

## Research of a Large Dielectric Plate Antenna Charging in Low-Altitude Polar Orbit Environment

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**Abstract** This paper reports the study of the charging of a large dielectric plate antenna in low-altitude polar orbit plasma environment. The work presented here consists of three parts. First, the surface charging of the large dielectric plate antenna and its effects due to aurora precipitate electron are analyzed. The antenna surface could charge to kV magnitude because of its thick dielectric plate, and the charging rate of the wake surface is nearly two times of the ram surface. Secondly, a spacecraft charging test equipment with plasma source and electron source was used to simulate the charging environment of the antenna components, and discharge was observed. Finally, in order to minimize risks associated with antenna surface charging, tin oxide (TO) coating based on kapton was applied. It could control surface charging potential below 100V and the insertion loss of the film was less than 0.1dB. TO coating on both sides of kapton can be used to minimize the internal charging level.

**Keywords:** spacecraft charging, antenna, auroral electron environment, electrostatic protection

### 1. Introduction

The spacecraft on the orbit can charge to a high charging level on its external surface when the satellite is at geosynchronous altitude, during geomagnetic substorms, or the polar orbit spacecraft at polar regions, encounters with aurora electron environment. Serious electrostatic discharges associated with surface charging can result in spacecraft anomalies. In addition, electromagnetic interference (EMI) resulted from the rapid discharge probably influences the performance of the surface material and the operation of special components in the spacecraft. The other important factor that resulted in spacecraft anomalies is attributed to internal

charging because space energetic electron penetrated the surface and stopped in insulators. Therefore, in order to ensure long-life and reliable of the spacecraft on-orbit, resolving the problem of spacecraft charging is very important<sup>[1]</sup>.

The communication system of the spacecraft is one of the most important payloads. The reliable working of the system is the key for completing the whole mission. Electrostatic protection of the antenna is an important part of the work that ensures success the mission. According to the construction and shape of the antenna and its exists environment, we adopt different resolving programmes toward electrostatic. This paper studies a special charging problem of a large microstrip patch (MP) array antenna in low-altitude polar orbit environment. The basic substrate of the antenna is Kevlar+Nomex honeycomb dielectric plate; there are electric isolated microstrip patch arrays on the radiation surface. While the spacecraft passed through the polar regions and encountered with aurora electron environment, the surface of the antenna can accumulate charge and affect the operation of the spacecraft.

### 2. Dielectric plate antenna charging and its affection

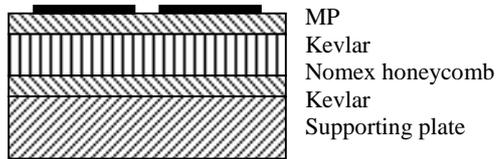
The basic substrate of the MP array antenna is Kevlar+Nomex honeycomb dielectric plate, there is an electric isolated MP array on the radiation surface, and its cross section is shown in Figure 1.

The charging of the antenna on the polar orbit spacecraft has been roughly analyzed and calculated. While the antenna is subjected to a plasma environment of ionosphere, it has no effect because there is only about -0.2V negative floating potential on the surface of the antenna. The charging rate of the dielectric plate of the antenna can be obtained by equation (1) when the spacecraft passes

through polar regions and encounters with a strong aurora precipitating particle<sup>[2]</sup>:

$$dV/dt=1/C_A(j_{net}-V/R) \quad (1)$$

V is surface potential at the time of t,  $C_A$  is unit area capacitance of the antenna,  $j_{net}$  is net current density on antenna surface, and R is dielectric resistance.



**Figure 1, Cross section schematic diagram of antenna**

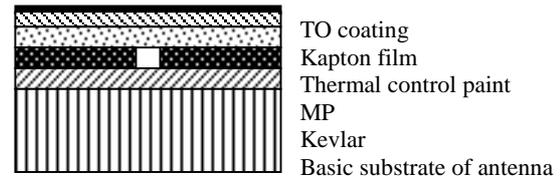
When the antenna sunlit, net current approximation is zero and the surfaces are unlikely to charge. However, the charging rate of antenna ram surface under auroral charging conditions would be about -870V/s and the charging rate of the wake surface about -1600V/s when the antenna locates in a shadow. So, even if the antenna passes through the aurora region in a short time, charging up kV magnitude would occur on its surface.

Differential charging on the antenna surface between basic dielectric substrate and MP, and deep dielectric charging can lead to electrostatic discharges, which may cause failure of the sensitive electronic devices in the spacecraft, and cause physical damage to the antenna structures.

### 3. Electrostatic protection

#### (1) Surface charging protection

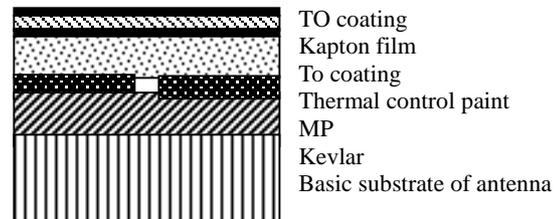
The electrostatic protection layer on antenna surface shouldn't influence the microwave transparency and must be considered by the thermal control requirements for antenna operation. So the surface charging protection plan is a TO coating based on Kapton layer, which with a surface resistivity range from  $10^9$  to  $10^{11}$  ohms per square, is covered on the antenna surface, and the kapton film surface toward antenna is sprayed with white paints (~100um) for thermal control. Figure 2 illustrates the structure diagram of the layer.



**Figure 2, Structure diagram of surface charging protecting layer**

#### (2) Deep dielectric charging protection

The internal charging of deep dielectric due to energetic electron insetting can not be ignored when charging protection of antenna surface is considered. In order to reduce the internal electric field strength built up by energetic electron insetting, add a TO coating on the other side of Kapton film of the surface charging protecting layer<sup>[5]</sup>. The construction is shown in figure 3.



**Figure 3 Deep dielectric charging protecting layer construction diagram**

## 4. Experiment

#### (1) Charging simulation experiment for antenna sample

SCF-900, a ground combined facility for simulating spacecraft charging, which was made by Lanzhou Institute of physics, was employed to complete charging simulation experiment on the unprotected antenna sample and the antenna covered with electrostatic protecting layer. The vacuum chamber is a horizontal stainless steel cylinder with a diameter of 0.9m and a total length of 1.6m. The pumping system of SCF-900 is based on oil diffusion pump providing fast evacuation from atmospheric pressure down to  $4 \times 10^{-4}$  Pa in about two hours. Two kinds of electron gun and a kauffamn-type plasma source with a spherical grid are attached to the facility. Materials charging tests are conducted on the horizontal mounting platform and small components charging tests are conducted on the vertical mounting platform. A surface potential meter with measurement range from 100V~20kV has peak value keeping function. The control system of the facility concentrate

on a workbench, and the computer is used to analyze data, a CCD camera is used to observe the actual images of arc events. The testing samples with length of 0.9m and width of 0.2m as a quarter sub-arrays of the antenna system are set on the vertical-mounting platform.

Antenna sample surface potential is measured after radiation for one minute under the selected electron energy and beam density, then plasma source is used to neutralize sample surface charges. Electron energy and beam density are changed and the above procedures are repeated.

Selected samples including:

1<sup>#</sup>, unprotected antenna plate, MP NOT grounded.

2<sup>#</sup>, unprotected antenna plate, MP grounded.

3<sup>#</sup>, protected antenna plate, TO film grounded, with a surface resistance of  $10^9$  ohms per square.

4<sup>#</sup>, protected antenna plate, TO film grounded, with a surface resistance of  $10^{11}$  ohms per square.

5<sup>#</sup>, protected antenna plate, TO film grounded, with a surface resistance of  $10^{12}$  ohms per square.

Electron beam density is  $2\text{nA/cm}^2$ , selected electron energies are 10kV, 15kV and 20kV respectively. Surface potential of MP and dielectric plate for 1<sup>#</sup> and 2<sup>#</sup> samples and surface potential of electrostatic protecting layer for 3<sup>#</sup>, 4<sup>#</sup> and 5<sup>#</sup> samples are measured respectively.

#### (2) Microwave characteristic experiment

A HP8720C vector network analyzer and its coaxial testing and adjusting system are used to examine the effects of input standing wave ratio properties and Microwave insertion loss for the antenna when electrostatic protection layer with different surface square resistance are used.

## 5. Experimental result

### (1) Experimental result of charging characteristic

The test results of charging potentials for 1<sup>#</sup>~5<sup>#</sup> samples are shown in Table 1.

### (2) Microwave characteristic test results

The insertion loss of electromagnetic wave is less than 0.1dB(that is, too low for our equipment to measure) when the electrostatic protection layer with surface square resistance of  $10^9 \sim 10^{11}$  ohms per square is covered on the antenna plate. However, the layer obviously affects the input standing wave ratio of MP array, e.g. frequency band turns narrower and the antenna performance becomes worse. When the white paint is removed from the electrostatic protecting layer, input standing wave ratio of MP array will not change obviously.

## 6. Discussion

(1) When antenna sample is not covered by an electrostatic protection layer, its dielectric plate would charge to kV magnitude and a high difference potential exists between MP and the around dielectric surface. In fact, obvious arc events have been observed in experimental process. Because antenna's basic substrate is made of an insulation material, MP grounded or not wouldn't modify the charging of dielectric plate. Except TO film with a surface resistance of  $10^{12}$  ohms per square, the film with surface resistivity of  $10^9 \sim 10^{11}$  ohms per square can be employed to reduce the surface potential of the antenna below 100 V.

**Table 1, Data of charging simulation experiment**

Electron beam energy (keV)	Surface potential (V)						
	1 <sup>#</sup>		2 <sup>#</sup>		3 <sup>#</sup>	4 <sup>#</sup>	5 <sup>#</sup>
	MP	Dielectric plate	MP	Dielectric plate			
10	<100	1360	<100	910	<100	<100	560
20	150	6400	<100	5400	<100	<100	1050
25	340	7000	<100	6200	<100	<100	1200

Electron beam density is  $2\text{nA/cm}^2$ , background pressure is  $2.6 \times 10^{-3}\text{Pa}$

(2) The insertion loss of electromagnetic wave is less than 0.1dB when electrostatic protection layer is covered on the antenna plate. However, the layer obviously affects the input standing wave ratio of MP array. The test results indicate that the thermal control white paint is far more important than the effects of kapton film and TO coating.

### 7. Conclusion

The following conclusion can be drawn:

(1) While the large dielectric plate antenna is in an auroral electron environment, the surface of dielectric basic substrate is charged up to several kilovolts. Thus the performance of the antenna could be influenced and the sensitive electronic devices aboard the spacecraft might be interfered or destroyed by electrostatic discharges due to surface charging and deep dielectric charging.

(2) The potential of antenna surface can be reduced to safety value by the electrostatic protection layer with a surface resistivity  $10 \times 11 \sim 10 \times 9$  ohms per square. Kapton coated by TO film on the double surfaces can mitigate the danger of deep dielectric charging.

(3) The insertion Loss of the electromagnetic wave of the electrostatic protection layer is minor, so the protection layer can be acceptable for a large microstrip array antenna for the Low-altitude polar orbit spacecraft if the influence of input standing wave ratio of antenna caused by the layer is considered in the design of the antenna.

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