Correlation of ISS Electric Potential Variations with Mission Operations

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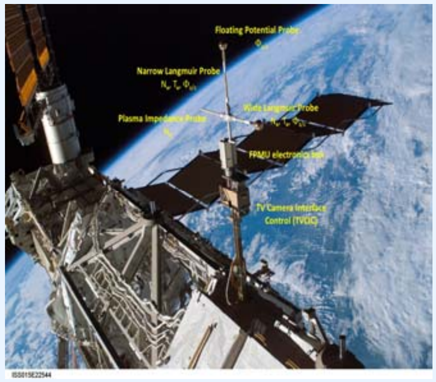
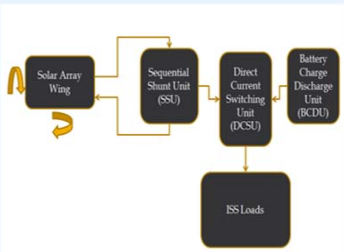
Introduction

Orbiting approximately 400 km above the Earth, the International Space Station (ISS) is a unique research laboratory used to conduct ground-breaking science experiments in space. The ISS has eight Solar Array Wings (SAW), and each wing is 11.7 meters wide and 35.1 meters long. The SAWs are controlled individually to maximize power output, minimize stress to the ISS structure, and minimize interference with other ISS operations such as vehicle dockings and Extra-Vehicular Activities (EVA). The Solar Arrays are designed to operate at 160 Volts. These large, high power solar arrays are negatively grounded to the ISS and collect charged particles (predominately electrons) as they travel through the space plasma in the Earth's ionosphere. If not controlled, this collected charge causes floating potential variations which can result in arcing, causing injury to the crew during an EVA or damage to hardware [1]. The environmental catalysts for ISS floating potential variations include plasma density and temperature fluctuations and magnetic induction from the Earth's magnetic field. These alone are not enough to cause concern for ISS, but when they are coupled with the large positive potential on the solar arrays, floating potentials up to negative 95 Volts have been observed. Our goal is to differentiate the operationally induced fluctuations in floating potentials from the environmental causes. Differentiating will help to determine what charging can be controlled, and we can then design the proper operations controls for charge collection mitigation. Additionally, the knowledge of how high power solar arrays interact with the environment and what regulations or design techniques can be employed to minimize charging impacts can be applied to future programs.

Floating Potential Measurement Unit

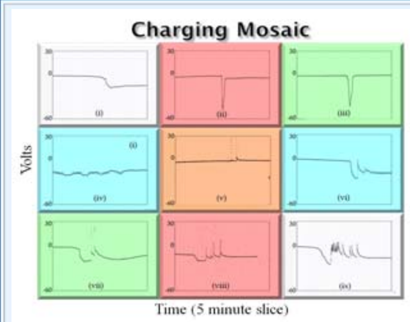


The Floating Potential Measurement Unit (FPMU) is a collection of four probes: the Plasma Impedance Probe (PIP), Wide-sweep Langmuir Probe (WLP), Narrow-sweep Langmuir Probe (NLP), and the Floating Potential Probe (FPP). Together, these instruments are able to determine the ISS floating potential (FP) as well as the ion and electron density (Ni, Ne) and electron temperature (Te) of the local plasma environment [2,3]. The collected data is downlinked to the FPMU Workstation at MSFC where it is processed and archived. The Space Environments Team at MSFC analyzes the collected data with respect to the ISS position along the orbital path, the timing of ISS eclipse and sunlit phases, and the current space weather conditions to determine the environmental sources causing significant changes in floating potential. We focus on FPP and WLP observations for this work. The FPP measures ISS frame potentials relative to the ambient plasma environment at a rate of 128 Hz allowing detailed monitoring of frame potential variations at high time resolution. Plasma density measurements are obtained from the WLP Ni parameter at a rate of 1 Hz. Electron density is assumed to be equal to the ion density due to quasi-neutrality. A description of the data analysis algorithms used to obtain the potentials and plasma density parameters from the FPMU instrument suite is described by Wright et al. 2008 [2].



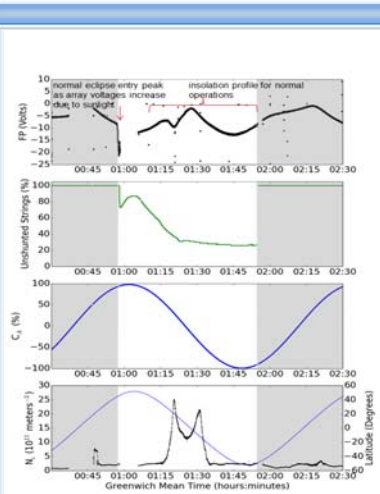
In order to determine charging levels related to ISS operations, it is important to understand how the ISS solar arrays operate. This is a basic block diagram of the operations being investigated for correlation with potential fluctuations. There are eight Solar Array Wings (SAW) on ISS, each has 82 strings of solar cells that are controlled individually to meet the changing power needs of the ISS.

The arrays rotate via Beta Gimbal Assemblies (BGA) and Solar Alpha Rotary Joints (SARJ) to maximize power production, minimize stress to the structure, and also move for other specific operations such as vehicle dockings. During insolation, the Sequential Shunt Unit (SSU) provides the automatic regulation of the arrays by turning strings of cells on and off as needed to support loads. When a When a string is "shunted" all generated current is sent back to the array, and the voltage on that string is zero. During the eclipse portion of the orbit, the Battery Charge Discharge Units (BCDU) provide the regulation of the power. The current flows into the Direct Current Switching Unit (DCSU) and is sent to the ISS loads [4].

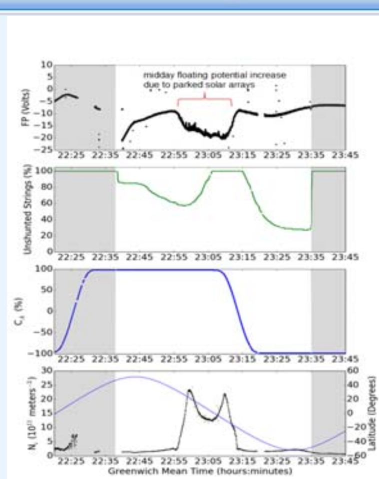


The Charging Mosaic illustrates a number of floating potential profiles currently being investigated for ISS. These are plots of the ISS floating potential (Volts) versus time. Each plot is a five minute time interval. They range from simple, well understood potential fluctuations to complex potential variations with currently unknown causes.

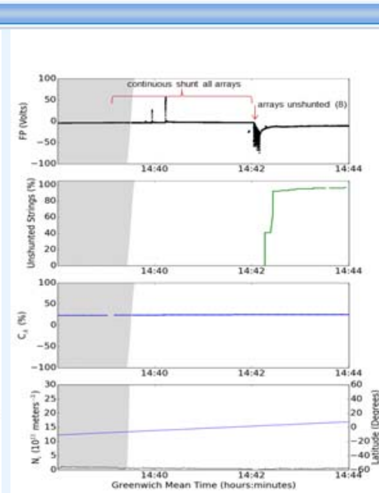
i. Normal eclipse exit: Characterized by a rise time less than ten seconds and decay time greater than one minute. This is typical of the ISS coming into sunlight. The arrays are pointed into ram and string voltages increase quickly.
ii. Rapid eclipse exit: Characterized by a rise time less than ten seconds and decay time less than one minute. These rapid potential peaks correlate with lower plasma densities.
iii. Eclipse entry: Floating potential increases as the ISS moves into darkness and arrays are unshunted.
iv. Auroral charging: With an inclination of 51.6 degrees, the ISS occasionally travels through an auroral event and floating potential increases occur from the precipitating auroral electrons. These events are independent of solar array operations.
v. Positive charging: Observed events have been less than one second in duration. The largest event observed was 55 Volts. The cause of these events is currently unknown.
vi. – ix) Additional uncharacterized peaks: These floating potential fluctuations are possibly a combination of the others caused by complex solar array operations. They occur during the early part of insolation (sunlit portion of the orbit).



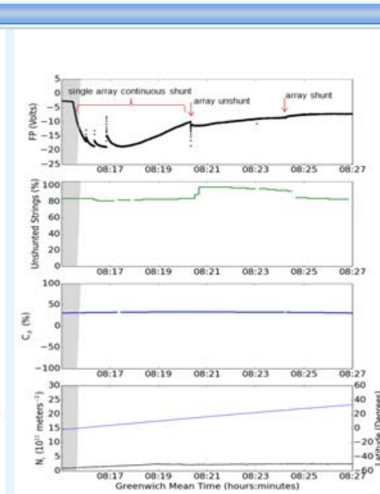
During normal operations, the arrays are approaching ram at eclipse exit and all strings are unshunted in order to supply power to the loads and recharge the batteries. The potential on the unshunted arrays quickly rises to 160 Volts. The exposed portions of the semiconductor and interconnects collect electrons increasing the negative floating potential of the ISS. The cover glass on the arrays collects electrons developing a potential barrier that slows the collection of electrons on the conductive surfaces [5]. By orbital noon, the batteries are charged which results in a decreased load. Many strings are shunted due to this decrease in load. At the same time, the arrays are no longer pointed in the ram direction, so the charge collection, and therefore floating potential, is minimized.



During special operations, such as vehicle dockings, the arrays are "parked", meaning they do not track the sun but stay in a designated position. This plot illustrates how this "parked" configuration affects the floating potential. Instead of the floating potential decreasing at orbital noon, it increases because the arrays are pointed in ram and still receiving enough sunlight to maintain a high positive voltage. When the arrays are unparked and begin moving out of the ram direction, the floating potential decreases accordingly.



This figure illustrates the results of shunting operations during insolation. In order to observe the effects of unshunting arrays in sunlight, all eight arrays were commanded to a shunt state until three minutes into insolation. While the arrays were shunted, large positive floating potential fluctuations were observed. As each array was unshunted, a large negative fluctuation occurred.



This figure illustrates a similar effect as the previous one. In this instance, one entire array was shunted due to an anomaly on ISS. As the station entered insolation with the array shunted, the positively oriented fluctuations occurred. Unshunting the array resulted in a rapid charging peak with a large negative potential. The array was again shunted, which had little effect on the floating potential. These floating potential profiles are not well understood, but occur regularly when an entire array is held in a shunted state as the ISS enters insolation and then unshunted in full sunlight. The low data rate (1/10 hertz) of ISS systems data creates a challenge for observing any correlations for these fast fluctuations.

References

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