Spacecraft Charging Interactions

Dr. Henry B. Garrett
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109
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Plasma Environment—Surface Charging

[Diagram showing plasma motions and the region of spacecraft charging.]

MARECS-A MISSION
GEOSYNCHRONOUS ORBIT 36,800 Km
281 IN-FLIGHT ANOMALIES REPORTED
85% DUE TO ESD
NUMBER OF ELECTROSTATIC DISCHARGE EVENTS VERSUS TIME (GMT)

LOW ENERGY PROTONS AND ELECTRONS
+++ HIGH ENERGY PROTONS
------ HIGH ENERGY ELECTRONS
........ MEDIUM ENERGY PROTONS

DAWN
8RE
4RE
TO SUN
DUSK
MAGNETOPAUSE
Spacecraft Charging Interactions

**ATS-6 Spectrogram of Geosynchronous Charging**

- **Plasma Injection**
- **Solar Eclipse at S/C**
- **Photoelectrons**

*Graph showing electron and ion energy over time.*
Theory of Spacecraft Charging: A Simple Picture …
Spacecraft Charging Interactions

**Theory of Spacecraft Charging: A Simple Example**

**FOR A NEGATIVELY CHARGED SPACECRAFT:**

\[ J_T(V) = J_{lo} \left( 1 - \frac{qV}{KT_I} \right) - J_{eo} \left( e^{qV/KT_e} \right) \]

**TYPICALLY AT GEOSYNCHRONOUS ORBIT:**

\[ \frac{qV}{KT_I} \sim 0 \]

**FOR CURRENT BALANCE:**

\[ J_T(V) = 0 \]

**THIS IMPLIES:**

\[ V = \frac{-KT_e}{q} \ln \left( \frac{J_{eo}}{J_{lo}} \right) \]
Electron Current versus Spacecraft Potential

30-95 KeV ELECTRON DATA

ATS-6 SPECTROGRAM

Day 264, 1976

ATS-6 POTENTIAL

ECLIPSE

LOG(J)

CPA

ATS-6

DENSITY

TEMP (KEV)

TIME (UT)
NASCAP Spacecraft Charging Code: Differential Potentials
Differential Potentials on SCATHA as Predicted by NASACP
DMSP Low Altitude Spacecraft Charging

AURORAL ARC

Spacecraft Track

AURORAL ARC
Auroral Effects on JPL Ops, Oct. 24, 2003

Lessons Learned: Geophysical Indices Critical to Rapid Anomaly Resolution for JPL Missions

Space Weather: Spectrogram

HOURS IN DAY 337 OF 1970
Electron and Proton Geo Plasma Distribution Functions

(A) ELECTRON DISTRIBUTION

- DISTRIBUTION FUNCTION
- MAXWELLIAN FIT
- 2 MAXWELLIAN FIT

ELECTRONS
9 / 30 / 69
1118 UT

(B) PROTON DISTRIBUTION

- DISTRIBUTION FUNCTION
- MAXWELLIAN FIT
- 2 MAXWELLIAN FIT

IONS
9 / 30 / 69
1118 UT
Two Maxwellian Approach to Charging Environment

**TWO MAXWELLIAN DISTRIBUTION FUNCTION**

\[ F_2(v) = \left( \frac{m}{2\pi} \right)^{3/2} \frac{n_1}{(KT_1)^{3/2}} e^{\frac{-mv^2}{2KT_1}} + \frac{n_2}{(KT_2)^{3/2}} e^{\frac{-mv^2}{2KT_2}} \]

**TWO MAXWELLIAN PLASMA MOMENTS**

- **NUMBER DENSITY:**
  \[ M_1 = n_1 + n_2 \]

- **NUMBER FLUX:**
  \[ M_2 = \frac{n_1}{2\pi} \left( \frac{2KT_1}{\pi m} \right)^{1/2} + \frac{n_2}{2\pi} \left( \frac{2KT_2}{\pi m} \right)^{1/2} \]

- **ENERGY DENSITY:**
  \[ M_3 = \frac{3}{2} n_1 KT_1 + \frac{3}{2} n_2 KT_2 \]

- **ENERGY FLUX:**
  \[ M_4 = \frac{n_1 m}{2\pi} \left( \frac{2KT_1}{\pi m} \right)^{3/2} + \frac{n_2 m}{2\pi} \left( \frac{2KT_2}{\pi m} \right)^{3/2} \]

**GEOSYNCHRONOUS PLASMA MODEL**

\[ M_i(A_p, LT) = (a + bA_p) \{ c + d \cos[2\pi(LT - e)/24] + f \cos[4\pi(LT - g)/24] \} \]
Geosynchronous 2 Maxwellian Statistics

STATISTICAL DISTRIBUTIONS OF KEY GEOSYNCHRONOUS PARAMETERS

LOCAL TIME/Kp VARIATIONS FOR KEY GEOSYNCHRONOUS PLASMA PARAMETERS
Spacecraft Charging Interactions

Modeled (Kp, LT) vs Observed Geo Plasma Parameters
**Summary:**

- **Surface Charging** comes in 2 forms:
  - “Absolute” or “Spacecraft to Plasma Ground”
  - “Differential Charging” between surfaces

- Absolute Charging (10-30 KV) roughly proportional to the ambient electron current once a threshold temperature (~2-3 KV) is exceeded → Need Te and Je estimates

- Differential Charging is very spacecraft configuration dependent (spinner vs 3-axis, shadowed surfaces, surface properties, etc.)

- Absolute Charging can have little effect but indicative of possible high levels of Differential Charging

- Differential Charging source of arc discharges (ΔV<100 V?)

- Space Weather Forecasting useful for Absolute Charging but need spacecraft modeling (NASCAP-2K) for Differential Charging
Worst Case Surface Potentials for Earth Environment in the Absence of Sunlight (Evans et al., 1989)
Recommended Guide to Spacecraft Charging

Title: Guide to Mitigating Spacecraft Charging Effects

Authors: Henry B. Garrett and Albert C. Whittlesey

Publisher: Wiley, 2012
BACKUP VIEWGRAPHS
“Analog” Model of Geo Orbit Environment

**Electron Time Variations**
- **Density (n#/cm³)**
  - Line with scale factor x10
  - Line with scale factor x10
- **Pressure (dynes/cm² x 10⁶)**
  - Line with scale factor x10
- **Energy Flux (erg/cm² sec ster)**
  - Line with scale factor x10
  - Line with scale factor x10
- **Number Flux (n#/cm² sec ster x 10⁶)**
  - Line with scale factor x5
  - Line with scale factor x5
- **Average Energy (eV)**
  - Values range from 1500 to 3000

**Ion Time Variations**
- **Density (n#/cm³)**
  - Line with scale factor x4
  - Line with scale factor x4
- **Pressure (dynes/cm² x 10⁹)**
  - Line with scale factor x2
  - Line with scale factor x2
- **Energy Flux (erg/cm² sec ster)**
  - Line with scale factor x2
  - Line with scale factor x2
- **Number Flux (n#/cm² sec ster x 10⁻⁷)**
  - Line with scale factor x4
  - Line with scale factor x4
- **Average Energy (eV)**
  - Values range from 5000 to 10000

**Local Time**
- Values range from 0 to 24