Spacecraft Charging Analysis of the Hughes 702 Satellite

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Abstract. The HS 702 is an innovative new line of high power, geosynchronous, communication satellites. The solar arrays use high efficiency gallium arsendide cells, and can be configured to generate up to 15 kW at end-of-life. A new feature on the HS 702 is angled solar reflector panels along both sides of the wings that form a trough and concentrate the sun's rays on the solar cells. Calculations using NASCAP/GEO, show that under non-eclipse conditions, photo electron emission from these solar reflectors will prevent spacecraft charging even during the most severe magnetospheric substorm. A surprising result is that even during eclipse, the reflectors will limit differential charging on the solar array to less than 16% of the overall satellite potential. This limiting occurs because the reflectors set up potential barriers that suppress secondary electron emission from the solar cell coverglasses. The result is that this type of reflector concentrator both helps array performance and controls spacecraft charging.

1. Background

The Hughes 702 spacecraft design is illustrated in Figure 1. The total deployed length is 40.9 m maximum, and the payload mass is up to 1200 kg. It uses an advanced xenon ion propulsion system (XIPS.) The spacecraft will operate in geostationary orbit. At end of life, the solar arrays with Spectrolab dual-junction gallium arsenide solar cells will generate up to 15 kW. This study focuses on the angled solar energy concentrator panels. They form a trough and their reflective, conductive surfaces concentrate the sun's rays. Their size and angle are such that the sun intensity on the solar cells is increased by a factor of two.

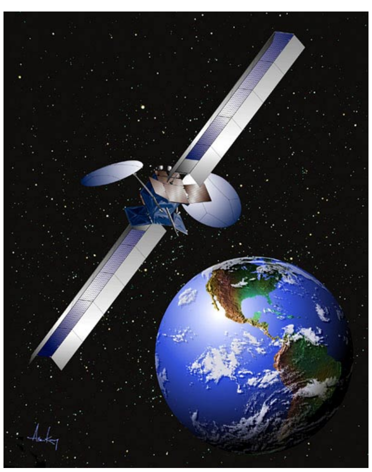

Figure 1. Artists conception of the HS 702 Satellite Design.

2. Spacecraft Charging

The net current to the spacecraft drives the spacecraft potential. The net current consists of the kilovolt electrons and ions from the environment, the secondary and backscattered electrons, and, in sunlight, photoelectrons. When the net current is positive, the spacecraft potential becomes more positive or less negative until it reaches a few volts positive. When the spacecraft reaches a couple of volts positive, the few volt secondary and photo electrons, are attracted back, the net current is zero, and the spacecraft potential is at equilibrium. When the net current is negative, the spacecraft potential becomes more negative until the kilovolt electrons are repelled, and the net current is zero.

Differential charging complicates this simple picture. The potential of each surface adjusts until the net current to that surface is zero. Sometimes, the geometry, surface materials, and environment are such that over a period of minutes a surface develops a potential negative with respect to infinity, and positive with respect to nearby surfaces. The surface electric field can be attractive to low-energy electrons, and secondary and photo electron emission is suppressed. This process is referred to as barrier formation and can enhance the overall charging.

Recently, two geosynchronous communications satellites (not built by Hughes Space & Communications) lost part of their solar arrays. One lost more than 15 percent of its total power capability. There is conclusive evidence that these losses were due to spacecraft charging initiated arcing on the solar array. The initial spacecraft charging arc between the solar cell coverglass and spacecraft ground initiates a secondary arc between neighboring solar cells that is feed by the solar array current. This secondary arc can lead to permanent damage. (Katz, et al., 1998; Hoeber, et al., 1998; Gelderloos, et al., 1998).

3. HS 702 Charging

Table 1 shows a simplified table of the net current to the insulating and conducting surfaces of the spacecraft. The environment used for these calculations is the Severe model environment from the 1984 NASA Design Guidelines (Purvis, et. al., 1984) This environment, while a poor description of actual environments, produces surface charging similar to that observed. In sunlight, the net current to all the surfaces is positive. Therefore, no sunlight charging is expected. In eclipse, the total net current is negative, and the net current to insulators is positive. The spacecraft will charge negative, and because some of the insulator surfaces have positive current, barrier formation is a possibility.

Table 1. Net Current to Spacecraft Surfaces

	Insulators	Conductors	Total
Area (m^2)	100	370	470
Eclipse Current (μA)	120	-500	-380
Sunlit Current (μA)	1800	3500	5300

Figure 2 shows the surface potentials as computed by NASCAP/GEO after 1000 s in the model environment. Figure 3 shows the time dependence.

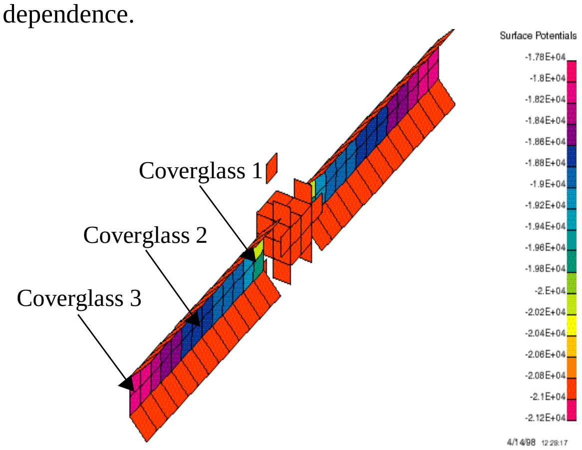

Figure 2. Surface potentials as computed by NASCAP/GEO after 1000s.

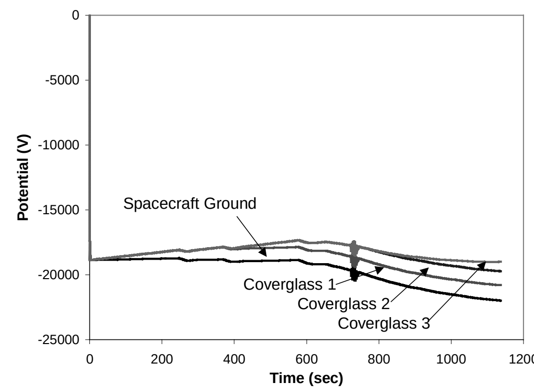

Figure 3. Time dependence as computed by NASCAP/GEO.

Barrier formation is limiting the potentials on the coverglass. The concentrators, with their large areas of grounded conducting surfaces, limit differential charging across the coverglass. To obtain the best results possible, we used NASCAP/LEO, which has an excellent surface electric field model and good geometric resolution. NASCAP/LEO does not have model time-dependant charging, so we used the spacecraft ground potential computed by NASCAP/GEO. Figure 4 shows the potentials around the solar array wing for two sets of boundary conditions. The concentrators and the solar array backs were taken to have a surface potential of –20 kV. Figure 4a has the physically correct boundary condition of zero electric field on the coverglass. For comparison, Figure 4b has –10 kV on the coverglass. There is a saddle point barrier of thousands of volts, from which secondary electrons could never escape. The high secondary yields of coverglass cause differential charging. The potential barrier stops the secondary electrons and stops the differential charging. For this case, the differential potential in the middle of the solar array wing is 0.5% of the overall potential. At the end of the solar array wing, the differential potential reaches 16%.

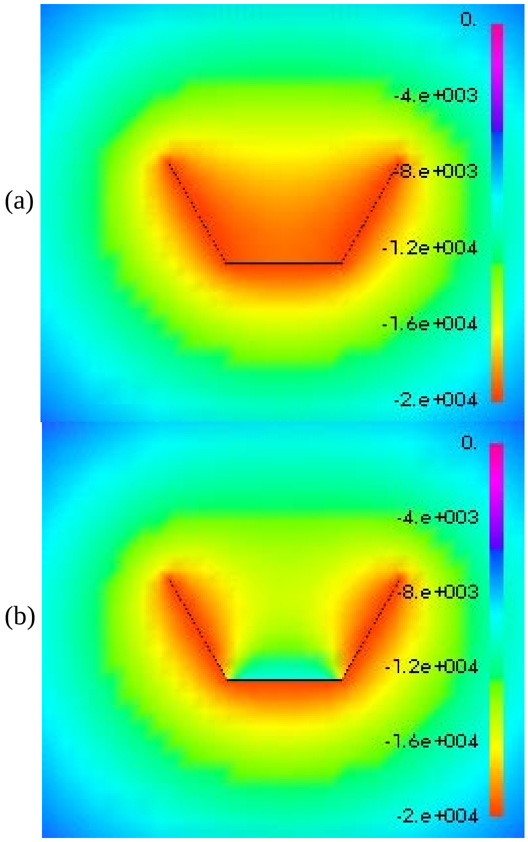

Figure 4. Potentials in space about the solar array wing as computed by NASCAP/LEO. The concentrator surfaces and the solar array back are at –20 kV. The coverglass has zero electric field in (a) and is at –10 kV in (b). (a) is physically correct.

4. Exit from Eclipse

All of the above calculations are for during eclipse with no current on the solar array and therefore no solar array arcing risk. We now ask, what happens if the spacecraft is charged and then comes into sunlight. We assume that the solar cell current is proportional to the visible light. While the dependence is highly non-linear, for the range of interest, the current is less than would be given by a linear relation. We also assume that the photoemission current is proportional to the amount of ultra-violet light, which is in turn proportional to the area of the Sun's disk above the ozonosphere.

In the penumbra, photoemission is less than in full sun and the string current is less than in full sun. There is a threshold below which no discharges occur. Table 1 gives that at 12% of the sun visible, the net current is greater than zero and potential decay begins. The question we need to answer is "Does the differential potential decay before the string current is high enough to sustain a discharge?"

Figure 5 is a scale drawing of the Sun, the Earth, and the ozonosphere from the perspective of a geosynchronous satellite. It takes between 5 and 15 minutes to go from no sun to full sun depending on the length of the eclipse. An equatorial eclipse, where the sun would be moving upward in Figure 5, has a long eclipse period and a short penumbra period. A polar eclipse, where the sun would be moving sideways in Figure 5, just the opposite. The ultraviolet light trains the visible light by about 10 seconds.

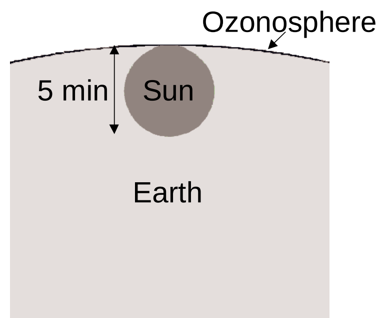

Figure 5. Scale drawing of the Sun, the Earth, and the ozonosphere from the perspective of a geosynchronous satellite.

When 12% of the sun is visible, the photocurrent emitted from conducting grounded surfaces is about equal to the sum of the incident, the secondary, and the backscattered currents. As the amount of the sun's disk area visible increases, the current is high enough and the capacitance to space is low enough that the spacecraft ground potential reaches zero in under a second.

While the spacecraft ground potential reaches zero quickly, the reduction of the differential potential across the coverglass is much slower. As the spacecraft ground potential goes to zero, the surface of the coverglass goes positive. To discharge the coverglass, electrons need to be attracted to the surface. The current from the environment is microamperes per square meter. The photo current from the concentrators is ten times larger. The electrons emitted from the concentrators are attracted to the positive potential coverglass. Above 150 V differential on the coverglass, about one-half the emitted photocurrent reaches the coverglass surface.

Figure 6 shows the differential potential across the coverglass as a function of the fraction of visible light, under the assumption that one-half of the photocurrent emitted from the concentrators reaches the coverglass. For both an equatorial and a polar eclipse, the potential decays before the visible light reaches 40% of full sun. As long as the solar arrays are designed so that at 40% of full sun the string current is below the discharge threshold, no discharges will occur. The polar case is least vulnerable, as the fraction of visible light is smallest upon completion of the potential decay.

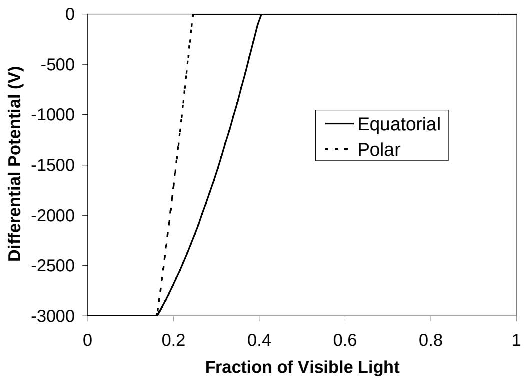

Figure 6. Differential potential across the coverglass as a function of the fraction of visible light.

5. Summary

The Hughes 702 design is resistant to spacecraft charging. The concentrators prevent charging in sunlight. In eclipse, the peak ground potential is -21 kV, the spacecraft ground charges at 200 kV/sec and differential charging occurs at 5 V/sec in the NASA Severe environment.

The concentrators suppress secondary electron emission, which limits the potential differences to about 16% of the spacecraft ground potential.

Upon exit from eclipse, the differential potential decay rate is about 250 V/s. The visible light is under 40% of full sun when all the potentials have decayed.

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