Appendix A
Nomenclature

A.1 Constants and Measurement Units

A	ampere (unit of current)
AU	astronomical unit (Earth to Sun distance, ~150,000,000 km)
C	coulomb
cm	centimeter
dB	decibel
deg	degree
e/cm^2	electrons per square centimeter
eV	electron volt
F	farad (measure of electrical capacitance)
ft	foot
GHz	gigahertz
h, hr	hour
Hz	hertz, unit of frequency (1 cycle per second)
in.	inch
J	joule (unit of energy)

K	kelvin
kÅ	kiloangstrom
kg	kilogram
keV	kiloelectron volt (10^3 eV)
km	kilometer
kΩ	kilohm (10^3 Ω)
kV	kilovolt (10^3 V)
m	meter, mass, milli
M	mega, million
mA	milliampere (10^{-3} A)
min	minute
mJ	millijoule (10^{-3} J)
MeV	million electron volt
mho	a unit of electrical conductance, the reciprocal of resistance in Ω, also known as the siemens (S)
MHz	megahertz (frequency, 10^6 Hz)
mil	one-thousandth of an inch = 0.001 in. = 0.0254 mm. Note: although mil is not an SI unit of measure, it is a standard unit of measure (unconverted to SI units) often used in this discipline to describe material thickness.
min	minute
mm	millimeter
mΩ	milliohm (10^{-3} Ω)
MΩ	megohm (10^6 Ω)
mV	millivolt
N/S	north/south
nA	nanoampere (10^{-9} A)
nC	nanocoulomb (10^{-9} C)
nF	nanofarad (10^{-9} F)
nm	nanometer (10^{-9} m)
ns	nanosecond (10^{-9} s)
nT	nanotesla (10^{-9} tesla), magnetic field unit
ohm (Ω)	unit of electrical resistance
pA	picoampere (10^{-12} A)
pF	picofarad (10^{-12} F)

q, Q	charge, coulombs
R	resistance (ohms, Ω)
R_e	radius compared to Earth (1 R_e ~ 6378.136 km)
R_j	radius compared to Jupiter (1 R_j ~7.1492 × 10^4 km)
R_S	radius compared to Saturn(1 R_S ~6.0268 × 10^4 km)
s/d	seconds per day (86400)
s/h	seconds per hour (3600)
sr	steradian
μC	microcoulomb (10^{-6} C)
μF	microfarad (10^{-6} F)
μJ	microjoule (10^{-6} J)
μm	micrometer (10^{-6} m)
μs	microsecond (10^{-6} s)
μW	microwatt (10^{-6} W)
V	volt, voltage
W	watt, West

A.2 Acronyms and Abbreviations

1-D	one dimensional
2-D	two dimensional
3-D	three dimensional
ACE	Advanced Composition Explorer
AC, ac	alternating current
ACR	anomalous cosmic ray
ADEOS-II	Advanced Earth Observing Satellite II; Japanese satellite (802.92 km, 98.62 deg, 101 min), Dec 2002-Oct 2003
AE8	NASA Space Radiation Model for Trapped Electrons
AF	Air Force

AFB	Air Force Base
AFGL	Air Force Geophysics Laboratory
AFRL	Air Force Research Laboratory
AIAA	American Institute of Aeronautics and Astronautics
ALT	altitude
AP8	NASA Space Radiation Model for Trapped Protons
ASTAR	web databases used to calculate stopping powers, ranges and related quantities, for electrons, protons and helium ions
ASTM	American Society for Testing Materials
ATS	Applications Technology Satellite (-5 and -6) geostationary satellites
CEASE	Compact Environmental Anomaly Sensor
CME	coronal mass ejection
CMOS	complementary metal-oxide-semiconductor
CNES	Centre National d'Etudes Spatiales, the French space agency
CPA	Charged Particle Analyzer
CPE	charged particle environment
CREME96	Cosmic Ray Effects on MicroElectronics 1996 (environmental code)
CRRES	Combined Release and Radiation Effects Satellite
CRRESELE	CRRES electron flux energy spectrum environmental code
CRRESPRO	CRRES proton flux energy spectrum environmental code
CRRESRAD	CRRES dose versus depth environmental code
CTS	Communications Technology Satellite
DC, dc	direct current (zero frequency)
DDD	displacement damage dose
DERA	Defense Evaluation and Research Agency
DESP	Space Environment Department (France)
DICTAT	DERA Internal Charging Threat Analysis Tool
div	division
DMSP	Defense Meteorological Satellite Program (800 km; 99 deg, 110 min)
DoD	Department of Defense
DS-1	Deep Space 1 (spacecraft)
DynaPAC	Dynamic Plasma Analysis Code
ECSS	European Cooperation on Space Standardization

e.g.	for example
EGS4	Monte Carlo transport code
EMC	electromagnetic compatibility
EMI	electromagnetic interference
EMP	electromagnetic pulse
ESA	European Space Agency
ESD	electrostatic discharge
ESTAR	web databases used to calculate stopping powers, ranges and related quantities, for electrons, protons and helium ions
etc.	And so forth
EURECA	European Retrievable Carrier
EVA	extravehicular activity
EUV	extreme ultraviolet
EWB	Environmental Work Bench
FEP	fluorinated ethylene propylene (Teflon® FEP)
FLUMIC	Flux Model for Internal Charging
FR4	flame retardant 4, common printed circuit board material
GaAs	gallium arsenide
Galileo	European plan for a GPS-like system of satellites; 23,222 km (14,429 mi) altitude, 56 deg inclination
Galileo	a NASA spacecraft sent to Jupiter, launched October 18, 1989, deliberately ended September 21, 2003
GCR	galactic cosmic ray
Geant4	a particle transport code, the European counterpart to MCNPX
GEO	geosynchronous Earth orbit (about 35,786 km, 22,236 mi, altitude, 24-hour period)
GEOSTA	geostationary
GHz	gigahertz (10^9 Hz)
Giove A, B	MEO precursor to European Galileo GPS satellite constellation. Launched Dec 28, 2005, and April 27, 2008, respectively
GIRE	Galileo Interim Radiation Electron Environment model
GOES	Geosynchronous Operational Environmental Satellite

GPS	Global Positioning Satellite (constellation, 20,100 km, 12, 490 mi, 55 deg, 718 min)
GRC	Glenn Research Center (formerly Lewis Research Center, LeRC)
GSE	Ground Support Equipment (or SE)
GSFC	Goddard Space Flight Center
GUI	graphical user interface
H^+	hydrogen ion
HBM	human body model
HDBK	handbook
HEO	highly elliptical orbit, used synonymously for Molniya
IC	integrated circuit
IDM	Internal Discharge Monitor (flown on CRRES)
i.e.	that is
IEEE	Institute of Electrical and Electronics Engineers
IESD	internal electrostatic discharge
INTELSAT	International Telecommunications Satellite Organization
IR	infrared
ISO	International Standards Organization
ISPICE	A computer transient circuit analysis program; first commercial version of SPICE
ISS	International Space Station (~390 km [~240 mi] altitude (varies), 51.6 deg, 92 min)
ISTP	International Solar-Terrestrial Physics
ITAR	International Traffic-in-Arms Regulations (restricted access to some information)
ITO	indium tin oxide
ITS	Integrated TIGER Series
I/V	current versus voltage
JAXA	Japanese Space Agency
JPL	Jet Propulsion Laboratory
LANL	Los Alamos National Laboratory
LAT	latitude
LED	light-emitting diode
LEM	lumped-element model

LEO	low-Earth orbit (about 200–2,000 km altitude, 124-1240 miles; e.g., 657 km, 1.5-hour period)
LET	linear energy transfer
LeRC	Lewis Research Center (now Glenn Research Center, GRC)
LNA	low-noise amplifier
MCNP	Monte Carlo N-Particle transport code
MCNPE	A version of MCNP modified to include transport of electrons
MCNPX	Monte Carlo N-Particle eXtended transport code
MEO	medium Earth orbit (about 2,000–25,000 km altitude, 1240–15,500 miles, ~6 hour period)
MIL	military
MLI	multilayer insulation (thermal blanket)
Molniya	an elliptical orbit (apogee ~39,300 km, perigee 538 km, 11.8-hour period, ~63.2 deg inclination)
MPA	magnetospheric plasma analyzer
MSFC	Marshall Space Flight Center
MUSCAT	Multi Utility Spacecraft Charging Analysis Tool
N/S	north/south
NASA	National Aeronautics and Space Administration
NASCAP	NASA Charging Analyzer Program, historic and generic
NASCAP/GEO	NASA Spacecraft Charging Analyzer Program for Geosynchronous Orbit (replaced by Nascap-2k)
NASCAP/LEO	NASA Spacecraft Charging Analyzer Program for Low Earth Orbit
Nascap-2k	latest version of NASCAP (as of 2011)
NGST	Northrop-Grumman Space Technology
NOAA	National Oceanic and Atmospheric Administration
NOVICE	a charged-particle radiation transport code
NSSDC	National Space Science Data Center
NUMIT	numerical model for estimating charging in dielectrics
ONERA	Office National d'Etudes et Recherches Aérospatiales, the French national aerospace research center
OSR	optical solar reflector
p	proton

PEO	polar Earth orbit (~80 deg or higher inclination, 700–1000 km altitude, 435–620 miles, ~100 min period)
PET	Proton/Electron Telescope
photo	photon–emitted particles, e.g., photoelectrons
PIC	particle in cell
PIX, PIX-II	Plasma Interactions Experiment
POES	Polar Operational Environmental Satellite (~80 deg or higher inclination 700–1000 km altitude, 435-620 miles)
POLAR	Potential of Large Objects in the Auroral Region (a NASCAP model)
PSTAR	web databases used to calculate stopping powers, ranges and related quantities, for electrons, protons and helium ions
PTFE	polytetrafluoroethylene (Teflon®)
QA	quality assurance
RC	resistor-capacitor
RF	radio frequency
RIC	radiation-induced conductivity
RP	reference publication
RSICC	Radiation Shielding Information Computational Center
RTV	room-temperature vulcanized (adhesive)
SAIC	Science Applications International Corporation
SAMPEX	Solar, Anomalous, and Magnetospheric Particle Explorer
SAMPIE	Solar Array Module Plasma Interactions Experiment
SATRAD	Saturn Radiation model
SCATHA	Spacecraft Charging at High Altitudes Satellite (1979–1986, 28,000 × 42,000 km [17,400–26,100 miles], 8.3-deg inclination)
SCR	silicon-controlled rectifier
SCTC	Space Communications Technology Center
SE	support equipment (nonflight hardware) (or GSE)
Sec	secondary emission
SEE	single-event effect
SEE	(NASA) Space Environment Effects Program
SEMCAP	Specification and Electromagnetic Compatibility Program

SEP	solar energetic particle (or proton) event
SEU	single-event upset
SHIELDOSE	charged-particle radiation transport code
Si	silicon
SI	Système Internationale or metric system of measurement
SOHO	Solar and Heliospheric Observatory
SOPA	Synchronous Orbit Particle Analyzer (Los Alamos)
SPE	solar proton event
SPENVIS	Space Environment Information System
SPICE	Simulation Program for Integrated Circuit Emphasis, a computer transient circuit analysis program
SPINE	Spacecraft Plasma Interactive Network
SPIS	Spacecraft Plasma Interactive System
sqrt	square root
SSO	semi-synchronous orbit, ~20,000 km (12,400 miles), 12 hour period
STD	standard
TID	total ionizing dose
TP	technical publication
TRACE	Transition Region and Coronal Explorer
TRIM	radiation transport code
TRW	TRW Incorporated (now Northrop Grumman)
TSS-1R	Tethered Satellite System—first re-flight
UCSD	University of California at San Diego
USA	United States of America
USAF	United States Air Force
UV	ultraviolet
VDA	vacuum deposited aluminum
WDC	World Data Center (NOAA)
ZOT	zinc orthotitanate paint

A.3 Defined Terms

Ap index	Daily world-wide geomagnetic activity index

Auroral Zone	Geomagnetic latitudes between ~60–70 deg north/south (N/S), where auroras are present.
Blow-off	The effect of an ESD when material and charge are expelled by an ESD.
Bonding	As used for ESD and electromagnetic compatibility (EMC), attaching something electrically to spacecraft chassis or electrically attaching conductive chassis parts to each other, as distinct from a deliberate current-carrying path; sometimes also called grounding, but generally there is not a problem in context.
Buried Charging	Refers to charging internal to a spacecraft, often meaning within dielectrics, but possibly in ungrounded (floating) metals. The authors prefer the term internal charging.
Conductor	For the purpose of this spacecraft charging document, a conductor is a material that is used for carrying current or is similarly conductive and acting as part of a shield or ground plane structure. Copper and aluminum are typical conductors. See Insulator, Dielectric, and ESD/static-Conductive.
Debye Length:	Characteristic distance (λ_D) in a plasma over which a plasma screens out (e.g., reduces) the electric field by 1/e.
Deep Dielectric Charging	Charging internal to dielectrics caused by energetic electrons. (See the term Buried Charging.) The authors prefer the term internal charging, unless specifically referring to dielectrics.
Dielectric	For the purpose of spacecraft charging, a dielectric is a resistive material that may be synonymous with Insulator. This document suggests dielectrics have a bulk resistivity of $>10^{10}$ Ω-cm or a surface resistivity of $>10^{9}$ Ω/square. See Insulator, Conductor, and ESD/static-Conductive.

ESD/static-conductive	For the purpose of spacecraft charging, an ESD/static-conductive material is one that is adequately conductive to conduct any space plasma charges to ground so that the charging effects have minimal or no impact on spacecraft operations. These are partially resistive materials that are neither conductors nor insulators. There is not an official definition in this document, but an approximate range of resistivity for ESD/static conductive materials is less than 10^8 Ω/square for thin materials and 10^7 Ω-cm for bulk materials. And it must be properly grounded to be useful for mitigation of spacecraft charging. See Dielectric, Conductor, and Isolation.
Faraday Cage	A completely enclosed metallic container; an electromagnetically shielded enclosure.
Floating	A conductor is floating if it is ungrounded or has no defined reference to chassis. (See the term Referenced.)
Geostationary	A geosynchronous orbit directly above the Earth's Equator (0 deg latitude), with a period equal to the Earth's rotational period and an orbital eccentricity of approximately zero. An object in a geostationary orbit appears motionless, at a fixed position in the sky, to ground observers.
Geosynchronous	A circular orbit in the equatorial plane of Earth at stationary Orbit, ~35,768 km (22,225 miles) altitude that matches the Earth's sidereal rotation period. The synchronization of rotation and orbital period means that for an observer on the surface of the Earth, the satellite appears to constantly hover over the same meridian (north-south line) on the surface, moving in a slow oscillation alternately north and south with a period of one day, so it returns to exactly the same place in the sky at exactly the same time each day.
Ground	A connection to a zero-volt reference point (ground), often the chassis. Note: Bonding is used

almost exclusively as a connection to chassis for other purposes such as space charge bleed-off, shield terminations, or fault current paths. Structure is used as ground for both bonding and circuit zero volt referencing, so the term structure ground is often used interchangeably with the term signal ground. For this reason, be careful when using the word "ground."

Insulator — For the purpose of spacecraft charging, an insulator is a highly resistive material that does not have adequate conductivity to discharge charge accumulation coming from the environment. There is not an official definition in this document, but an approximate range of resistivity for insulators is greater than 10^9 Ω/square for thin materials and 10^8 Ω-cm for bulk materials. See Dielectric, Conductor, and ESD/static-conductive.

Internal Charging — The buildup of charge on the interior parts of a spacecraft from higher energy particles.

L1–L5 — Lagrange/Libration Points. (Astronomical.) For a third body, locations of orbital positions requiring minimum energy maintenance with respect to two other (larger) bodies.

Molniya — An elliptical orbit with an apogee of ~39,300 km, perigee of 538 km [~24,400 and 334 mi, respectively], an 11.8-hour period, and a ~63.2 deg inclination. Molniya orbits are named after a series of Soviet/Russian *Molniya* (Russian for: Lightning) communications satellites which have used this type of orbit since the mid-1960s.

ohm per square — A measure of surface resistivity. The resistance of a flat relatively thin sheet of the material, measured from one edge of a square section to the opposite edge. Properly, units are in ohms.

Referenced — Not ungrounded, meaning that there is a defined path to ground, even if the referenced item is not at ground. For example, the +28-V power line is not

	grounded, but it is referenced to ground, and thus it is not floating. It cannot accumulate stray charges.
Spacecraft Charging	The buildup of charge in and on spacecraft materials; a significant phenomenon for spacecraft in certain Earth and other planetary environments.
Triple Junction Point	In this document, refers to a place in solar arrays where a dielectric, a conductor, and space all meet at one point. Intense electric fields may exist and cause ESDs at solar array triple junction points.
Victim	Any part, component, subsystem, or element of a spacecraft that can be adversely affected by an arc discharge (or field effects, in the case of some science instruments).

A.4 Variables

(typical units unless specified otherwise)

BS	backscattered
C	capacitance
CPH	photoelectron current
dE/E	Energy channel width (dE) expressed as fraction of nominal median energy (E) for channel
E	electric (fields), energy, East
H field	Magnetic field (common usage)
i	differential angular intensity (or flux); (example: ions/(cm^2-s-sr-keV))
I	integral angular intensity (or flux); (example: electrons/(cm^2-s-sr))

I	current (A)
I_{pk}	peak current (A)
j	omnidirectional differential flux; (example: electrons/(cm^2-s-MeV))
J	omnidirectional integral flux; (example: electrons/(cm^2-s))
J	current per unit area (A/cm^2)
N_E	electron number density
N_I	ion number density
R	resistance (Ω)
RE	density of electron plasma environment
RI	density of ion plasma environment
T	temperature
TE	temperature for electron plasma environment
TI	temperature for ion plasma environment
TP	Technical Publication
TR	discharge current risetime
v	velocity
Vb	voltage breakdown; breakdown voltage
Vc	co-rotation velocity of specified region
Vsw	solar wind bulk velocity
Vth	solar wind thermal velocity
yr	year

A.5 Symbols

~	approximately
°	Degree (deg is preferred)
>	greater than
<	less than
±	plus or minus
d	day
e	electron (charge = 1.6022×10^{-19} coulomb)
ε	total permittivity $\varepsilon = \varepsilon_0 \times \varepsilon_r$, dielectric constant
ε_0	free space permittivity (= 8.85×10^{-12} F/m)
ε_r	relative permittivity
g	gram
H	magnetic field (or B in free space)
l	length
μ	mu, or micro, representing a factor of 10^{-6}
ρ	rho (volume resistivity) (ohm-m or ohm-cm, Ω-m or Ω-cm)
ρ_s	rho-sub s (surface resistivity) (SI unit: ohm; more commonly, "ohms per square")
s	second
S	siemens (reciprocal of resistance, also mho) (1/R)
σ	sigma (conductivity; units: $(\text{ohms-cm})^{-1}$)
t	time, thickness
Ω	resistance (in ohms)