIC spectrum was calculated by DICTAT in SPENVIS | 46 |
| Figure 5-4: | Current density v shielding depth curve for the peak of the outer radiation belt L=4,4, B/B0=1,0 with nominal date 21/09/1994 according to the FLUMIC model as calculated by the Mulassis tool in SPENVIS. The FLUMIC spectrum was calculated by DICTAT in SPENVIS | 48 |

CEN/TR 17603-20-06:2022 (E)**Tables**

| | |
|---|----|
| Table 4-1: Meanings of the material properties used in SPIS | 35 |
| Table 5-1: Current density v shielding depth values for a geostationary orbit with longitude 195deg East with nominal date 21/09/1994 according to the FLUMIC model as calculated by the Mulassis tool in SPENVIS. The FLUMIC spectrum was calculated by DICTAT in SPENVIS..... | 47 |
| Table 5-2: Current density v shielding depth values for the peak of the outer radiation belt L=4,4, B/B0=1,0 with nominal date 21/09/1994 according to the FLUMIC model as calculated by the Mulassis tool in SPENVIS. The FLUMIC spectrum was calculated by DICTAT in SPENVIS..... | 48 |
| Table A-1 : Type of environments and order of magnitudes of density and temperature encountered along typical orbits..... | 55 |
| Table A-2 : Order of magnitudes of key plasma and charging parameters expected in typical environments | 55 |
| Table A-3 : ECSS-E-ST-10-04 worst case charging environment..... | 56 |
| Table A-4 : NASA-HDBK-4002A worst case charging environment..... | 56 |
| Table A-5 : NASA 'more realistic' geosynchronous worst case environment specification | 57 |
| Table A-6 : Severe charging environments in GEO 0 | 58 |

CEN/TR 17603-20-06:2022 (E)

European Foreword

This document (CEN/TR 17603-20-06:2022) has been prepared by Technical Committee CEN/CLC/JTC 5 "Space", the secretariat of which is held by DIN.

It is highlighted that this technical report does not contain any requirement but only collection of data or descriptions and guidelines about how to organize and perform the work in support of EN 16603-20.

This Technical report (CEN/TR 17603-20-06:2021) originates from ECSS-E-HB-20-06A.

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

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

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

Introduction

Spacecraft charging occurs due to the deposition of charge on spacecraft surfaces or in internal materials due to charged particles from the environment. Resulting high voltages and high electric fields cause electrostatic discharges which are a hazard to many spacecraft systems. Broadly speaking, spacecraft charging can be divided into surface charging, which is caused by plasma particles with energy up to several 10s of keV and internal charging which is caused by trapped radiation electrons with energy around 0,2 MeV and above.

Both surface and internal charging have been associated with malfunctions and damage to spacecraft systems over many years.

1

Scope

Common engineering practices involve the assessment, through computer simulation (with software like NASCAP 0 or SPIS 0), of the levels of absolute and differential potentials reached by space systems in flight. This is usually made mandatory by customers and by standards for the orbits most at risk such as GEO or MEO and long transfers to GEO by, for example, electric propulsion.

The ECSS-E-ST-20-06 standard requires the assessment of spacecraft charging but it is not appropriate in a standard to explain how such an assessment is performed. It is the role of this document ECSS-E-HB-20-06, to explain in more detail important aspects of the charging process and to give guidance on how to carry out charging assessment by computer simulation.

The ECSS-E-ST-10-04 standard specifies many aspects of the space environment, including the plasma and radiation characteristics corresponding to worst cases for surface and internal charging. In this document the use of these environment descriptions in worst case simulations is described.

The emphasis in this document is on high level charging in natural environments. One aspect that is currently not addressed is the use of active sources e.g. for electric propulsion or spacecraft potential control. The tools to address this are still being developed and this area can be addressed in a later edition.

2

References

| EN Reference | Reference in text | # | Title |
|----------------|-------------------|--------|--|
| EN 16601-00-01 | ECSS-S-ST-00-01 | [RD.1] | ECSS-S-ST-00-01, ECSS system – Glossary of terms |
| EN 17603-10-04 | ECSS-E-ST-10-04 | [RD.2] | ECSS-E-ST-10-04, Space engineering, Space environment |
| EN 17603-20-06 | ECSS-E-ST-20-06 | [RD.3] | ECSS-E-ST-20-06, Space engineering, Spacecraft charging |
| | | [RD.4] | Myron J. Mandell, Victoria A. Davis, David L. Cooke, Member, IEEE, Adrian T. Wheelock, and C. J. Roth, Nascap-2k Spacecraft Charging Code Overview, IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 34, NO. 5, OCTOBER 2006 |
| | | [RD.5] | Benoit Thiébault, Benjamin Jeanty-Ruard, Pierre Souquet, Julien Forest, Jean-Charles Matéo-Vélez, Pierre Sarrailh, David Rodgers, Alain Hilgers, Fabrice Cipriani, Denis Payan, and Nicolas Balcon, SPIS 5.1: An Innovative Approach for Spacecraft Plasma Modeling, IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 43, NO. 9, SEPTEMBER 2015. [SPIS can be downloaded from http://dev.spis.org/projects/spine/home/spis] |
| | | [RD.6] | D. Payan, V. Inguibert, and J.-M. Siguier, ESD and secondary arcing powered by the solar array – toward full arc free power lines, 14 th SCTC, ESTEC, 2016 |
| | | [RD.7] | M. Bodeau, Updated current and voltage thresholds for sustained arcs in power systems, IEEE Trans. on Plasma Science, Vol. 42, No. 7, 2014 |
| | | [RD.8] | C. Imhof, H. Mank, and J. Lange, Charging simulations for a low earth orbit satellite with SPIS using different environmental inputs, 14 th SCTC, ESTEC, 2016 |
| | | [RD.9] | Yeh and Gussenhoven, The statistical electron environment for Defense Meteorological Satellite Program eclipse charging, JGR, vo.92, no.A7, pp.7705-7715, 1987 |

CEN/TR 17603-20-06:2022 (E)

| EN Reference | Reference in text | # | Title |
|--------------|-------------------|---------|---|
| | | [RD.10] | F. Lei, P. R. Truscott, C. S. Dyer, B. Quaghebeur, D. Heynderickx, P. Nieminen, H. Evans, and E. Daly, MULASSIS: A Geant4-Based Multilayered Shielding Simulation Tool, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 49, NO. 6, DECEMBER 2002 |
| | | [RD.11] | Adamec, V. and J. Calderwood, J Phys. D: Appl. Phys., 8, 551-560, 1975. |
| | | [RD.12] | D.J.Rodgers, K. Ryden G.L. Wrenn, P.M. Latham, J. Sorensen, & L. Levy (1998). An Engineering Tool for the Prediction of Internal Dielectric Charging, Proc. 6th Spacecraft Charging Technology Conference, Hanscom, USA |
| | | [RD.13] | R. Hanna, T. Paulmier, P. Molinie, M. Belhaj, B. Dirassen, D. Payan and N. Balcon, J. Appl. Phys. 115, 033713 (2014)] |
| | | [RD.14] | Insoo Jun, Henry B. Garrett, Wousik Kim, and Joseph I. Minow, Review of an Internal Charging Code, NUMIT, IEEE TRANSACTIONS ON PLASMA SCIENCE, VOL. 36, NO. 5, OCTOBER 2008 |
| | | [RD.15] | F. Lei, D. Rodgers and P. Truscott, MCICT MONTE-CARLO INTERNAL CHARGING TOOL, Proc. 14 th Spacecraft Charging Technology Conference, ESA/ESTEC, Noordwijk, NL, 08 APRIL 2016 |
| | | [RD.16] | Alex Hands, Keith Ryden, Craig Underwood, David Rodgers and Hugh Evans, A New Model of Outer Belt Electrons for Dielectric Internal Charging (MOBE-DIC) IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 62, NO. 6, DECEMBER 2015 |
| | | [RD.17] | G. P. Ginet, P. O'Brien, S. L. Huston W. R. Johnston, T. B. Guild, R. Friedel, C. D. Lindstrom, C. J. Roth, P. Whelan, R. A. Quinn, D. Madden, S. Morley, Yi-Jiun Su, AE9, AP9 and SPM: New Models for Specifying the Trapped Energetic Particle and Space Plasma Environment, Space Science Reviews November 2013, Volume 179, Issue 1-4, pp 579-615 |
| | | [RD.18] | B. Jeanty-Ruard, A. Trouche, P. Sarrailh, J. Forest. Advanced CAD tool and experimental integration of GRAS/GEANT-4 for internal charging analysis in SPIS. Spacecraft Charging Technology Conference SCTC 2016, Apr 2016, NOORDWIJK, Netherlands. |

CEN/TR 17603-20-06:2022 (E)

| EN Reference | Reference in text | # | Title |
|--------------|-------------------|---------|---|
| | | [RD.19] | D. Payan, A. Sicard-Piet, J.C. Mateo-Velez, D.Lazaro, S. Bourdarie, et al.. Worst case of Geostationary charging environment spectrum based on LANL flight data. Spacecraft Charging Technology Conference 2014 (13 th SCTC), Jun 2014, PASADENA, United States. |
| | | [RD.20] | Gussenhoven, M.S. and E. G. Mullen (1983), Geosynchronous environment for severe spacecraft charging, J. Spacecraft and Rockets 20, N°1, p. 26. |
| | | [RD.21] | Matéo-Vélez, J.-C., Sicard, A., Payan, D., Ganushkina, N., Meredith, N. P., & Sillanpää, I. (2018). Spacecraft surface charging induced by severe environments at geosynchronous orbit. Space Weather, 16. |
| | | [RD.22] | NASA-HDBK-4002A, Mitigating in space charging effects – a guideline, 03-03-2011 |
| | | [RD.23] | Inguibert, V., Siguier, J. M., Sarrailh, P., Matéo-Vélez, J. C., Payan, D., Murat, G., & Baur, C. Influence of Different Parameters on Flashover Propagation on a Solar Panel. IEEE Transactions on Plasma Science (2017) |
| | | [RD.24] | E. Amorim, D. Payan, R. Reulet, and D. Sarrail, “Electrostatic discharges on a 1 m2 solar array coupon – Influence of the energy stored on coverglass on flashover current,” in Proc. 9th Spacecraft Charging Technol. Conf., Tsukuba, Japan, Apr. 2005 |
| | | [RD.25] | R. Briet,, “Scaling laws for pulse waveforms from surface discharges,” in Proc. 9th SCTC, Tsukuba, Japan, Apr. 2005., |
| | | [RD.26] | D. C. Ferguson and B. V. Vayner, “Flashover current pulse formation and the perimeter theory,” IEEE Trans. Plasma Sci., vol. 41, no. 12, pp. 3393–3401, Dec. 2013 |
| | | [RD.27] | J.-F. Roussel et al., “SPIS multiscale and Multiphysics capabilities: Development and application to GEO charging and flashover modelling,” IEEE Trans. Plasma Sci., vol. 40, no. 2, pp. 183–191, Feb. 2012. |
| | | [RD.28] | J. A. Young and M. W. Crofton, “The effects of material at arc site on ESD propagation,” in Proc. 14th SCTC, Noordwijk, The Netherlands, Apr., pp. 1–7, 2016 |
| | | [RD.29] | P. Sarrailh et al., “Plasma bubble expansion model of the flash-over current collection on a solar array-comparison to EMAGS3 results,” IEEE Trans. Plasma Sci., vol. 41, no. 12, pp. 3429–3437, Dec. 2013 |

CEN/TR 17603-20-06:2022 (E)

| EN Reference | Reference in text | # | Title |
|--------------|-------------------|---------|--|
| | | [RD.30] | V. Inguibert et al., "Measurements of the flashover expansion on a real-solar panel—Preliminary results of EMAGS3 project," IEEE Trans. Plasma Sci., vol. 41, no. 12, pp. 3370–3379, Dec. 2013. |
| | | [RD.31] | A. Gerhard et al., "Analysis of solar array performance degradation during simulated flashover discharge experiments on a full panel and using a simulator circuit," IEEE Trans. Plasma Sci., vol. 43, no. 11, pp. 3933–3938, Nov. 2015 |
| | | [RD.32] | Sarno-Smith, Lois K., Larsen, Brian A., Skoug, Ruth M., Liemohn, Michael W., Breneman, Aaron, Wygant, John R., Thomsen, Michelle F., Spacecraft surface charging within geosynchronous orbit observed by the Van Allen Probes, Space Weather, Volume 14, Issue 2, Pages 151–164, February 2016 |
| | | [RD.33] | Ganushkina, N. Yu., Amariutei, O. A., Welling, D., Heynderickx, D., Nowcast model for low-energy electrons in the inner magnetosphere, Space Weather, Volume 13, issue 1, pp. 16-34, 2015 |
| | | [RD.34] | NASA Technical paper 2361, 1984 Design guidelines for assessing and controlling spacecraft charging effects |
| | | [RD.35] | Matéo-Vélez, J.-C., Sicard, A., Payan, D., Ganushkina, N., Meredith, N. P., & Sillanpää, I. (2018). Spacecraft surface charging induced by severe environments at geosynchronous orbit. Space Weather, 16. https://doi.org/10.1002/2017SW001689 |

koniec náhľadu – text ďalej pokračuje v platenej verzii STN