EFFECT OF CONDUCTIVE SURFACE COATINGS ON GEO SPACECRAFT CHARGING

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ABSTRACT

A study has been undertaken to evaluate the effect of material selection on surface charging of GEO satellites. A generic communications satellite, primarily covered with dielectrics, is used as the baseline for this analysis. The substorm environment has both a charging and a relaxation phase. Once the charging characteristics are computed, the materials are changed, one type at a time, to determine the effect of a change. It was found that dark conductors cause increased charging while sunlit conductive coating reduce charging. Photoemission properties are important when considering large conductive areas of satellites.

INTRODUCTION

This paper reviews the charging behavior of a typical geosynchronous orbit (GEO) communications satellite subjected to a design geomagnetic substorm. The substorm encounter used in this study lasts for 40 minutes. It includes both a charging and relaxation phase to bound the charging levels[1]. The model is then modified, one material type at a time (from dielectric to semiconductive), to determine the effect of the change on the charging behavior of the modified spacecraft. The objective of this paper is to provide guidance on the effect of using semiconductive materials on the charging behavior of GEO satellites. While this is not an absolute set of behavior characteristics since the actual effect of these changes are area and orbit position dependent, it does indicate the trends expected with such changes.

ANALYSIS

Design Substorm Environment

The substorm environment used in this study is taken from the NASA design guidelines document[2]. These environments are defined in terms of frequency of occurrence which is inversely proportional to the substorm intensity. Hence, a 90% frequency of occurrence substorm would essentially be benign, while a 10% frequency of occurrence substorm would be a severe one which could occur at this level or higher 10% of the time in orbit. The design substorm used here is a variable one that starts at 90% for 5 minutes, followed by a 40% substorm for an additional 5 minutes, followed by a 10% substorm for 15 minutes. The relaxation phase has a 40% substorm for 5 minutes followed by a return to 90% substorm for 10 minutes (see Figure 1).

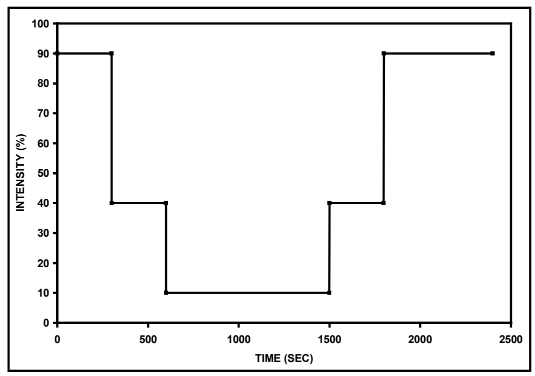

Figure 1
Design Substorm Environment

All of the analyses of this evaluation used this substorm environment model. The encounters were always assumed to occur at local dawn (06:00 hours) on September 23 (equinox). This meant that shadowing of the body by the antenna reflectors had to be considered.

Analytical Charging Code

The analysis was conducted using the SENSIT (Spacecraft Environmental Interaction Toolbox) computer code[3]. This is an engineering computer code developed to compute both surface and dielectric charging, Only the surface charging portion of the code is used in this analysis.

ANALYTICAL RESULTS

In the following discussion of the analytical results, only the following areas in the model will be considered:

-Satellite structure potential (structure and plate 85 - a grounded conductor)

-Solar Array surfaces: Plate 105 for coverglass and plate 113 for rear of array.
- Sunlit Kapton on Spacecraft body: Plate 124
- Dark Kapton adjacent to sunlit: Plate 126
- Dark OSR on spacecraft body: Plate 39

GEO Satellite Baseline Model

Model Description

The GEO spacecraft model used in this analysis is shown in Figure 2. It is a three axis stabilized satellite with two solar array wings mounted to the north and south panels of the body. The solar array wings rotate to track the sun and are constructed with aluminum honeycomb and graphite epoxy face sheets. The rear side is coated by a dielectric paint while the solar cells have fused silica coverglass.

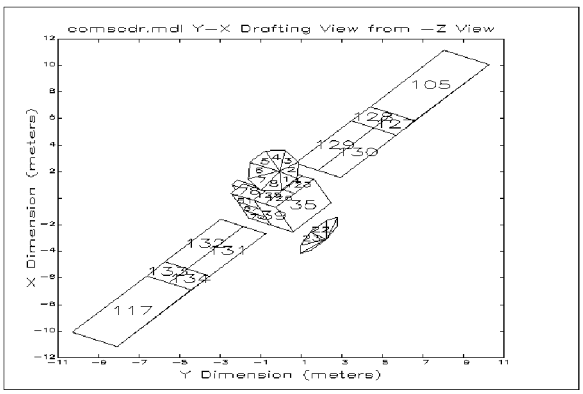

Figure 2
Analytical Model of GEO Satellite

The spacecraft body is earth oriented so that the antenna reflectors point to the earth. The north and south panel are covered with Optical Solar Reflector (OSR) radiator coatings. The rest of the spacecraft body is covered by Kapton outer layer thermal blankets except for the tip of the antenna feed which is a conductor (plate 85). The antenna reflectors have a dielectric paint on the earth facing surface and thermal blankets on the back.

The antenna reflectors will cast a shadow on the spacecraft between 05:00 and 11:00 hours. Shadowing will also occur between noon and midnight, but for this study the concern is for shadowing at local dawn. At that time the reflector shadow will fall across the bottom half of the body thermal blanket. This shadow effect is exhibited by plates 124 and 126.

The dielectrics used on this model, then, are dielectric paint, Fused silica, OSR and Kapton. The objective of this study is to determine the effect on the charging levels of changing each of these materials to semiconductors.

Baseline Model Charging Response

Structure: As shown in Figure 3A, the charging of the structure here is significant. At the end of the severe charging phase (1500 seconds), the structure is charged to -2550 volts relative to the space plasma potential. This charging continues through the relaxation phase of the substorm encounter finally reaching -3850 volts at 2400 seconds. At this point, the charging is just starting to turn around heading back towards zero volts. The reason for this behavior is that, even though the substorm current densities have been reduced, the net current to the satellite is still negative causing the voltage gradient to continue going negative. When the spacecraft charging investigation was just starting in the mid-seventies, anomalies were found to be at a time when a substorm (as determined by ground measurement) was past its peak and starting to relax.

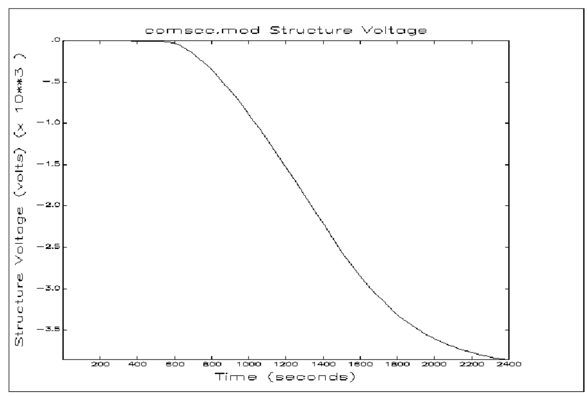

Figure 3A
Baseline Design Structure Potential

Solar Array: The solar array response to the substorm is shown in Figure 3B. The solar cell coverglass raises to about +450 volts relative to the structure while the painted back side falls to about -1200 volts at the end of the severe charging encounter. During the relaxation phase, the coverglass raises to +1650 volts (relative to the structure) and the paint to about -200 volts. The paint voltages do not represent a problem since the paint has a voltage dependent resistivity and the values predicted are too severe.

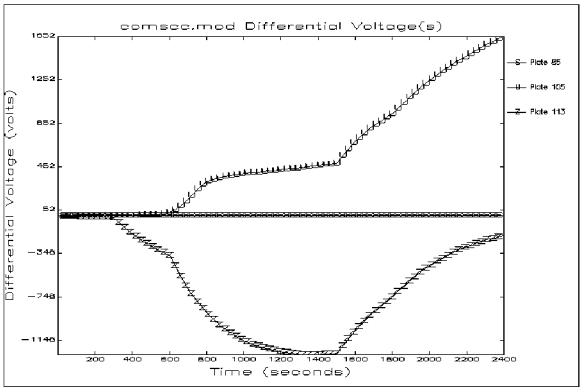

Figure 3B
Baseline Design - Solar Array Differential Voltages

The coverglass however, represents a potentially serious concern. At the high voltages predicted, then inverted voltage gradient discharge are very probable. These discharges have been observed in the laboratory and were found to have a threshold of between -1500 and -2000 volts[4].

Partially Shadowed Kapton Surfaces: As a case for the charging effects on the side of a spacecraft body that is partially shadowed and partially sunlit, consider the surfaces shaded by the antenna reflector. The reflectors cast shadows on different parts of the spacecraft as it moves over its orbit. At the times considered in this report, the shadow is cast on the subdivided surfaces. This charging is shown in Figure 3C. At the end of the severe charging encounter (1500 seconds), the sunlit Kapton surface is at about +600 volts while the shadowed surface is at -1800 volts. If the surface is a single piece of Kapton, then the 2400 volt differential across the shadow line would not be a serious concern. However, if this shadow line falls across gap or surface edge, then there could be discharges. This same concern would exist on the Kapton insulated backside of the antenna reflectors since they are also partially shadowed.

Optical Solar Reflector (OSR): The OSR charging response is also shown in Figure 3C. These surfaces charge to -2.7 KV relative to the structure after the severe substorm encounter. This creates an electric field slightly in excess of 13 MV/cm and this could cause discharges. During the relaxation phase of the substorm, this surface starts to return to structure potential.

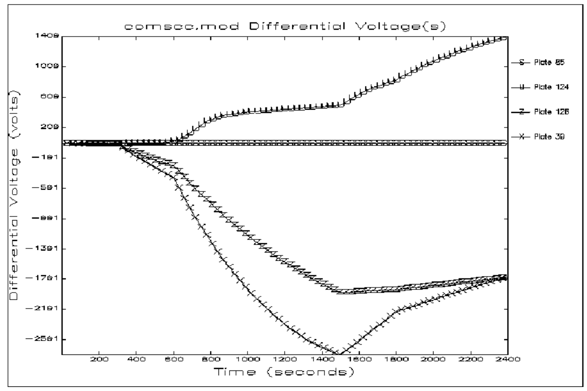

Figure 3C
Baseline Design-
Partially Shaded Dielectric Differential Voltages

GEO Satellite Model - Modification 1

Modification Description

For this model, the back of the solar array was left as a bare graphite epoxy, semiconducting surface. The possibility of epoxy pockets existing in the conductive surface was not considered. If such pockets do exist, then they would charge as dielectrics and probably create a worse charging condition than before. All other surfaces of the spacecraft were left as in the baseline model.

Modification 1 Charging Response

Structure: The structure charging response to the substorm environment model is shown in Figure 4A. The structure potential (relative to the space plasma potential) reaches -4.6 KV after the severe portion of the substorm and continues charging reaching -4.8 KV during the relaxation phase before beginning to recover at 2400 second after the start of the encounter. This maximum is 25% greater than the baseline design.

Solar Array: The solar array response is shown in Figure 4B. As expected the back of the array remains at the structure potential but the coverglass now charges to a larger positive value. After the severe substorm encounter, the glass voltage is 600 volts above the structure while after 2400 seconds, the glass reaches +1700 volts and is still rising. This means that the inverted voltage gradient discharge is still possible.

Partially Shadowed Kapton Surfaces: The partially shadowed Kapton surface charging response is shown in Figure 4C. As can be seen, there are still large voltage gradients across the shadow line. This modification shifts the voltages on the spacecraft body, but does not affect the voltage gradients.

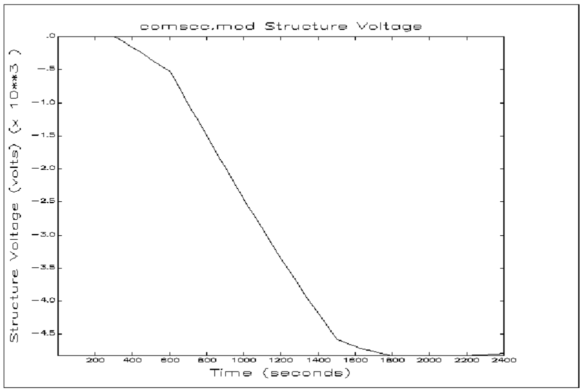

Figure 4A
Modification 1 - Structure Potential

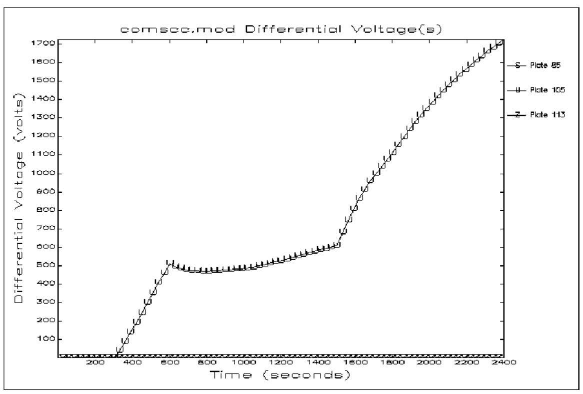

Figure 4B
Modification 1 - Solar Array Differential Voltages

OSR: OSR differential voltages for this modification are also shown in Figure 4C. As can be seen, this modification reduces the differential voltage to about -2 KV. This effect is consistent with the fact that the surface potential relative to space plasma potential must remain constant for highly resistive materials.

GEO Satellite Model - Modification 2

Modification Description

This modification returns the back of the array to a painted dielectric surface and changes the coverglass to Ceria doped microsheet. This makes the sunlit portions of the array more conductive than it was using the fused silica. The material properties for the coverglass were taken from tests run in France.

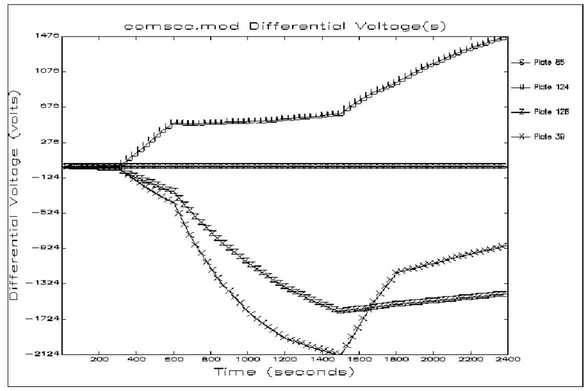

Figure 4C
Modification 1 - Partially Shadowed Kapton Differential Voltages

Modification 2 Charging Response

Structure: The structure response is shown in Figure 5A. Here, the overall structure potential is reduced. After the severe substorm encounter, the structure is charged to -2.2 KV, but reaches -3 KV in the relaxation phase of the substorm. This is about a 21% reduction in structure charging compared to the baseline design. This reduction is the result of the increased photoemission allowed from the sunlit array due to the reduced resistivity of the coverglass.

Solar Array: The solar array charging characteristics of this modification are shown in Figure 5B. The coverglass differential voltages are reduced to about 650 volts above the structure potential. This essentially removes the concern for inverted voltage gradient discharges. The array back charges to a slightly larger value, but this is not significant.

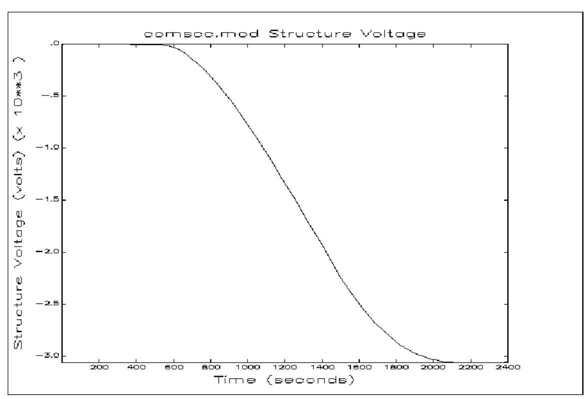

Figure 5A
Modification 2 - Structure Potential

Partially Shadowed Kapton Charging Response: The charging response of these surfaces are shown in Figure 5C. As can be seen, there is little change in the voltage differentials across the shadow line. The OSR materials also remain at the baseline charging levels.

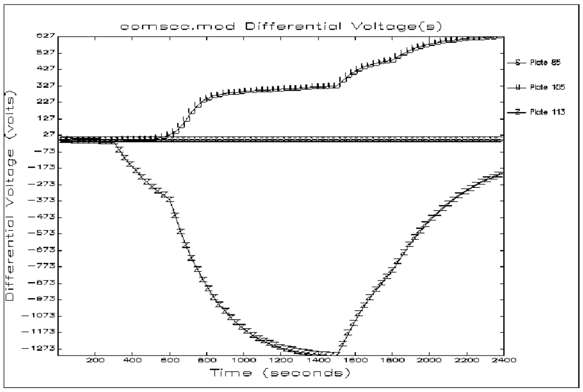

Figure 5B
Modification 2 - Solar Array Differential Voltages

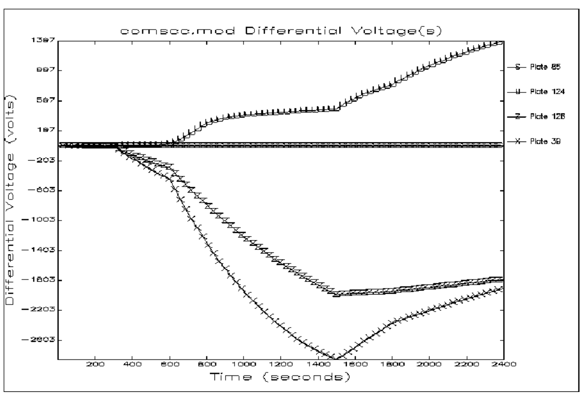

Figure 5C
Modification 2 - Partially Shadowed Kapton Differential Voltages

GEO Satellite Model - Modification 3

Modification Description

This modification returns the coverglass to fused silica and coats the OSR radiator surfaces with a thin, transparent semiconductive ITO material.

Modification 3 Charging Response

Structure: The change made in this modification again results in dark surfaces being made more conductive. As with the modification 1 change, this results in the structure being driven more negative than the baseline case. Since the ITO coated coverglass area is smaller than the array backs, the structure potential is not driven to as large a change as in modification 1. In this case, the change is a 10% increase. The OSR differential voltages all remained at zero relative to the structure. Since the changes are similar to the Modification 1 case, the charging charts have not been included in this report.

GEO Satellite Model - Modification 4

Modification Description

This modification returned the ITO/OSR coverings to plain OSR, and changes all Kapton to a conductive form of Kapton. This Kapton is assumed to have a surface resistivity of 20 Mohms/square and a bulk resistivity of 200 Mohm-m. Photoemission is assumed to be more like a metal and was set at 40 $\mu A/m^2$ rather than the usual $20\mu A/m^2$. The other properties are the same as Kapton.

Modification 4 Charging Response

Structure: The structure potential for this case is shown in Figure 6A. As can be seen, charging does not start until about 250 seconds after the 10% environment encounter. It then falls off rapidly to about -2545 volts or the same as the baseline case. However, the recovery back to zero volts (relative to the space plasma potential) is equally rapid. Photoemission has a pronounced effect on the recovery. If the Kapton photoemission were 20 $\mu A/m^2$, then charging would be similar to the baseline case. If the photoemission were $55\mu A/m^2$, then the structure would not charge; it would remain within +/- 10 volts.

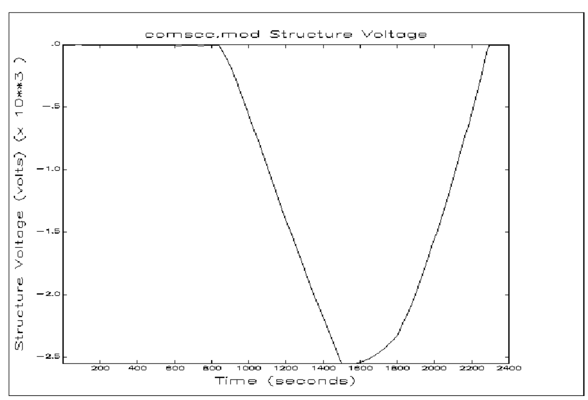

Figure 6A
Modification 4 - Structure Potential

Solar Array: The solar array behavior is shown in Figure 6B. The coverglass starts to charge about the same time as the structure reaching about +500 volts relative to the structure at the end of the severe environment encounter. In the relaxation phase, it rises to about +1215 volts at which point the secondary yield reaches 1 and the voltage starts back towards zero. The dielectric paint on the back of the array reaches about -1200 volts and then decays. Discharges could occur, but it is not as likely as the previous cases.

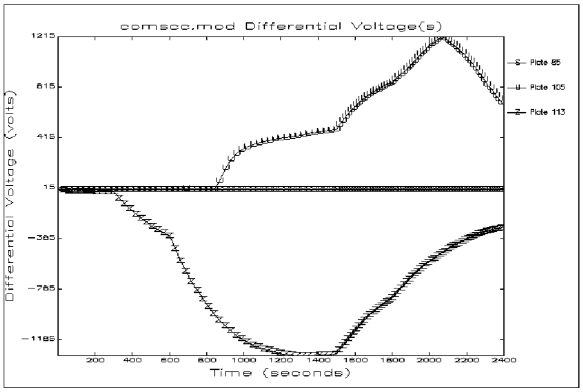

Figure 6B
Modification 4 - Solar Array Differential Voltages

<u>Partially Shadowed Kapton:</u> Since the Kapton is considered a conductor, the surface voltage stays at the structure potential. All of the shadowing concerns have been removed.

<u>OSR:</u> This one drawback to this design modification is shown in Figure 6C. The dark dielectric OSR charges to -3.3 KV after the severe substorm encounter. During the relaxation phase, the differential voltage reduces. This charging is 22% larger than in the baseline design and could cause discharges.

CONCLUDING REMARKS

This evaluation of the effect of using conductive coatings to replace dielectrics on the exterior of GEO satellites has revealed the following results:
1) Conductive surfaces on the dark surfaces of a satellite increase the charging levels.

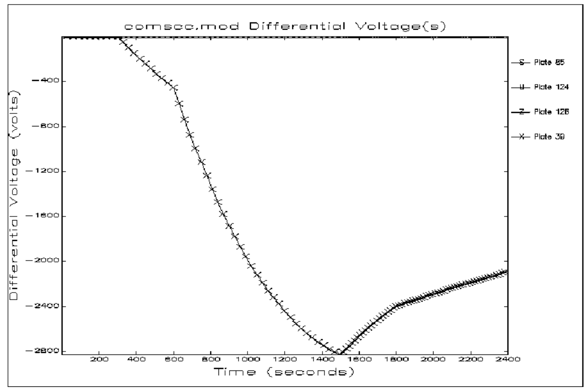

Figure 6C
Modification 4 - OSR Differential Voltages

2) Conductive surfaces on sunlit surfaces will result in lessening the charging levels.
3) Charging in the relaxation phase of substorms can be more severe than in the substorm onset.
4) Charging evaluation must consider shadowing and therefore analysis must be conducted at various times over the orbit and several times during the year.
5) Photoemission is very important when large areas of conductive materials are used on satellites.

REFERENCES

1) Stevens, N.J., Pang, W.P., and Jones, M.R.; "Effect of Configuration and Orbital Position on Spacecraft Charging Using ATS-6 Maximum Sunlight Charging Environment and the GEOCAT Engineering Analysis Tool", AIAA Paper 93-0570, January 1993.
2) Purvis, C.K., Garrett, H.B., Whittlesey, A.C. and Stevens, N.J.; "Design Guidelines for Assessing and Controlling Spacecraft Charging Effects", NASA TP-2361, September 1984.
3) Stevens, N.J. and Jones, M.R., "SENSIT Environmental Interaction Engineering Code", AIAA Paper 95-0595, January 1995.
4) Stevens, N.J., Mills, H.E. and Orange, L.; "Voltage Gradients in Solar Array Cavities as Possible Discharge Sites in Spacecraft Charging Induced Discharges", <u>IEEE Transactions in Nuclear Science</u>, Vol NS-28, December 1981, pp 4558-4562.