Appendix J
Key Spacecraft Charging Documents

This Appendix is a sampling of the many possible information sources relevant to this field. It is heavily colored by the principal authors' knowledge, experience, and prejudices; and it has omitted many worthy references to keep it to a manageable size. The curious reader may dig deeper by following references in these documents. Additional, more specific, sources are referenced in the text following each chapter or appendix. The various charging conference records themselves contain a wealth of technical papers.

J.1 United States Government Documents

J.1.1 DoD

AFGL-TR-77-0288 — H. B. Garrett, *Modeling of the Geosynchronous Orbit Plasma Environment - Part 1*, 1978.

AFGL-TR-78-0304 — H. B. Garrett, E. G. Ziemba, and S. E. Deforest, *Modeling of the Geosynchronous Plasma Environment - Part 2, ATS-5 and ATS-6 Statistical Atlas I*, 1978.

AFGL-TR-79-0015 — H. B. Garrett, R. E. McInerney, S. E. Deforest, and B. Johnson, *Modeling of the Geosynchronous Orbit Plasma Environment - Part 3, ATS-5 and ATS-6 Pictorial Data Atlas*, 1979.

AFRL-VS-TR-20001578 — *6th Spacecraft Charging Technology Conference*, October 26-29, 1998, Air Force Research Laboratory, Hanscom Air Force Base, Massachusetts. D. L. Cooke and S. T. Lai, compilers.
This conference is documented on one or more CDs, one of which is contained in SEE Publication SEE/TP-2005-600 (J. Minor, compiler, NASA MSFC). The CD contains photo images of electronic files for the 1st through the 8th Spacecraft Charging Conferences.

AFWAL-TR-88-4143, Vol. II — W. G. Dunbar, *Design Guide: Designing and Building High Voltage Power Supplies*, Materials Laboratory, Air Force Wright Aeronautical Laboratories, Patterson Air Force Base, Ohio, August 1988.
Contains good design ideas.

MIL-STD-461 — *Requirements for the Control of Electromagnetic Interference Characteristics of Subsystems and Equipment*. Various versions; version F is the latest as of 2007.
Generally, a good EMC design will be helpful at mitigating space charging and ESD effects.

MIL-STD-462 — *Measurement of Electromagnetic Interference Characteristics*, July 31, 1967.

MIL-STD-883G — *Test Method Standard for Microcircuits, Method 3015.7, Electrostatic Discharge Sensitivity Classification*, March 22, 1989.
This describes Vzap tests for measuring ESD response of electronic parts to the human body model for ESD.

MIL-STD-1541A — *Electromagnetic Compatibility Requirements for Space Systems*.
Appendix E.9 of this Handbook has a "Schematic Diagram of Arc Source" as copied from MIL-STD-1541A (30 December 1987).

MIL-STD-1686 — *Electrostatic Discharge Control Program for Protection of Electrical and Electronic Parts, Assemblies, and Equipment* (*Excluding Electrically Initiated Explosive Devices)*, October 25, 1995.

MIL-STD-1809 — *Space Environment for USAF Space Vehicles*, February 19, 1991.
This includes some electron spectra that can be used in the electron transport codes. It has good information that supplements Earth environmental information in this version of NASA-HDBK-4002A.

PL-TR-93-2027(I) — *Proceedings of the Spacecraft Charging Technology* Conference, 1989, Volume I., R. C. Olsen, ed., October 31– November 3, 1989, Naval Postgraduate School, Monterey, California.
More detailed explanations of the space environment and its interactions with spacecraft.

J.1.2 NASA

NASA-CP-2004-213091 — *Spacecraft Charging Technology Conference*, J. L. Minor, compiler. October 20-24, 2003, Marshall Space Flight Center, Huntsville, Alabama.
More detailed explanations of the space environment and its interactions with spacecraft.

NASA-CP-2071 *Spacecraft Charging Technology – 1978*. (Also AFGL-TR-79-0082.) October 31–November 2, 1978. United States Air Force Academy, Colorado Springs, Colorado.
More detailed explanations of the space environment and its interactions with spacecraft.

NASA-CP-2182 *Spacecraft Charging Technology – 1980* (also AFGL-TR-81-0270.), November 12-14, 1980, United States Air Force Academy, Colorado Springs, Colorado.
More detailed explanations of the space environment and its interactions with spacecraft.

NASA-CP-2359 *Spacecraft Environmental Interactions Technology – 1983* (also AFGL-TR-85-0018.) October 4-6, 1983, United States Air Force Academy, Colorado Springs, Colorado.
More detailed explanations of the space environment and its interactions with spacecraft.

NASA-HDBK-4001 *Electrical Grounding Architecture for Unmanned Spacecraft*, February 17, 1998.
This is a handy general document. Notice that the grounding diagrams show that the circuit grounds exit the boxes and apparently connect to a remote ground; this is a schematic and not a physical diagram. The grounds should be contained within the box for the EMC reason that it should not act as a radiator (antenna) of noise into or out of the box.

NASA-HDBK-4002 *Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects*, National Aeronautics and Space Administration, Washington, District of Columbia, February 17, 1999.
One of the two base documents for NASA-HDBK-4002A along with NASA TP-2361.

NASA-HDBK-4002A — *Mitigating in-Space Charging Effects—A Guideline*, National Aeronautics and Space Administration, Washington, District of Columbia, March 3, 2011.

NASA-HDBK-4006 — *Low Earth Orbit Spacecraft Charging Design Handbook*, June 3, 2007.
This document is written by two of NASA's senior researchers in spacecraft charging, recognized experts on charging (and discharging) of solar arrays in space plasmas. It is a fine reference to have on your bookshelf for spacecraft charging. See also NASA-STD-4005.

NASA-RP-1354 — J. L. Herr and M. B. McCollum, *Spacecraft Environments Interactions: Protecting Against the Effects of Spacecraft Charging*, November 1994.

NASA-RP-1375 — R. D. Leach and M. B. Alexander, *Failures and Anomalies Attributed to Space Charging*, August 1995.

NASA-STD-4005 — *Low Earth Orbit Spacecraft Charging Design Standard*, June 3, 2007.
The NASA standard for LEO charging, it gives mitigation techniques for LEO, some of which are also applicable to GEO and polar environments. See also NASA-HDBK-4006.

NASA TMX-73537 — *Proceedings of the Spacecraft Charging Technology Conference* (also AFGL-TR-77-0051), C. P Pike and R. R. Lovell, eds. October 27-29, 1976, United States Air Force Academy, Colorado Springs, Colorado, 1977.
More detailed explanations of the space environment and its interactions with spacecraft.

NASA/TP-2003-212287 — D. C. Ferguson and G. B. Hillard, *Low Earth Orbit Spacecraft Charging Design Guidelines*, February 2003.
See paragraph 3.2.4.2 for added information.

NASA TP-2361 — *Design Guidelines for Assessing and Controlling Spacecraft Charging Effects*, 1984.
One of the two base documents for NASA-HDBK-4002A. Listed as historical reference; some of the deleted sections can provide more background information and illustrations. Its Section 2.3 describes charge loss in a discharge. Its Section 3.1.2.3 describes retarding potentials on large portions of dielectrics.

J.2 Non-US Government Documents

J.2.1 American Society for Testing Materials (ASTM)

ASTM D-257-61 — *Standard Test Methods for DC Resistance or Conductance of Insulating Materials*, 1961. Uses test methods appropriate for normally dielectric materials. For measurement of highly resistive materials often used for space charging applications, special measurement methods should be used. (See ASTM D 257-91.)

ASTM D-257-91 — *Standard Test Method for DC Resistance or Conductance of Insulating Materials*, 1991. Good for measuring high values of resistance.

ASTM D-3755 — *Standard Test Method for Dielectric Breakdown Voltage and Dielectric Strength of Solid Electrical Insulating Materials under Direct-Voltage Stress*, March 10, 1997.

J.2.2 European Cooperation for Space Standardization (ECSS)/European Handbooks

These documents are available via the ESA-ESTEC website, including unpublished drafts. The website is http://www.ecss.nl. Accessing documents requires registration on the website, but the only requirements for a user are to supply an ID and the users e-mail address to:

ECSS Secretariet
ESA-ESTEC
Noordwijk, The Netherlands

ECSS-20-06 — *Spacecraft Charging-Environment-induced Effects on the Electrostatic Behaviour of Space Systems*.
Unpublished draft that should be published because of its useful content.

ECSS-E-ST-20-06C — *Space Engineering, Spacecraft Charging Standard*, July 31, 2008.
This is intended to be a set of design rules but is far more than that. It contains the background physics and provides a wealth of space-charging information, both scientifically and practically oriented. The standard is a very good educational reference. Sometimes, however, it is not explicit in that it may provide two or more answers to the same question (e.g., what environment to use).

J.2.3 European Space Research and Technology Centre

SP-476 — *7th Spacecraft Charging Technology Conference; 2001: A Spacecraft Charging Odyssey*, April 23-27, 2001, Noordwijk, The Netherlands.

J.2.4 Japan Aerospace Exploration Agency (JAXA)

SP-05-001E — *9th Spacecraft Charging Technology Conference*, T. Goka, compiler. April 4-8, 2005. Epochal Tsukuba, Tsukuba, Japan.

J.2.5 Other

QinetiQ/KI/SPACE/HB042617 D. J. Rodgers, *Spacecraft Plasma Interaction Guidelines and Handbook*, June 30, 2004. Produced for ESA/ESTEC by QinetiQ Itd, Farnborough, Hampshire, England.
Another good reference for persons wishing further background on the subject. Draft accessed at http://www.space.qinetiq.com/spigh/Technical%20note%201.pdf on April 14, 2011.

SD 71-770 *The Effects of Radiation on the Outer Planets Grand Tour*, November 1971 (also NASA-CR-127065, National Aeronautics and Space Administration).
Prepared for the Jet Propulsion Laboratory by Space Division, North American Rockwell. This old document is available on the NASA Technical Reports Server, http://ntrs.nasa.gov/search.jsp.