Temporal Evolution of the Plasma Sheath Surrounding Solar Cells in Low Earth Orbit

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I. INTRODUCTION

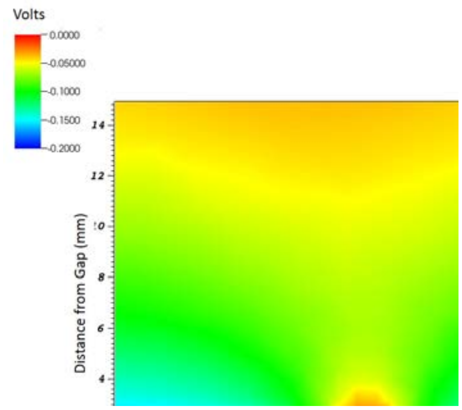
High voltage solar array interactions with the space environment can have a significant impact on array performance and spacecraft charging. Over the past 10 years, data from the International Space Station has allowed for detailed observations of these interactions over long periods of time. Some of the surprising observations have been floating potential transients, which were not expected and are not reproduced by existing models. In order to understand the underlying processes producing these transients, the temporal evolution of the plasma sheath surrounding the solar cells in low Earth orbit is being investigated.

Most of the previous research has focused on steady-state interactions which have resulted in a good understanding of the steady-state processes. A few studies have been performed to investigate eclipse exit rapid charging events. The results of these studies suggested that the magnitude and duration of these events could be caused by the time it takes for the potential barrier to form on the solar array [Ferguson et al., 2009, Hui, 2011, Huang et al., 2014]. The floating potential transients recently observed are much larger and faster than the rapid charging events that were previously studied [Willis et al., 2016]. The transients occur when an ISS solar array is unshunted in full sunlight and could be a more extreme manifestation of the same physical processes described in previous studies. It is also possible that system or instrumental effects are present.

The focus of this research is to provide information that will help answer the question as to whether or not these transient events are caused by the same processes described in rapid charging event studies. Specifically, the goal is to determine whether or not the electron collection to exposed high voltage surfaces can be responsible for the transients when the temporal evolution of the potential structure surrounding the solar cells is taken into account. The temporal evolution of the potential structure is key to understanding the time dependent nature of electron collection and being studied using particle-in-cell (PIC) simulation and lumped element modeling (LEM).

II. PARTICLE IN CELL SIMULATION

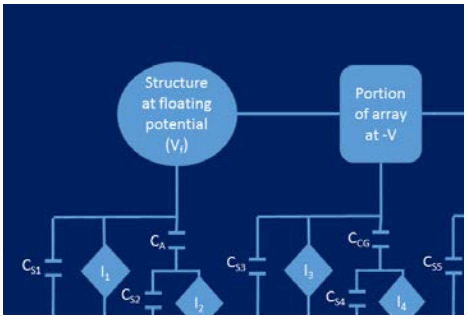
The objective of this study is to make progress toward understanding the temporal evolution of the potential barrier development surrounding solar cells. Initial PIC simulations using the Spacecraft Plasma Interaction System (SPIS) [Roussel et al., 2008], have been performed in order to visualize the barrier potential over the solar cell gap at different applied voltages. The string voltage of approximately 160V is spread across 400 solar cells. Steady-state simulations were performed for cells at 50V, 120V, and 150V. For the steady-state condition, the cover glass potential is set to -.2V, which is an expected value for low Earth orbit (LEO). These results can be used to compare with the analytic barrier potential solution provided in Mandell et. al. [6].



The barrier potential is defined as the maximum negative potential along the trajectory extending from the center of the gap. The SPIS simulation shows the barrier formation and replicates the general structure of the potential. The location and size of the barrier are, however, different. The results from the analytical solution predicts a barrier potential of -0.04 Volts at 6mm from the gap, and the SPIS simulation shows a barrier potential of -0.07 Volts at 6mm from the gap. In general, the SPIS simulations show more screening than is predicted by the analytical solution. The analytical solution for the barrier potential uses a combination of a maximally screened solution and an unscreened solution. The SPIS simulation results compare better with the maximally screened portion of the analytical solution, which also predicts a barrier potential of -0.07 Volts at 6 mm from the gap. Future work with the SPIS simulation will include allowing starting the simulation in a transient state and allowing the barrier to develop in time to reach the steady-state condition.

III. LUMPED ELEMENT MODEL

A LEM is being developed that builds on the previous work reported by [Ferguson et al., 2009, Hui, 2011, Huang et al., 2014] in order to study the controlling factors of the transient events. The purpose of developing this model is to provide a means for testing the results of the PIC simulation and to perform parametric studies to understand the implications of the PIC simulation results on other unknowns, such as ion collection current. The model is illustrated in Figure 2. C_{S1} - C_{S6} are the capacitances attributed to the plasma sheath, C_A is the capacitance of the anodized coating on the ISS structure, and C_{CG} is the capacitance of the solar cell cover glass. Each of the currents, I_1 – I_6, is defined based on plasma properties, collection area, and surface voltage.



The current collection attributed to electron collection on each cell in one string is defined according to the development of the barrier potential and the charging of the cover glass. Initially, as the voltage on the solar cells rise, the potential of the uncharged cover glass is also positive. The total electron current is found by summing the results for all cells with a positive bias.

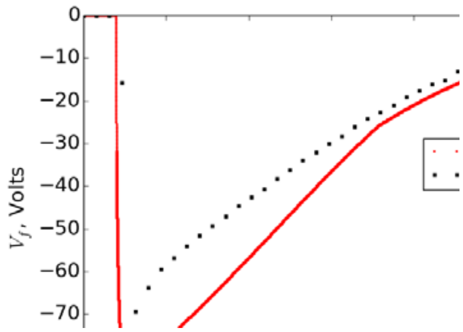
The ion collection to the negative portions of the array is more simply modeled as in the previous RCE studies by using the current density attributed to spacecraft motion. The total ion current to the array is found by summing the results for all cells with a negative bias.

The structure is modeled as two cylindrical collectors; one for the conductive areas and one for the dielectric coated areas.

Using the currents defined above, the current balance equation is solved for the floating potential. Initial results from the simulation compared with FPMU data for a transient event are shown in Figure 3. The results agree well and indicate that it is possible these transient events are caused by interactions with the environment; however more work is needed to verify the assumptions in the model.

IV. Summary

Initial results from the PIC simulation and the LEM simulation have been presented. The PIC simulation results show that more detailed study is required to refine the ISS solar array current collection model and to understand the development of the current collection in time. The initial results from the LEM demonstrate that is it possible the transients are caused by solar array interaction with the environment, but there are presently too many assumptions in the model to be certain. Continued work on the PIC simulation will provide valuable information on the development of the barrier potential, which will allow refinement the LEM simulation and a better understanding of the causes and effects of the transients.



Acknowledgment

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