

WORKING GROUP REPORT ON ADVANCED HIGH-VOLTAGE  
HIGH-POWER, AND ENERGY-STORAGE SPACE SYSTEMS

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## I. INTRODUCTION

Space systems in the future will probably include high-voltage, high-power energy-storage and -production systems. Two such technologies are high-voltage ac and dc systems and high-power electrodynamic tethers. Here high-voltage systems are ones in which the voltage significantly exceeds one or more of the characteristic energies associated with the surrounding plasma or surfaces. Two of the characteristic energies are the electron temperature and the ionization potential of the neutral environment. An understanding of this synergistic interaction is crucial to optimizing the operation of these systems.

The working group identified several plasma interaction phenomena that will occur in the operation of these power systems (see Table 1). The Space environment will induce arcing and power leakage in these systems, which can be especially significant since they are high-power systems. The environment will also couple to the system through electromagnetic interference and high-energy radiation, which has associated with it all the well-known charging issues. In the other direction, these power systems will couple to the environment in many ways. These include induction of electromagnetic waves in the environment, sheath structures that may be detached, outgassing into the environment and the possibility of ionization of the outgassed products, and deposition of large-scale plasma clouds and currents in the vicinity of the power system. All of these things may lead to long-term modification of the space environment that will then affect how the environment modifies the system.

The working group felt that building an understanding of these critical interaction issues meant that several gaps in our knowledge had to be filled (see Table 2). Such gaps will be filled by creative use of predictive theory, modeling, and definitive experiments. It was felt that definitive experiments were hampered in two ways. First, the measurement technology for designing definitive experiments often does not exist. For example, it was felt that developing techniques (and appropriate hardware/software) for measuring distribution functions rapidly and in detail was critical for understanding in all areas of plasma interactions. Second, the engineering community needs to build an understanding of how to scale appropriately from ground-based to space-based experiments. Without such understanding, the value of ground-based experimental results is never clear.

The working group felt that certain aspects of dc power systems have become fairly well understood. Examples of these are current collection in quiescent plasmas and snap over effects. However, high-voltage dc and almost all ac phenomena are, at best, inadequately understood. In addition, there is major uncertainty in our knowledge of coupling between plasmas and large-scale current flows in space plasmas. These gaps in our knowledge will be addressed in the following paragraphs.

## II. AC PLASMA INTERACTIONS

There is very little available knowledge about terminal properties, including current collection and impedance, of devices that can radiate large amplitude ac into the space-plasma environment. We therefore are unable to predict plasma coupling, plasma heating, plasma instabilities, plasma noise, plasma-wave generation and the effects of these interactions on communication systems, power systems, and on-board experiments. Time-varying sheaths induced by high-voltage ac systems will induce unknown effects in other systems nearby.

We therefore need to develop the ability to numerically simulate ac-electrode-plasma interactions. Large-scale space experiments also appear crucial. We need both of these in order to gain understanding and the ability to predict for design purposes. Otherwise, we will be unable to design any large-scale, large-amplitude system.

## III. CURRENT COLLECTION IN TURBULENT MAGNETOPLASMAS

Our fundamental understanding of plasma-turbulence mechanisms, especially in strong magnetic fields, is deficient and therefore we are unable to evaluate, in advance, the degree of turbulence and therefore its effects on the coupling currents between spacecraft components and their surroundings.

We therefore cannot intelligently design time baselines for concurrent running of various kinds of active space experiments. We therefore need ground experiments followed by larger-scaled experiments in space, involving turbulence generated by active experiments. We also need experiments in which high voltage on spacecraft surfaces is produced in some way other than by beam emissions.

## IV. HIGH-VOLTAGE DISCHARGING

We do not know how to reliably predict surface flashover, breakdown thresholds, and system impacts including discharge currents, total released charge, and resulting EMI effects, in anything except simple situations already tested. We do not understand the mechanisms involved in surface flashover, and our understanding of negative-potential arcing contains important deficiencies. This will endanger operations of power systems for the space station. Induced RF noise from discharges can also disrupt communications.

We therefore need a vigorous program of ground tests that will reveal the mechanisms governing all types of arc discharge and will elucidate methods of controlling these.

## V. RAM/WAKE EFFECTS AT HIGH VOLTAGE

We have very little experience in trying to understand ram/wake effects at high voltages. We therefore are limited in our ability to make detailed predictions of effects of the near-wake plasma environment on operational systems. This will increasingly affect our ability to design proposed arrangements of system components to avoid harmful interactions as these become progressively more complicated.

We therefore need a vigorous program of theory and simulation, together with ground experiments in order to extend our existing knowledge of lower-voltage spacecraft wake phenomena to high-voltage situations that will arise as a result of planned space activities and system designs.

## VI. PLASMA-PLASMA, PLASMA-SYSTEM, AND PLASMA-CONTACTOR INTERACTIONS

The coupling between two or more distinct plasmas has been identified as a science/technology issue pertinent to large high-voltage systems. Such plasmas may be intentionally generated, or appear as an undesirable contaminant. Our present level of understanding is not sufficient to accurately model the interaction as potentially dangerous to anticipated systems. For example, a contactor plasma, expected to ground a structure while coupling a large current to the ambient plasma, could develop instabilities that would open the circuit, disrupt the power system, and create unwanted exotic plasma effects. Existing theory and experiment, some borrowed from other contexts, can be utilized to design new experiments, theoretical studies, and simulations to directly address this issue.

## VII. TETHERS

We do not know how large-scale current flows move through the ionosphere including what limits the magnitude of such currents and how substantially they perturb the exosphere.

This is an essential element in the production of power using electrodynamic tethers, and may have an important impact on any system with impressed voltages separated by large distances. "Large" here means large compared to sheath size and ion gyroradii so that nonlocal currents are driven in the plasma.

To address this issue we need to develop theories for ionospheric nonuniformities on a large scale, and for flows around large (several gyroradii) structures. Space-based experiments are critical. These should include large space experiments to examine current flows and STS-based experiments for testing closure. Remote measurements of flows should also be attempted, to trace the "circuit" or flow paths.

Finally the working group felt that all of this suggested work needs to be performed in concert with the technology development. We suggest that a system of guidelines be developed early to direct work. These guidelines will have to be somewhat device specific in that a power system such as a tether is not free to match low-voltage specifications.

In general though, such systems as a solar power array should have an upper voltage specified in advance so that theory and experiment can be developed with a specific goal in mind. For an "early" system such as the space station, this should be done as rapidly as possible for all development considerations. For later facilities, guidelines should allow for future growth within these systems rather than guaranteeing a "planned obsolescence."

Table 1. Plasma Issues

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environment --> system	system --> environment
Arcing V X B induced potentials EMI	EMI Sheaths Ionization Grounding issues Plasma couplings Closure path Amount of current How big a region Disturbance of large regions of the ionosphere Long-term modification of the environment - heating, mass additions to the environment

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Table 2. Gaps in Our Knowledge

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All ac interactions with plasma High voltage ac/dc interactions with plasmas Coupling between plasmas Large-scale current flows Measurement technology
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