'Spacecraft Plasma Interaction eXperiment in India - an Introduction'

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ABSTRACT:
Possibility of arcing in high voltage arrays have necessitated the theoretical and experimental study of charging and arcing by Indian Space research Organisation (ISRO), which is planning to increase the satellite bus voltage above the current level of 42 volt. The study, named Spacecraft Plasma Interaction eXperiment (SPIX) was undertaken, together with Institute for Plasma Research (IPR), India to (i) develop software, which is able to predict the floating potential of an object of simplified geometry in space plasma typically of geosynchronous bimaxwellian type, which is also able to calculate the differential potential between two such objects, (ii) to develop software to solve the differential equations describing primary arcing phenomena developed by Cho, a pioneer in the field [1], (iii) to study the primary arcing threshold and frequency and to identify the arcing sites of a solar array coupon immersed in a LEO like laboratory plasma and to (iv) find out the arcing threshold of sustained arcs by introducing a solar array simulator voltage between adjacent strings in a solar array coupon immersed in a LEO-like plasma environment. The experiments have largely yielded results akin to that of other investigators, although some differences have been observed in some experiments. A short term future aim would be to increase the sample space in the last type of experiments mentioned above.

1. INTRODUCTION

Indian Space Research Organisation (ISRO), the primary agency doing space related work in India, has made arrays of up to 6kW and successfully flown them. Conventionally, ISRO has the 42 volt array. Higher power requirements and some specific payload constraints have necessitated the development of high voltage array. Since high voltage arrays are much more likely to arc and get destroyed compared to those operating at lower voltages in the presence of space plasma, a study project was undertaken, which has been named SPIX, an acronym for Spacecraft Plasma Interaction eXperiment. This project was executed jointly by ISRO and Institute for Plasma Research, Gandhinagar, Gujarat, India. The project had elements of theoretical and modeling work and experimental study. The theoretical study was aimed at calculating the potential of a conducting body of simple geometry in space plasma as well as finding the potential difference between a conductor and a tiny patch of dielectric present on its surface. This was aimed at arriving at a simple but reasonably accurate model of the potential difference that is found between the metallic and insulating parts of the solar array, the latter typified by, for example, the coverglass of the solar cell. Another aim was to find a simple way of solving the differential equations developed by Cho [1], which relates the shapes of the oscilloscope traces of the primary arcs to the electrical parameters that make up the solar cell coupon, thereby gaining a deeper understanding of the arcing phenomenon. The experimental study was aimed at studying the primary and secondary arcing thresholds and their relation to the coupon configuration and identification of the arcing sites so as to arrive at mitigating techniques.

2. CHARGING AND ARCING CODES

The charging code calculates the floating potential of a spherical conductor placed in the geosynchronous orbit plasma. The plasma parameters which can be given as input are either single or double maxwellian. The currents to and from the conductor considered by the software are:

1. Flux due to ambient electrons
2. Flux due to ambient ions
3. Emission of secondary electrons due to the electron impact
4. Backscattering of electrons
5. Emission of ion-induced secondary electrons and
6. Emission of photo-electrons due to UV radiation.

The other currents are neglected as their contributions in a realistic case are negligible. In the equilibrium condition the total current to the body is zero. The voltage at which this happens is the floating potential. All except the first two among the above are strong functions of the material and different formulas like Whipple-Dionne formula are used to calculate these currents.

The potential difference between two adjacent materials: one -a conductor and another- a dielectric is calculated by another module. This is done by a 'patch-on-sphere' code where the geometry is very much simplified. The dielectric is a very small patch on the conductor. A small leakage current goes from the dielectric to the conductor. This gives a different equilibrium potential for the dielectric. The results of the code have been compared against the European SPENVIS code and are in good agreement [2].

We have used the circuit model for the primary arcs from [1] and we have solved the circuit equations using Scilab routines unlike the author himself who had used Laplace transforms to do the same. We feel that this is an easier and simpler way. Our results, naturally, are the same.

3. EXPERIMENTAL SET-UP

In the experimental setup, test solar array coupons were exposed to plasma interaction experiments. These experiments were performed to develop LEO like condition in the laboratory. Plasma of density ~ $1x10^{12}m^{-3}$ was obtained using argon gas. This was developed in the test chamber of size 1 m in length and 1 m in diameter. The chamber could be opened at both ends, with dome shaped end flanges having view ports and access ports for various diagnostics. The chamber was evacuated by a diffusion pump with pumping speed of 3000 l/s backed by rotary pump. The chamber was cooled by copper tubes brazed on the outer surface. The solar panel coupons (300 mm x 300 mm) were mounted on insulating supports, facing towards the view ports. Position of the coupon was such that it could be focused completely from one of the view ports using a CCD camera. The ends of the solar cells were connected with insulating cables to high voltage vacuum compatible feed-throughs.

Experiments were carried out in what we denote as Cho's configuration [1] and NASA configuration [3]. Cho's configuration corresponds to the set up where the feed-throughs were shorted and were connected to an external capacitor (0 or 33 pF), which in turn was connected to an external power supply (0 to -600 V) through a variable resistance (1 – 200 kilo ohm). The solar cell arrays in this case could be biased from -300 V to -600 V. NASA configuration corresponds to the case where, in addition to the above, a solar array simulator voltage is introduced between two adjacent strings. (Fig 1) The former configuration is designed to study the primary arcing phenomena and the latter to study secondary arcs. The pulsed arc current was measured with two current transformers CT-1 (having response of 1.0V/A) and CT-2 (having response of 1.0 V/A). A Tektronix make (Model no: P6015A) 1000 X HV probe was used to monitor the applied voltage wave form on oscilloscope. A 350 MHz digital oscilloscope with 1 Gb/s sampling rate was used for fast data acquisition during arcing event. The output of 1000 X HV probe, CT-1 and CT-2 are connected to different channels of the oscilloscope. After pumping the chamber to the base pressure, argon gas was introduced to the operating pressure of 5 x 10^{-5} mbar. Thoriated tungsten filaments were heated to emit primary electrons which were accelerated to impact-ionize the background gas to form plasma. The plasma density was measured using Langmuir probes. The plasma density was controlled by controlling the total discharge power.

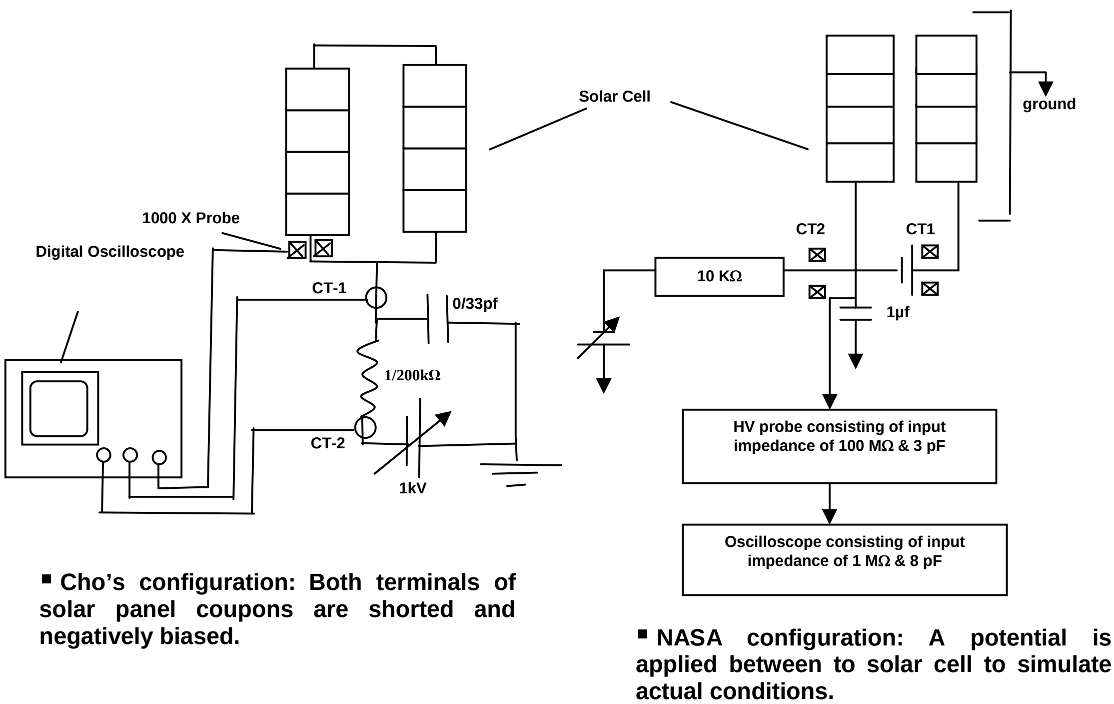

Figure 1: Schematic diagram of the circuits used.

4. RESULTS AND DISCUSSION

In Cho's configuration we found that the number of primary arcs is least for GaAs cells rather than Si or multijunction cells. This may be because GaAs cells which we have used have smaller area. It was also found that grouting reduces the number of primary arcs. We have two types of grouting – partial and full. In the first one all portions except the coverglass and interconnect are immersed in RTV adhesive. In the second case, even the interconnect is immersed in adhesive. We found that even partial grouting helps reduce the number of primary arcs and with full grouting the numbers of arcs are even lower. Even without grouting also, the number of arcs we observed was less than that in [1]. This is very surprising to us.

We have done some preliminary studies in NASA configuration but the sample space is not high. Here we found that the no arcing occurs in any coupon ever below 20VA. With higher gap less number of major arcs occurred with same capacitor and current limit values. With large value of external capacitor and low value of current limit, there may be more chances of major or sustained arcs. The probable reason is that large value of capacitor charges more and at the time of arc it gives more charge/current to the circuit and in this condition low value current limit is not effective. No major arc was observed even after removing current limit from fully grouted coupon with triple junction cells up to 100V. So full grouting is a better option rather than increasing the string gaps from the point of view of preventing major arcs. However, the grouting should not stress the interconnects during temperature cycling and it should not peel off due to the space environment. More experiments needs to be done before we finalize on our option.

5.ACKNOWLEDGEMENT

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