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Operating in the Space Plasma Environment; A Spacecraft Charging Study of the Solar X-Ray Imager✱

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Introduction

The natural space environments pertinent to the design and performance of Earth orbiting spacecraft are the geomagnetic field, the Earth's gravitational field, ionizing radiation, ambient plasma, meteoroids/orbital debris, the neutral thermosphere, and the solar and thermal environments. These environments interact with spacecraft causing a range of effects which can interfere with spacecraft operations. In particular, the interaction between spacecraft and the ambient plasma causes a phenomena known as spacecraft charging which is the accumulation of charged particles on the exposed surfaces of a spacecraft.

The effects attributed to spacecraft charging can be of serious engineering concern. Charged surfaces can attract ionized contaminants increasing surface contamination. Scientific instruments designed to measure the properties of the space environment and that are electrically referenced to ground may not get a true reading due to the buildup of electric fields about the spacecraft. Arc discharging is seen as the primary mechanism by which spacecraft charging disturbs spacecraft operations. Discharges result in a rapid release of large amounts of charge and can cause physical surface damage. The discharge process can generate large structural currents which can couple into spacecraft electronics causing operational anomalies ranging in severity.

These effects bring about the need for spacecraft programs to adopt a protection plan to evaluate the impact of spacecraft charging related effects on mission operations. A protection plan involves defining the natural space plasma environment to which the mission will be exposed, performing analysis to determine how the interaction between the environment and the space system will affect mission goals and objectives, and developing design guidelines with the purpose of reducing or eliminating spacecraft charging related effects.

Several of the key elements needed for a protection plan were addressed by a joint Air Force/NASA effort started in 1975. Plasma properties were defined through flight experiments, and interaction phenomena were studied with space and ground-based experiments. Products of the joint effort include environment definition documents, generic design guideline handbooks, and computer codes designed to simulate the interaction between a spacecraft and the environment. The NASA Charging Analyzer Program (NASCAP) computer code (now known as NASCAP/GEO due to the development of its counterpart for low Earth orbit NASCAP/LEO) was developed to analyze spacecraft charging at geosnychronous orbits caused by the encounter with a magnetic substorm, a situation which has been documented to cause charging levels in the kilovolt range. NASCAP/GEO considers the important charging currents and geometric electric field effect to model the buildup of charge and electric fields on and around a spacecraft. Surface voltage levels attained by the a three-dimensional model of the spacecraft assist in evaluating the probability and location of arc discharges on the spacecraft.

This study presents the results of a spacecraft charging effects protection study conducted on the Solar X-ray Imager (SXI). The SXI is being developed by NASA Marshall Space Flight Center for NOAA's Space Environment Laboratory, and will be used to aid in forecasting energetic particle events and geomagnetic storms. Images will provide information on the intensity and location of solar flares, coronal mass ejections, and high speed solar streams. The SXI will be flown on a next-generation Geostationary Operational Environmental Satellite (GOES) sometime in the mid to late 1990's.

Charging due to the encounter with a worst-case magnetic substorm environment is modeled using the NASCAP/GEO computer code. Charging levels of exterior surfaces and the floating potential of the spacecraft relative to plasma are determined as a function of spacecraft design, operational configuration, and orbital conditions. Areas where large surface voltage gradients exist on or near the SXI are identified as possible arc-discharge sites. Results of the charging analysis are then used to develop design recommendations that will limit the effects of spacecraft charging on the SXI operation.

SXI and GOES Geometry

The SXI is a circular tube approximately .76 m long and .2 m in diameter. It is positioned between the solar array and the body of the spacecraft connected to the solar array boom. The SXI is oriented with its long axis perpendicular to the plane of the solar array ensuring a good view of the sun. Figure 1. shows the three-dimensional model of the GOES and SXI developed using NASCAP/GEO and used in the charging analysis.

Factors Influencing Charging in GEO

In GEO, most of the adverse effects caused by spacecraft charging depend on the levels of differential charging that occur. This is characterized by parts of a spacecraft charging to different potentials relative to each other. Differential charging can result in arc-discharges if the electric field between different regions exceeds breakdown thresholds.

Several factors influence the level of differential charging that occurs for given magnetic substorm characteristics. Most depend on the electrical properties of the spacecraft outer surface materials. These include the amount of dielectric material that comprises the spacecraft outer surface area, and sun/shade effects. Presently the only sure way to eliminate differential charging is to make the entire spacecraft outer surface conductive and tie all elements to spacecraft ground.

Modeling Summary

The charging behavior of the SXI was studied for several orbital configurations and operational modes. Modeling was concentrated on the 1800 and 2400 LT configurations since these are demonstrated to be regions where the most severe charging occurs. Seasonal sun-angle variations were accounted for by conducting simulations for summer, fall and winter orientations. Different surface material combinations were modeled on the SXI in order to determine the combination which resulted in the least probability of arc-discharge in its vicinity.

Overall Charging Behavior: 1800 Local Time Configuration

As an example of the charging behavior, figure 2 shows the predicted surface potentials occurring at the end of a 35 minute charging simulation for an 1800 LT orbital configuration in summer. It is assumed that the spacecraft is initially in a quiescent environment and encounters the substorm environment at time zero while in sunlight. The solar array substrate is assumed to be uncoated Kapton, and the SXI thermal blanket is covered with a conductive coating of indium-tin oxide. Differential charging develops due primarily to sun/shade effects. The shaded Kapton substrate charges highly negative because of the lack of photoelectron emission, an important current source at geosnychronous altitudes. The accumulated negative charge dominates the electrostatic field, forming a potential barrier in front of the more positive solar array and preventing a portion of the photoelectrons from leaving. As a result the cover-glass charges negatively as well. The fields generated by the shaded Kapton and other shaded regions affect the charging behavior of the rest of the spacecraft including the SXI, driving the spacecraft ground potential negative. These long range electric field effects and the formation of potential barriers are some of the keys to understanding spacecraft charging at geosnychronous altitudes.

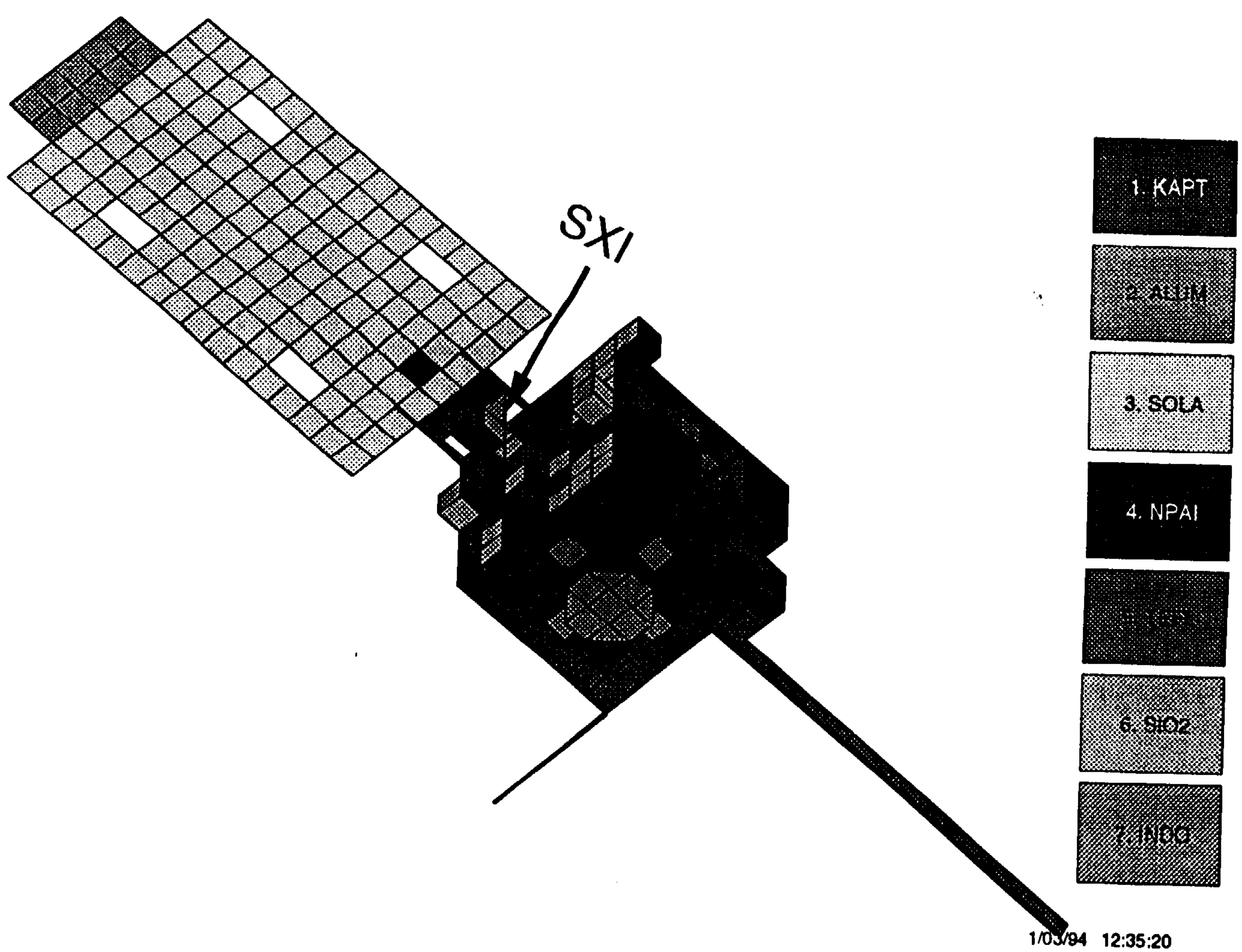
<u>SXI Charging Behavior</u>

The main purpose of this study is to determine whether the differential potentials which develop in the vicinity of the SXI are large enough to cause concerns about arc-discharge. In figure 2 the SXI thermal blanket was assumed to be coated by conductive indium-tin oxide and connected to spacecraft ground. Differentials on the order of 6 kilovolts formed between the SXI conductive regions and nearby shaded Kapton thermal blankets. This suggests that one should avoid placing shaded dielectrics in the vicinity of the SXI to decrease the probability of a discharge known as "flashover" between the dielectrics and the SXI.

Based on the results of the charging analysis design recommendations are made that limit the detrimental effects caused by spacecraft charging on the operation of the SXI.

NASCAP/GEO GOES SPACECRAFT MODEL
1800 Local Time Configuration

Figure 1.



NASCAP/GEO PREDICTED SURFACE POTENTIALS

WORST CASE SUBSTORM ENVIRONMENT
1800 Local Time Configuration SUMMER

Figure 2.