Extremne Spacecraft Charging in Polar Low Earth Orbit

Introduction

Spacecraft in low altitude, high inclination (including sun-synchronous) orbits are widely used for remote sensing of the Earth’s land surface and oceans, monitoring weather and climate, communications, scientific studies of the upper atmosphere and ionosphere, and a variety of other scientific, commercial, and military applications. These systems episodically charge to frame potentials in the kilovolt range when exposed to space weather environments characterized by a high flux of energetic (∼10’s kilovolt) electrons in regions of low background plasma density. Auroral charging conditions are similar in some ways to the space weather conditions in geostationary orbit responsible for spacecraft charging to kilovolt levels. We first review the physics of space environment interactions with spacecraft materials that control auroral charging rates and the anticipated maximum potentials that should be observed on spacecraft surfaces during disturbed space weather conditions. We then describe how the theoretical values compare to the observational history of extreme charging in auroral environments. Finally, a set of extreme DMSP charging events are described varying in maximum negative frame potential from ~0.6 kV to ~3 kV, focusing on the characteristics of the charging events that are of importance both to the space system designer and to spacecraft operators. The goal of the presentation is to bridge the gap between scientific studies of auroral charging and the need for engineering teams to understand how space weather impacts both spacecraft design and operations for vehicles on orbital trajectories that traverse auroral charging environments.

Surface Charging Physics

Surface charging is the result of a current balance on the surface of a spacecraft. Charging is described by the time dependent current balance relation

\[ \frac{dQ}{dt} = I = \sum_i q_i \frac{dV}{dt} = 0 \] (at equilibrium)

where \( Q \) is the total charge and \( q_i \) the surface charge accumulating on the surface area \( A \), \( C \) is the capacitance of the area \( A \), and \( V \) the voltage of the surface. The currents as a function of surface potential \( V \) of importance to surface charging are

\[ I = \sum \left( -I_1(V) \text{ incident electrons} \right. \left. -I_{2c}(V) \text{ backscattered electrons} \right. \left. -I_{2b}(V) \text{ conduction currents} \right. \left. +I_{2s}(V) \text{ secondary electrons due to } I_1 \right. \left. +I_{2s}(V) \text{ secondary electrons due to } I_2 \right. \left. +I_{10}(V) \text{ photons} \right. \left. +I_{\text{act}}(V) \text{ active current sources, beams, thrusters} \right) \]

Identification of Auroral Charging

`~300 Volts`

Auroral charging is readily identified from the “ion line” signature that appears in ion electrostatic analyzer records. Here, the ion line in the DMSP F9 satellite SSJ/4 instrument ion record is the result of ambient low energy ions accelerated by the spacecraft potential from an initial energy \( E_i \), to a final energy \( E = E_i \log_{10} V \) where \( V \) is the charge of the ion and \( \phi \) the spacecraft surface potential in volts.

Charging Simulations

(a) 1 m x 1 m x 2 m in darkness solar cells on aluminum

(b) 3m x 2m x 2m in darkness solar cells on Kapton

Nasca-2k surface charging simulations using a realistic harsh auroral charging environment derived from the DMSP F13 satellite for input to the charging code. The simulations show that spacecraft regardless of size are susceptible to auroral charging when their orbits encounter auroral charging environments.

Frequency and Distribution of Auroral Charging

(a) DMSP Charging Frequency

(b) Distribution of DMSP and Freja Charging Events

A wealth of information on solar cycle variations and local time distributions of auroral charging events have been obtained from the DMSP and Freja spacecraft [Frooninckx and Sojka, 1992; Anderson, 2000, 2001; Wahlund et al, 1999; Erickson and Wahlund, 2005]. These studies show that auroral charging is most common during solar minimum and most commonly encountered in the midnight sector of the auroral oval.

Charging Analysis Tool

Quantitative information for the charging events is obtained using a software package that processes SSJ records and allows users to extract time series of frame potential and charging rates along with maximum potential and the number of time intervals the potential exceeds a threshold value. The information is written to an external file for later analysis.
Future work is planned to extend the study to a wider range of charging events to more fully characterize the auroral charging environment.

### Discussion and Summary

The examples shown here are the result of an initial effort to characterize extreme auroral charging events. These events are encountered infrequently or exceed the three worst

<table>
<thead>
<tr>
<th>Event</th>
<th>Date</th>
<th>Duration</th>
<th>Max Volts</th>
<th>Event Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>25 June 2011</td>
<td>300 sec</td>
<td>2 kV</td>
<td>High potential reached in 300 sec</td>
</tr>
<tr>
<td>2</td>
<td>13 June 2010</td>
<td>200 sec</td>
<td>3 kV</td>
<td>Rise time of spacecraft potential is rapid</td>
</tr>
<tr>
<td>3</td>
<td>16 June 2011</td>
<td>100 sec</td>
<td>4 kV</td>
<td>Peak potential reached in 100 sec</td>
</tr>
<tr>
<td>4</td>
<td>20 June 2010</td>
<td>150 sec</td>
<td>3 kV</td>
<td>Peak potential reached in 150 sec</td>
</tr>
</tbody>
</table>

### Acknowledgements

DMSF SU/4 and SS/5 electrostatic analyzer records were obtained from the NOAA National Geophysical Data Center (NGDC). Operational Limit Scan images are from the NOAA Space Physics Interactive Data Resource (SPIDR) application. Magnetic kp indices were obtained from NOAA NGDC. USRP file: DMSP CE f16_2010_949.txt; DMSP CE f16_2011_1392.txt; DMSP CE f16_2012_06_3010_293713.txt; DMSP CE f16_2011_04_08_0646_2_646.txt; DMSP CE f16_2010_06_3010_2064_0646.txt; DMSP CE f16_2010_06_3010_2252_1392.txt.


Frooninckx, T.B., and J.J. Sojka, Solar cycle dependence of spacecraft charging, JGR, 100, 5229, 1995.


### References

Frooninckx, T.B., and J.J. Sojka, Solar cycle dependence of spacecraft charging, JGR, 100, 5229, 1995.

