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FINDINGS OF THE JOINT WORKSHOP ON **EVALUATION OF IMPACTS OF SPACE STATION FREEDOM GROUND CONFIGURATIONS**

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ABSTRACT

A workshop to consider the effects of the various proposed SSF grounding schemes was held at NASA Lewis Research Center May 22-24, 1990. Experts from the plasma interactions community evaluated the impacts of environmental interactions on SSF under each of the proposed grounding schemes. The grounding scheme chosen for the Space Station Freedom (SSF) power system was found to have serious implications for SSF design. Interactions of the SSF power system and structure with the low Earth orbit (LEO) plasma differ significantly between different proposed grounding schemes. Environmental constraints will require modification of current SSF designs under any grounding scheme. Maintaining the present, negative grounding scheme compromises SSF safety, structural integrity, and electromagnetic compatibility, and will increase contamination rates over alternative grounding schemes. One alternative, positive grounding of the array, requires redesign of the primary power system in Work Package Four. Floating the array reduces the number of circuit changes to Work Package Four but adds new hardware. Maintaining the current design will affect all Work Packages. However, no impacts were identified on Work Packages One, Two or Three by positively grounding or floating the array, with the possible exception of extra corona protection in multi-wire connectors.

INTRODUCTION:

Interactions of spacecraft with the natural environment have been of concern ever since the Gemini space program. Since that time, much has been learned of spacecraft/environment interactions, especially as new technology has been developed and flown.

Space Station Freedom (SSF) represents a significant increase in spacecraft size and power levels. Old rules of thumb must be re-examined and their validity retested before applying them to the new technology. In the 1980's, with the advent of the STS, efforts were begun to understand how large spacecraft interact with the ionospheric plasma. By 1986, recommendations were made to ground SSF to the positive side of its arrays. Many engineers in Work Package 4 used a positively grounded array as a baseline at a time when the primary power distribution system was AC. In 1989, when the primary power changed to a DC distribution system, power system designers assumed a negatively grounded system. However, the plasma interactions community raised concerns about this grounding scheme in meetings of the Space Station Plasma Interactions and Effects Working Group, through a change request proposal to change the grounding scheme to a positive ground, and through letters and conversations with SSF personnel.

On May 22-24, 1990, experts on the Low Earth Orbit (LEO) environment plasma interactions met with engineers from the major Space Station Freedom contractors, and representatives of NASA management to evaluate the impacts of the different proposed power system grounding schemes for Space Station Freedom. It was known that the interactions of SSF with the ambient LEO environment would be quite different for the different grounding schemes. The impacts of these interactions on the safety, weight, feasibility, operating requirements, maintenance and reliability or risk of SSF were in need of evaluation to support an imminent decision on the SSF grounding scheme. The results reported here are the result of that evaluation process. An attempt has been made to bring to bear all known engineering and physical facts about interactions with the LEO environment to evaluate the impacts of all the proposed grounding schemes. An effort has been made to be as quantitative as possible. It is hoped that this report will be a first step in the necessary evaluation of the environmental issues regarding SSF grounding.

The first day of the Workshop was devoted to presentations about what we can expect in the way of grounding-related SSF environmental interactions, how they may be estimated, and what kinds of answers need to be obtained. Ground rules for the next day's calculation sessions and the basic premises of the Workshop were presented. These basic premises are repeated below:

- SSF operations and designs can be optimized by including considerations of physical processes of environmental interactions.
- In LEO, current balance will be satisfied - positive and negative collected currents must balance.
- The grounding configuration chosen for the Space Station will influence all systems.
- Our understandings of the laws of physics (models, theories, equations, empirical guidelines) are sufficient that some predictions of the interactions and their impacts may be made.
- No one wants a SSF that won't work well.

On the following day, the Workshop split up into four working groups, The FLOATING POTENTIALS AND GROUND CURRENTS WORKING GROUP, the ATOMIC OXYGEN, SPUTTERING, MATERIALS DEGRADATION AND CONTAMINATION WORKING GROUP, the CORONA, ARCING, AND INSULATION WORKING GROUP, and the ARC RATES AND EFFECTS, EMI, AND KAPTON PYROLIZATION WORKING GROUP. Much of the following is the result of their calculations and estimates.

SPACECRAFT/PLASMA INTERACTIONS:

The ionosphere in LEO is a conductive plasma. Any spacecraft placed in this environment will come to an equilibrium potential relative to the plasma such that no net current is collected. If the spacecraft has a distributed voltage (driven, perhaps, by an illuminated solar array) which permits currents to be collected from the plasma, then part of the spacecraft will be positive relative to the plasma potential ("zero volts"), collecting electrons, and the rest will be negative relative to the plasma, collecting ions. The electrons are very light, mobile, and easily collected. The ions are massive, slower moving, and difficult to collect. Therefore, the total spacecraft voltage relative to the plasma will be such that most of its area will be negative of the plasma potential and only a small part will be positive. Figure 1 illustrates these points. It also shows that if a spacecraft structure is grounded to the positive side of the solar array then it will be near zero volts because its surface area adds to the surface area which can collect electrons. If the spacecraft is grounded to the negative side of the solar array it will be driven negative by most of the array-generated voltage. Many experiments on the Space Shuttle and free-flying LEO spacecraft have shown these concepts to be sound.

In the past, these effects have been seen on spacecraft in LEO conditions, but the voltages and spacecraft sizes were such that they only had to be considered in correcting and interpreting results of scientific experiments. However, the physical size and voltage level of the SSF power system require that plasma effects be considered in the design.

BASIC ASSUMPTIONS ABOUT THE SSF POWER SYSTEM:

The objective of this workshop was to investigate the consequences of various grounding schemes. In order to justify the practicality of the grounding configurations chosen for evaluation, some features of the power distribution system were noted. Details of the power system are discussed in reference 1.

With this background three possible grounding configurations were identified. Additional configurations may be identified but their consequences are covered in this set, and they give rise to additional levels of impracticality.

The first configuration identified has the array grounded with the primary power distribution on its negative side and the secondary power distribution also grounded on the negative side. This is the concept currently being used to design the power distribution system [Fig. 2].

The second configuration is to ground the array and the primary power system positive, and ground the secondary power distribution negative. The ground reference would change sign across the transformer in the DDCUs (DC to DC Converter Units). The primary power distribution system would have positive referenced circuitry [Fig. 3].

The third configuration would float the solar arrays and negatively ground both the primary and secondary power distribution systems. For this configuration a DDCU would have to be added outside the alpha joint, either in the DCSU (DC Switching Unit) or just after the SSU (Sequential Shunt Unit). This may require an additional DDCU for each solar array mast. Such a DDCU would have different requirements than the DDCUs which convert to the secondary power system and, in general, will not have interchangeable parts. This would permit most of the power distribution circuitry to have a negative ground. But the SSU and some support circuitry might need to be grounded separately and electrically isolated from the rest of the system [Fig. 4].

PLASMA/SSF GROUNDING:

If the structure is grounded to the negative side of the array, the structure/array will float nearly the entire array voltage negative in the daytime (about -150 to -130 V negative of the ionospheric plasma). This is to balance the positive ion collection by the structure and array with the electrons collected by the array [Figure 2]. At night, when no voltage is generated by the array, the structure will be near plasma potential.

With the structure grounded to the positive side of the array, the positive structure is electron collecting, while nearly the entire array must be ion collecting to balance this [Figure 3]. As a result the structure is only slightly positive relative to the plasma. However, the negative side of the array now floats nearly 160 V negative relative to plasma.

A floating array would permit the array to float relative to plasma, and permit the structure to float near plasma potential [Figure 4]. This option combines some environment interactions advantages with a slightly reduced arc probability due to the slightly more positive floating array.

IDENTIFIED IMPACTS OF GROUNDING SCHEMES ON SSF:

Grounding configurations considered in this effort were:

1. Solar arrays (SA), primary power distribution (PC), and secondary power distribution (SC) all grounded negative.
2. SA and PC grounded positive and SC grounded negative.
3. SA floating, but both PC and SC grounded negative.

Some of the relevant effects of these configurations are presented in matrix form in Table I. This table gives both advantageous and disadvantageous impacts. Additional details of the impacts, the methods used to quantify and evaluate them, and detailed recommendations on implementing the different grounding schemes can be found in reference 1.

SUMMARY:

There are technical problems with all grounding designs which will affect SSF's costs and/or schedule. They arise for a variety of reasons, involving design changes to accommodate identified deficiencies in the current design or to accommodate the alternative grounding schemes.

Present design (Negative Ground):

The present design grounds all systems negative, and ties the ground to the negative side of the array. This will cause SSF ground and structure to float 130 to 150 V below plasma. Safety concerns are raised because of the 140 V difference between SSF and free flying bodies such as the docking of Shuttle or astronauts on EVA. Interlock mechanisms will need to be incorporated to prevent thruster firings or venting events while these other bodies are connected to or touching SSF because such events will cause currents through the spacecraft body or the Extravehicular Mobility Unit (EMU) of about 10 amps. Alternatively, active charge control systems (hollow cathodes or other plasma contactors) could be used to limit potentials. However, these will increase the plasma density around the entire SSF and will exacerbate other interactions (such as array current collection).

Arcs will occur on the structure. The present anodized surface will break down under the electric field imposed on it. Arcs will be triggered by micrometeoroid impacts, but their characteristics are unknown. Arcs analogous to solar array arcs may occur on the structure.

The SSF structure design will need to be re-evaluated. Erosion rates are increased because of sputtering by ions accelerated by the -140 V structure potential to holes in the anodization caused by dielectric breakdown or debris impacts. This will compromise the structural integrity of the trusses in from five to thirteen years.

Large currents that violate present EMI requirements will occur. In addition to the solar array related currents, a current of about one Amp DC is expected because of leakage currents through the structure anodization. This will increase over the lifetime of SSF. Voltage transients of 160 V and current transients of about 10 Amps are expected during thruster firings. During arcs, similar voltage swings and transient currents up to 100 Amps may occur. Additional shielding may be required on equipment.

Finally, contamination rates on Solar Arrays, Thermal Coating, and Optics will be increased because of the increased sputtering of the structure.

Positive ground:

In order to ground the solar array and primary power distribution positively while maintaining negative ground on the secondary power system, Work Package Four will have to redesign the primary power distribution system. Either NPN technology will have to be replaced with PNP technology or circuits will need to be more complicated. Also the DDCUs will need minor modifications for their insulation to survive increased corona occurrence, as will multi- wire connectors. Solar array arcs have a slightly higher risk of occurring because of the -160 V maximum negative potential rather than the -140 Volts on the negative grounded system. The sputtering problem on the solar arrays will be slightly increased.

Floating:

In order to float the array, new hardware will be needed. New additional DDCUs will be required. These DDCUs will not be parts-compatible with the other DDCUs because they must tolerate higher voltages, higher power levels, and higher corona levels.

Summary of impacts:

Environmental constraints require modification of present SSF designs. Maintaining the current grounding scheme compromises Safety, Structural Integrity, Electromagnetic Compatibility, and will increase contamination rates. Positive grounding of the array requires reworking of the primary power system, which impacts Work Package Four. Floating the array reduces the number of circuit changes to Work Package Four but adds new hardware.

TABLE I. PRIMARY POWER GROUNDING CONFIGURATION ASSESSMENT

IMPACTS CONFIGURATION	ADVANTAGEOUS IMPACT	DISADVANTAGEOUS IMPACT
Modules/Truss grounded to negative end of solar array (current design approach - see Fig. 2)	o -140 V vs -160 V max potential on solar array with respect to plasma (a minimal advantage)	o All Work Packages impacted by plasma effects o Safety (EVA/Docking) compromised by induced voltages and 10 amp current through EMU vents o Thermal control materials must be re-evaluated, redesigned or substituted o Truss structure seriously questionable in 5-13 years o Large plasma-induced currents and voltages to be accommodated o Contamination increased by sputtering o Conducted EMI requirement not met
Modules/Truss grounded to positive end of solar array (see Fig. 3)	o Module/Truss voltage near plasma potential eliminates structural sputtering, insulation req. o Thermal coatings: no change o Minimum plasma/structure current o No new EVA/Docking safety problems o Keeps impacts & redesign issues in a single Work Package	o 200 V vs 160 V maximum DC potential in power connectors to DDCU o Redesign of DC-DC Converters required o Corona design requirements increased in DDCU o Redesign of primary power control circuitry
Modules/Truss floating with respect to solar array (see Fig. 4)	Same as above	o Corona design requirements slightly increased in new, additional DDCU o Design new DDCU (160 V to 160 V) o Redesign of solar panel power control circuits

Maintaining the current negative ground design will affect all Work Packages. However, no impacts were identified on Work Packages One, Two or Three by positively grounding or floating the array, with the possible exception of increased corona protection in multi-wire connectors.

REFERENCES:

1. Ferguson, D.C., Snyder, D.B., and Carruth, R., *Report of the Joint Workshop of the Space Station Freedom Plasma Interactions and Effects Working Group, the Space Station Freedom Plasma Working Group, and the Space Station Freedom EMI/EMC and Electromagnetic Effects Working Group on Evaluation of Impacts of Space Station Freedom Grounding Configurations, May 22-24, 1990,* in publication.

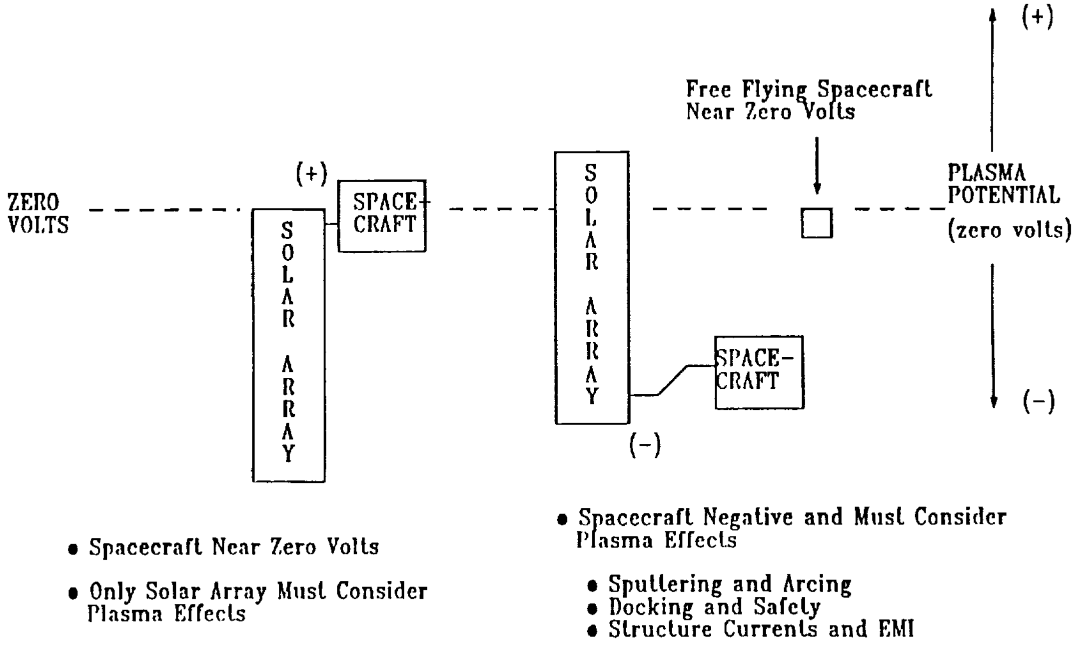


Figure 1. How a spacecraft with High Voltage Solar Arrays floats in the plasma.

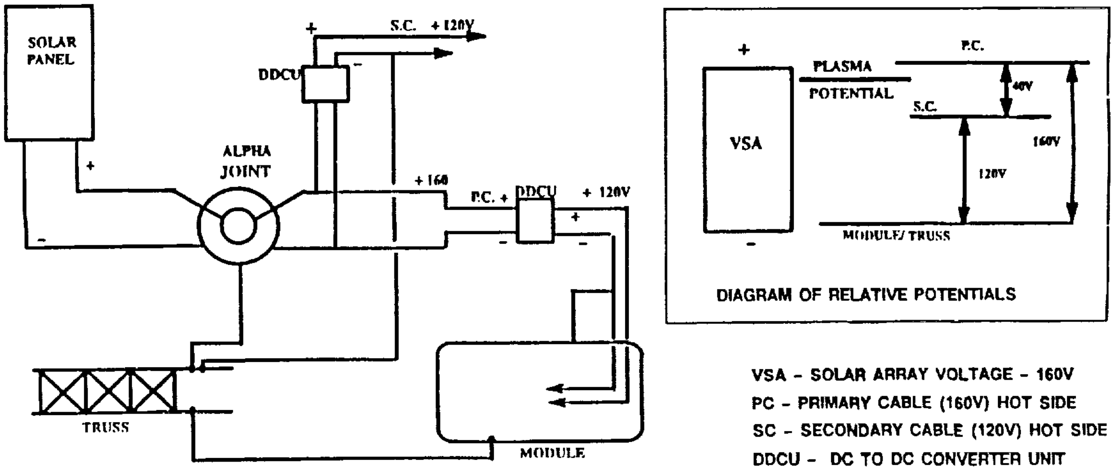
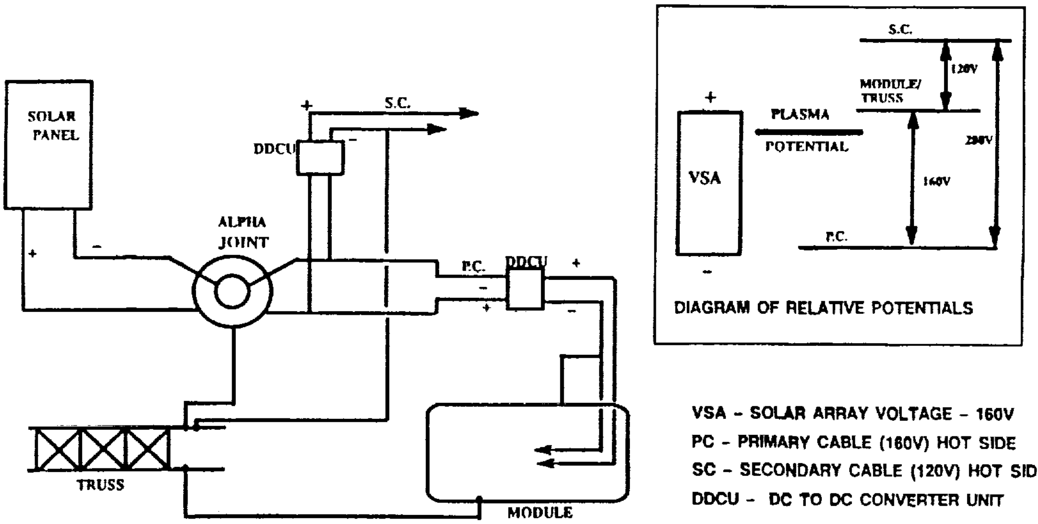
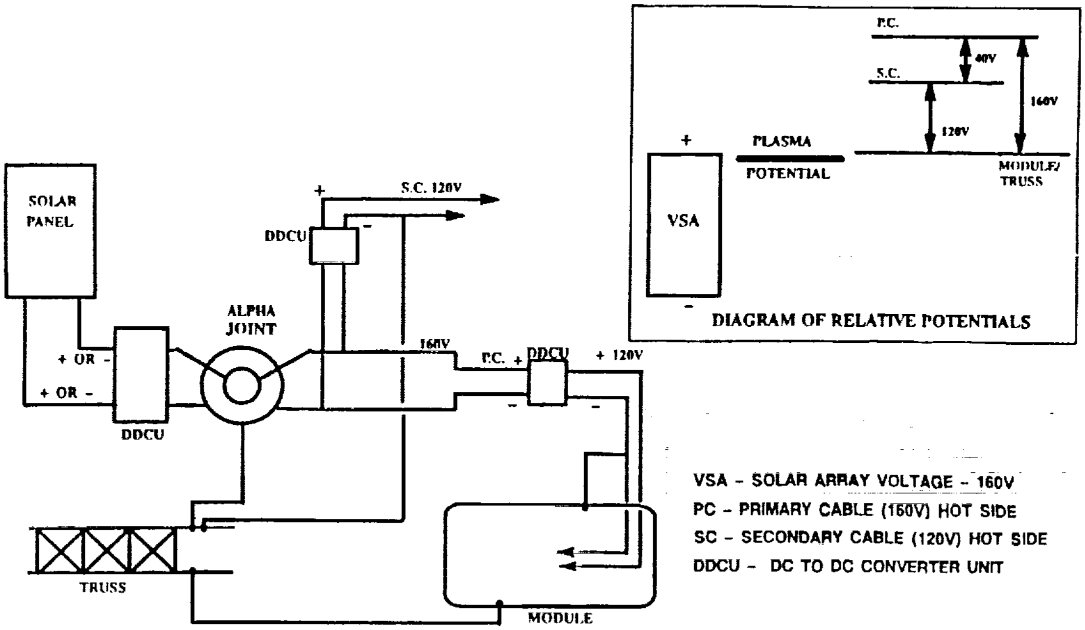


Figure 2. The presently baselined SSF Negative Ground Configuration.



VSA - SOLAR ARRAY VOLTAGE - 160V
PC - PRIMARY CABLE (160V) HOT SIDE
SC - SECONDARY CABLE (120V) HOT SIDE
DDCU - DC TO DC CONVERTER UNIT

Figure 3. A Positively Grounded Solar Array with Negatively Grounded Secondary.



VSA - SOLAR ARRAY VOLTAGE - 160V
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SC - SECONDARY CABLE (120V) HOT SIDE
DDCU - DC TO DC CONVERTER UNIT

Figure 4. Floating the Solar Array and Negatively Grounding the Secondary Power.