INITIAL CORRELATION RESULTS OF CHARGE SENSOR DATA FROM SIX INTELSAT VIII CLASS SATELLITES WITH OTHER SPACE AND GROUND BASED MEASUREMENTS

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Abstract. Six satellites operated by INTELSAT in geosynchronous orbit are equipped with electrostatic charge sensors that monitor surface-charging characteristics continuously on board each spacecraft. As part of the feasibility work undertaken to relate these sensor outputs to the prediction of damaging events, including ESDs on board each spacecraft, the telemetry data from all sensors were compiled, categorized and compared with the environmental data obtained from the LANL particle sensors in GEO. The results of these comparisons show good correlation between the high charge events recorded by INTELSAT VIII/VIIIA surface charge sensors and the LANL plasma analyzers. Comparisons with ground based magnetometer data and Kp indices also show good correlation. Results of these comparisons including those during high solar activity periods and the corresponding statistical and cross-correlation analyses are described in this paper. Design, implementation and operational characteristics of the onboard sensors are also summarized. The possibility of using the data from these sensors in conjunction with the data obtained from other sources for hazard warnings during magnetic storms and other space events is discussed.

1. Introduction

Six satellites operated by INTELSAT in geosynchronous orbit are equipped with charge sensors called Charge Plate Assemblies (CPA). They monitor surface charging levels continuously onboard each spacecraft. The circuit is described by Bogorad et al. [1995]. Four of the spacecraft, designated I801, I802, I803, I804, and I805 in this paper, are owned by INTELSAT. The other two, designated I803 and I806, are owned by New Skies Satellites N.V.

As part of a feasibility study undertaken to determine if these sensor can be used for the prediction and diagnosis of damaging events including electrostatic discharges on board each spacecraft, the telemetry data from all of the sensors were compared with the data obtained from a number of public sources. The data included geomagnetic indices, ground-based magnetometer data, and plasma data from nearby spacecraft. The latter included the electron temperature and the spacecraft frame potentials measured by Magnetospheric Plasma Analyzers (MPA) provided by Los Alamos National Laboratory [Bame et al., 1993].

There are two CPA sensors on each of the I801 through I806 vehicles: the –z (minus z) sensor faces anti-Earthward, and the y sensor faces south (except on the I805 and I806 vehicles where it faces north). We have limited our analysis to the –z sensors because the y sensors exhibited some anomalous behavior. The –z sensors were found to provide reliable results when they were in darkness from approximately 1800 to 0600 local satellite time. Both 1-minute and 20-second resolution data were used for the study.

2. Sources of Data

- The data from the CPA instruments on the I801, I802, I803, I804, I805 and I806 spacecraft were received directly from INTELSAT, 3400 International Drive, NW, Washington, DC 20008.
- Planetary magnetic indices, Kp, were obtained from the Space Environment Center, Boulder, CO, National Oceanic and Atmospheric Administration (NOAA), US Dept. of Commerce.
- The data from the Magnetospheric Plasma Analyzers (MPA) on satellites 1989-046, 1990-095, 1991-080, 1994-084, and LANL-97A (L97A) were obtained from the CDAWeb (Coordinated Data Analysis Web) and from the Los Alamos Energetic Particle Data website. The CDAWeb site (http://cdaweb.gsfc.nasa.gov/cdaweb/istp_public) is a U.S. Government Public Information Exchange Resource operated by the Space Physics Data Facility at NASA's Goddard Space Flight Center. This web site provides public data from current space physics missions. The Los Alamos site (http://nis-www.lanl.gov/nis-projects/mpa/) provides public MPA data.
- The ground-based magnetometer data from Narssarsuaq, Greenland were obtained from the Space Physics Interactive Data Resource (SPIDR) of the National Oceanographic and Atmospheric Administration/National Geophysical Data Center. This web site (http://spidr.ngdc.noaa.gov) provides public data from current space and geophysics investigations.
3. Charge Plate Assembly On-Orbit Data Analysis

3.1. Disturbed Geomagnetic Conditions

The CPAs charge to significant negative voltages during active geomagnetic intervals. For example, Figure 1 shows the zenith pointing (−z) CPA response on five of the vehicles during November 1998. The CPA traces are offset from one another by factors of 1000 V for clarity and are shown in order of decreasing east longitude. The bottom panel shows the Kp index. The most active days (6 to 9 and 13 to 14 November) corresponded to the largest negative-going signals on each vehicle, as expected from the known dependence of spacecraft surface charging on geomagnetic activity [H. C. Koons and D. J. Gorney, 1991].

Note that the amplitudes of the signals varied from vehicle to vehicle consistently throughout the month-long interval. I802 showed the largest negative-going signals, and I801 the smallest.

3.2. Local Time Dependence

We surveyed the local time dependence of the CPA signals during disturbed times (Kp = 6 to 9) using the 1-minute resolution measurements from I804 from November 1997 to May 2000. The −z CPA data shown in Figure 2 had a consistent baseline on the dayside near −50 V. It had only a couple of signals below −100 V between ~0800 and 1700 local satellite time. Local time organized the response of each vehicle under all geomagnetic conditions, with most of the largest signals occurring on the nightside between midnight and dawn.

The −z CPAs have significant negative voltages only when they are in shadow (that is, when the spacecraft is at local times between ~1800 and 0600).

November 1997 to May 2000 major to severe storms (Kp = 6 to 9)

Figure 2. Zenith facing CPA on I804 versus local time during major to severe magnetic storms.

3.3. Quiet Geomagnetic Intervals

During quiet geomagnetic intervals (Kp = 0, 1, or 2) CPA signals below a few hundred volts negative occur on the nightside only a few percent of the time. Figure 3 shows data from March 1999. This is an example of a quiet time period when a CPA measured a significant negative voltage. Both days were geomagnetically quiet, yet near local midnight on the 20th the CPA measured −250 V for ~1 hour. The nearby L97A vehicle with an MPA instrument onboard also charged negative near local midnight. Contrast this event with the passage through local midnight on the next day, where neither spacecraft measured any charging. The coincident measurements of charging on the nearby vehicle demonstrate that the charging measured by the CPAs

Figure 3. Coincident charging of I804 and L97A on 20 March 1999.
only the nightside of the orbit and parameterize the data signals on I804 from May 1999 to May 2000. We show conditions. Figure 5 plots the distribution of CPA seeing a more negative CPA voltage increased. This different responses are most likely caused by differing negative than -300 V occurring 5% of the time. The distributions measured amplitudes below -300 V. This never happened with the I801 vehicle, and happened less than 1% of the time on I803 through I806. The I802 CPA showed the highest gain with signals more negative than -300 V occurring 5% of the time. The different responses are most likely caused by differing calibrations for the instruments.

3.4. Kp Dependence

We find that as Kp increased, the probability of seeing a more negative CPA voltage increased. This indicates that a more severe surface-charging environment existed during periods with more disturbed conditions. Figure 5 plots the distribution of CPA signals on I804 from May 1999 to May 2000. We show only the nightside of the orbit and parameterize the data by the geomagnetic conditions. The histograms were scaled by factors of 10 for clarity. The distributions all show a peak between 0 and -100 V regardless of the state of the environment. A second maximum moves to more negative voltages as geomagnetic activity increases.

The Kp index has been used to select the extremes in the environment (quiet versus severe storms) in order to quantify the range of the CPA responses on a single vehicle. Figure 6 shows that the likelihood of a signal more negative than -400 V on I804 varied by a factor of 5000, from 0.001% in quiet times to 5% in severe storms. In both cases, roughly half of the time the CPA remained near its baseline between -100 V and 0 V. Given any 3-hour interval with a high Kp, we find only a 30% probability that there was a significant (more than 100 V negative) charging response at the spacecraft. This points out the importance of having charging sensors on the spacecraft, rather than relying on Kp to identify charging periods.

Figure 4. Cumulative percent occurrences for all six -z CPAs during quiet times.

Figure 5. Distribution of CPA voltages binned according to geomagnetic conditions for the nightside portions of the orbit.

Figure 6. Cumulative percent occurrences for I804 during quiet days and severe storms.

Figure 7. Satellite constellations at 0 UT in November 1998; (red) CPAs, (blue) MPAs.
3.5. Correlation of CPA Response with the Plasma

We compared the CPA measurements on I804 with a known indicator of surface charging on a nearby spacecraft — the MPA on L97A. This spacecraft was chosen for the comparison because it is within 1 hour of local time of I804. Figure 7 shows the constellations of the geostationary satellites with the CPA and the MPA instrumentation onboard. The other choice for a comparison is between 1990-095 and I801 and/or I806. However, we chose the I804/L97A pair because the MPA plasma measurement coverage for the 1990-095 vehicle was usually less than 100%, and was often only an hour or so per day in late 1998.

The MPAs measure ion and electron densities and temperatures, including the electron energy range responsible for surface charging (~30 eV to 40 keV). The ion measurements from an MPA also provide a measurement of the vehicle’s frame potential relative to the ambient plasma.

In Fig. 8 we compare the I804 CPA voltage with the measurement of the L97A vehicle’s frame potential derived from the MPA ion spectrograms. The figure shows an electron injection observed at both vehicles on 1 November 1998; the dashed line roughly indicates the onset of the injection. Both spacecraft charged negative, with voltage profiles that closely reflected the electron temperature profile (red trace at bottom).

Figure 9 shows a more complicated interval on 18 November 1998. In this case, there were at least three...
distinct electron injections. The voltage profiles from both vehicles again followed the electron temperature.

We can quantify the striking correlation in the previous figures between the electron temperature and the CPA voltage profiles. Figure 10 compares the CPA voltage with the perpendicular electron temperature divided by \(-17\); this was the result of a fit by eye, and may later be improved with a fit to more of the data. Even so, this simple scaling shows that the \(-z\) CPA responds to the local electron temperature, and the resulting spacecraft potential closely follows the frame potential on a nearby vehicle.

3.6. Correlation with Ground-Based Magnetometers

As substorm-injected electrons drift eastward, the electrons that precipitate into the atmosphere create currents in the ionosphere. Ground-based magnetometers measure the magnetic fields associated with these currents. The bottom panel of Figure 11 shows an abrupt charging event at I803 that occurred on April 6, 2000 near 0330 UT (the time identified by the dashed line in the figure). The geomagnetic field line through I803 intersects the ground near 320° East Longitude, 63° North Latitude. This magnetic footpoint is within a few degrees of the magnetometer station at Narssarssuaq, Greenland at 314° East Longitude, 61° North Latitude. The magnetometer data (top panel of Fig. 11) shows the abrupt onset of a perturbation from ionospheric currents at essentially the same time as the I803 event.

3.7. Correlation of CPA Signals on Neighboring Vehicles

A charging environment can change significantly with time as the constellation moves through it. Figure 12 compares the onsets of the event on 7 April 2000 as measured at four spacecraft. Note the similar periodic change in potential at I803, I801, and I806. Even though these CPA measurements are not intercalibrated, the figure suggests that the charging environment almost disappeared in the ~20 minutes it took the I805 spacecraft to rotate into the same local time range.

3.8. Time Constants Measured From On-Orbit Data

The CPA voltage profiles depend on the electron temperature, and the time scales for the rise and decay of the CPA measurements appear to reflect the time constants of the environment. Figure 13 shows an electron injection on 1 November 1998 measured with the MPA instrumentation on vehicle L97A at 86 second resolution and the I804 CPA response. This was a single injection that occurred between midnight and

Figure 11. Greenland magnetometer response to a substorm injection in coincidence with a charging event on I803 at ~0300 UT on 6 April 2000.

Figure 12. Onset times of activity observed on 7 April 2000.

Figure 13. CPA charging profile and MPA electron temperature during the charging event on 1 November 1998 at 1910 UT.
0500 local time. The smooth curves in Figure 13 that follow the voltage and temperature profiles are fits of the form

\[ V(t) = V_0 \exp(t/t_0) \]

and

\[ T(t) = T_0 \exp(t/t_0) \]

where \( V_0 \), \( T_0 \), and \( t_0 \) are constants. The initial electron temperature rise and the corresponding CPA voltage fall to maximum negative voltage and the subsequent decays of the temperature and voltage were fit separately. Each fit yielded one characteristic time constant \( t_0 \) for each portion of a profile.

The e-folding time of the rising portion of the temperature profile was 8.4 minutes, similar to the time scale of 9.5 minutes for the CPA to fall to maximum negative voltage. The voltage took longer to decay back to its baseline (e-folding time \( \approx 77 \) minutes) compared to the electron temperature (e-folding time \( \approx 48 \) minutes).

The thin black traces in Figure 14 are the CPA voltage profiles for five similar events that occurred between 0 and 5 hours local time on 1804. The events are from passes through local midnight on the following days: 1 and 19 January 1998; 17 January 1999; and 15 and 27 February 1999. The profiles for the 5 events are superimposed with a common time scale such that 0 minutes indicates the first 1-minute average that showed a deviation from the baseline.

Each event lasted roughly 2 hours and had varying amplitudes. As in the 1 November 1998 event, the time to reach maximum negative voltage was less than the decay time. To quantify the characteristic times, the 5 profiles were averaged (red trace in Figure 14) and the falling and rising portions were again fit to exponential functions in time.

The fits shown in Figure 14 adequately described both parts of the CPA response, with e-folding time scales for reaching maximum negative voltage and a return to the baseline of 10 minutes and 100 minutes, respectively. These e-folding times reflect the time scales of the rise and fall of the electron temperatures and not the time constants of the CPA circuit.

4. Conclusions

The \( -z \) CPA sensors indicate when a surface-charging environment is present at the spacecraft’s orbital location between 1800 and 0600 hours local time. That is the part of the orbit when those sensors are in darkness. Since this local time corresponds with most of the region where surface charging occurs, the local time limitation is not a significant constraint on the use of the measurements. The present satellite constellation of CPA and MPA charging measurements cover about half of geosynchronous orbit. If combined they would significantly enhance situational awareness for spacecraft operators and perhaps provide short-term warnings of severe charging events.

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References

