# Progress in Spacecraft Environment Interactions I: Assessment of Spacecraft Charging Hazards on the International Space Station

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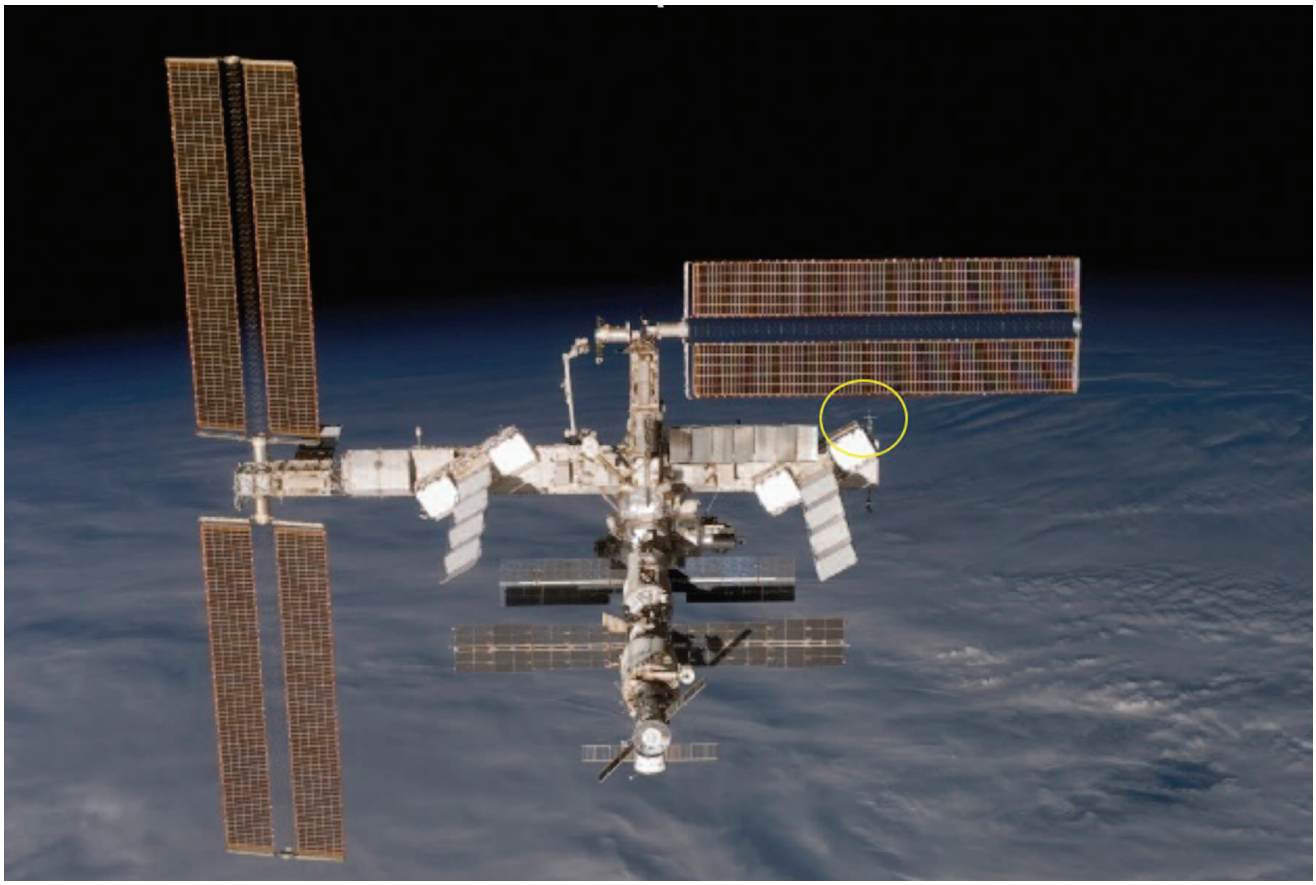


***Fig. 1.*** *ISS build stage and configuration (Stage 12A.1) during the Floating Potential Measurement Unit (FPMU) data session presented in figure 2. The location of the FPMU is the small + sign-shaped-object marked by the yellow circle. The velocity vector is very nearly parallel to the pressurized elements (Service Module, FGB, Node 1, U.S. Lab) axis, and directed into the page. The velocity vector is perpendicular to the truss structure.*

Orbital inclination (51.6 deg) and altitude (nominally between 350 and 460 km) determine the natural environment factors affecting the performance and reliability of materials and systems on the International Space Station (ISS). ISS operates in an electrically conductive low-pressure ionized gas (plasma) medium, which is the F2 region of Earth's ionosphere, while flying through the geomagnetic field at orbital velocity. ISS is also exposed, albeit infrequently, to geomagnetic storm and auroral electron environments during the high-latitude portions of the orbit.

The dominant spacecraft charging processes affecting ISS are: 1) magnetic induction, or motional electromagnetic force, caused by flight of a large metallic vehicle at orbital speed through Earth's magnetic field; 2) the interaction of the 160V U.S. solar array wings (SAWs) (in a negative polarity electrical system ground/common configuration) with the Earth's ionospheric plasma; and 3) possible auroral (energetic precipitating electrons) charging of ISS and extravehicular activity hardware at high latitudes.

## Progress in Spacecraft Environment Interactions I: Assessment of Spacecraft Charging Hazards on the International Space Station *continued*

From elementary gas kinetics and plasma physics, we know that any object immersed in a plasma will collect charge until the electrical potential of the object relative to the surrounding plasma (the floating potential [FP]) prevents further charge collection. Because electrons are much less massive than ions, and are correspondingly easier to collect, the surface and structural potentials of a small (<10 m) satellite in low-Earth orbit will be on the order of -1V to -5V. If the satellite is larger (>10 m) and is equipped with a high-voltage electrical power system (EPS) configuration that can interact with the F2 plasma, a much higher FP is possible as was observed on many ionsopheric space probes. Finally, if spacecraft latitude is high enough (50 to 90 deg), and the ionospheric plasma density is low enough, the auroral electron environment may charge the spacecraft to even higher voltages as has been reported for the Defense Meteorological Program satellites, among others.

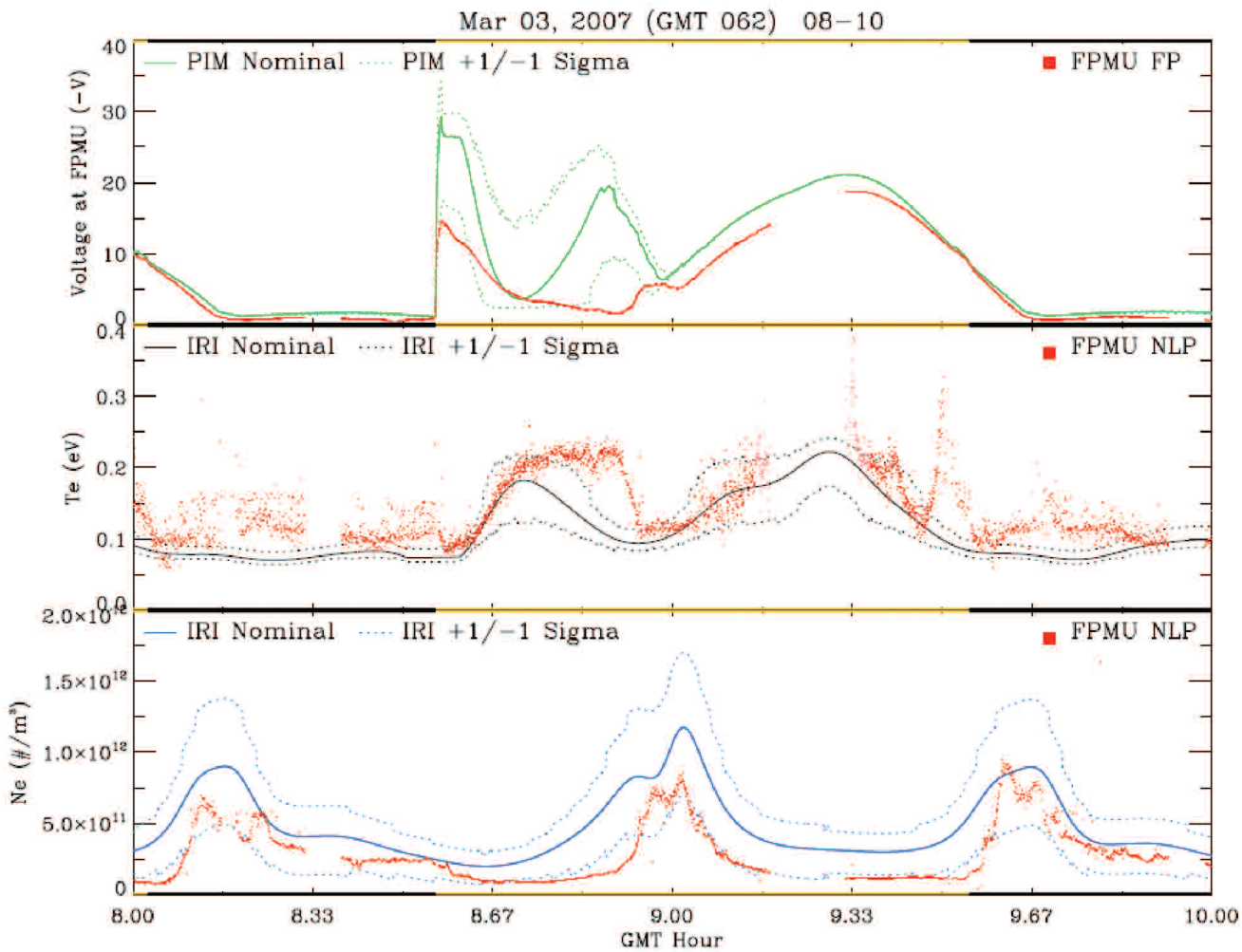
Early in development, ISS was expected to generate hazardous FP values on conducting structure as a result of the combined effects of magnetic induction on such a large spacecraft and high-voltage SAW/EPS interactions with the ionosphere. If the magnitude of structure FP is great enough, thin dielectric surface coatings on exposed conductive structure (most but not all of the ISS external structure) can collect an electrical charge of opposite polarity from the F2 plasma until dielectric breakdown arcing may occur because the voltage gradient across the thin surface film is so high.

Early preflight estimates of the ISS FP were on the order of -140V during the eclipse exit to orbital noon portion of every orbit. For that reason, ISS is equipped with a set of two plasma contactor units (PCUs) designed to provide a low-impedance return path to the ionosphere for electrons collected by the high-voltage photovoltaic system. Subsequent ISS flight data have shown that the PCU system effectively limits FP to values less than -40 V on the truss and pressurized elements, as required. When the PCUs are not operating, the spacecraft charging processes mentioned above do cause a negative FP to develop, although the magnitude and duration of the negative FP values are far less severe than suggested by the early preflight estimates. The need to develop and validate a new, valid ISS spacecraft charging model was obvious.

The ISS Plasma Interaction Model (PIM) is the new ISS spacecraft charging model. It is used with the most current version of the International Reference Ionosphere (IRI), which predicts a climatologically average ionosphere along the ISS orbital flight path for the range of dates and times of interest. Real ionospheric variability about the climatologically defined mean is determined by comparing IRI predictions to the relevant satellite and incoherent scatter radar measurements used to build the IRI model producing the ISS Ionospheric Variability Specification (IVS). The IVS enables calculation of probabilities of occurrence of ionospheric environments differing by some number of standard deviations ($\sigma$) from the climatologically defined mean. Verification and validation of the PIM/IRI/IVS ISS spacecraft charging forecast tool is in progress as ISS build and operations continue using the Floating Potential Measurement Unit (FPMU).

ISS charging in any particular ionospheric environment depends on a number of spacecraft configuration and operational factors, such as: 1) orientation of the active SAW surface to the velocity vector; 2) SAW solar illumination conditions; 3) SAW regulation, spacecraft flight attitude relative to the velocity vector; and 4) ISS build stage. For any particular ISS configuration, charging increases as electron density (Ne) increases and decreases as electron temperature (Te) increases. So, a severe charging environment corresponds to a high Ne and low Te ionospheric environment.

The FPMU, recently deployed on ISS, is providing ongoing measurements of ISS charging as construction continues with the addition of more 160V SAW modules, truss segments, and pressurized modules and has already provided important direct verification of the PIM/IRI/IVS charging forecast tool across one major ISS configuration change.




The excellent agreement between the predictions of the PIM/IRI model and FPMU measurements taken during the ISS 12A.1 stage is shown in figure 2. The FPMU measurements have been validated by both inter-instrument comparisons and comparison with ground-based ionsopheric measurements produced by the National Science Foundation ISR facility at Millstone Hill (operated by the Massachusetts Institute of Technology) as well as the global Digisonde Network (University of Massachusetts at Lowell).

*Figure 2: Comparison of FPMU FP/Ne/Te measurements with PIM/IRI predictions for the Greenwich mean time (GMT) date/time shown (March 3, 2007). As ISS enters daylight and voltage builds on the SAWs (between 08.33 and 08.67 GMT), an eclipse exit charging peak is measured by FPMU and is in good agreement with the PIM prediction using the -1σ IRI charging environment (-1σ Ne, 0σ Te). Very high electron temperatures corresponding to >-1σ ionospheric charging environments (> +1σ Te) were observed during the rest of the day pass, so PIM/IRI under-predicts FP with the climatologically defined mean IRI charging environment. The broad peak at 9.33 GMT represents collection of electrons by conducting structure on ISS, driven by magnetic induction charging at high latitude.*