Extreme Spacecraft Charging in Polar Low Earth Orbit

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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 (>10^6 electrons or ions) 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 spacecraft 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 spacecraft 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 an electrostatic balance on the surface of the spacecraft. Charging is described by the time-dependent current balance relation:
\[ \frac{dA}{dt} = \sigma \left( \Phi - \Phi_0 \right) + Q(t) + \sum I_i(t) \]
where \( Q \) is the total charge and \( \Phi \) the surface charge accumulating on the surface area \( A \), \( C \) is the capacitance of the area \( A \), and \( \Phi_0 \) the voltage of the surface. The currents as a function of surface potential \( \Phi \) of importance to surface charging are:
\[ I_i(t) = \begin{cases} +1(V) & \text{incident ions} \\ -1(V) & \text{incident electrons} \\ +2(V) & \text{backscattered electrons} \\ +1(V) & \text{conduction currents} \\ -1(V) & \text{secondary electrons due to I} \\ -1(V) & \text{secondary electrons due to I} \\ +1(V) & \text{photoelectrons} \\ +1(V) & \text{active current sources (beams, thrusters)} \end{cases} \]

Identification of Auroral Charging
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 SU4 instrument ion record is the result of ambient low energy ions accelerated by the spacecraft potential from an initial energy \( E_0 \approx 0 \) eV to a final energy \( E \approx 10 \) keV where \( q \) is the charge of the ion and \( \Phi \) the spacecraft surface potential in volts.

Charging Analysis Tool
Quantitative information for the charging events is obtained using a software package that processes SU4 records and allows users to extract time series of frame potential and charging rate 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.

Example of Charging Event
[Auroral Charging Event, Anderson, 2012]
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 by spacecraft in polar low Earth orbit but are the kind of event that drive spacecraft design. We have focused on the extreme potentials, duration of charging events to more fully characterize the auroral charging environment.

Future work is planned to extend the study to a wider range of charging events to more fully characterize the auroral charging environment.

Acknowledgements

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References