IAC-02-IAA.6.3.02

LEO Spacecraft Charging Guidelines

G.B Hillard and D.C. Ferguson
NASA Glenn
Cleveland, OH, USA

53rd International Astronautical Congress
The World Space Congress - 2002
10-19 Oct 2002/Houston, Texas

LEO SPACECRAFT CHARGING GUIDELINES

G.B. Hillard and D.C. Ferguson
NASA Glenn Research Center
Cleveland, Ohio USA
grover.b.hillard@grc.nasa.gov

ABSTRACT

Over the past decade, Low Earth Orbiting (LEO) spacecraft have gradually required ever-increasing power levels. As a rule, this has been accomplished through the use of high voltage systems. Recent failures and anomalies on such spacecraft have been traced to various design practices and materials choices related to the high voltage solar arrays. NASA Glenn has studied these anomalies including plasma chamber testing on arrays similar to those that experienced difficulties on orbit. Many others in the community have been involved in a comprehensive effort to understand the problems and to develop practices to avoid them. The NASA Space Environments and Effects program, recognizing the timeliness of this effort, has commissioned and funded a design guidelines document intended to capture the current state of understanding. We present here an overview of this document, which is now nearing completion.

INTRODUCTION

Historically, power systems on US space vehicles have operated at the nominal 28 V dc inherited from the aircraft industry. At such low voltages, plasma interactions in LEO are negligible and have not been a consideration in spacecraft design. High power systems now being deployed for space applications operate at higher voltages in order to reduce power loss and system mass. The emergence of such systems is motivated primarily by a desire to save weight. Since the resistance of the necessary cabling is a strongly decreasing function of mass per unit length and cable losses are proportional to current squared, it is desirable to furnish power at higher voltages and lower currents. A further consideration is the reduced effect of magnetic interactions (torque and drag) that will follow from low current operation.

While high voltage systems are clearly desirable to the power system designer, they suffer the drawback of interacting with the ionospheric plasma in several different ways. First, conducting surfaces whose electrical potential is highly negative with respect to the plasma undergo arcing. Such arcing not only damages the material but results in current disruptions, significant EMI, and large discontinuous changes in the array potential.

One of the difficulties in predicting the onset of arcing has been the realization that the threshold potential for arcing depends critically not only on the design of the solar cells, but also in the manner cells are laid down and connected. In the early 1990's traditional wisdom focused on the observation that silicon cells using traditional silver-coated interconnects exhibited a threshold potential for arcing of about -230 volts relative to the plasma. Yet, since that time, catastrophic failures have occurred on operating solar arrays at much lower voltages.

An additional effect that plagues surfaces at high negative potential lies in the fact that inbound ions, accelerated by the high fields, cause sputtering from surfaces with which they impact.

For solar arrays or other surfaces that are biased positively with respect to the plasma, a second effect occurs. Such surfaces collect electrons from the plasma, resulting in a parasitic loss to the power system. Since the mass of an electron is much less than an ion, the magnitude of current density is much greater for surfaces with positive bias. At bias potentials greater than about 200 volts, sheath formation and secondary electron emission from the surface causes the entire surrounding surface, normally an insulator, to behave as if it were a conductor. This effect, often referred to as "snapover", results in large current collection from even a very small exposed area.

Besides producing a power loss, currents collected by biased surfaces will significantly affect the potentials at which different parts of the spacecraft will "float." Because of their large mass and low mobility, ions collected by negatively biased surfaces result in a relatively small plasma current density. The lightweight electrons, on the other hand, are readily collected by positively biased surfaces. Ram and wake effects further complicate the picture. Ram energy is considerably higher than ambient thermal energy so ram flow enhances ion collection relative to surfaces that are oblique to plasma flow.

The spacecraft, reacting to these various current sources, must necessarily reach equilibrium at whatever potential results in a net collected current of zero. The worst situations occur when the spacecraft power system uses a negative ground. In such a configuration, large surfaces are negative and must collect slow moving ions to balance the current from electron collection that now occurs only from relatively small areas of positive surface. In the worst case, parts of the spacecraft will be biased with respect to the ionosphere to a level very near the maximum voltage used on the solar arrays.

As experience has accumulated within industry and government, the need to capture the state of understanding has become pressing. Recognizing this, the Space Environments and Effects (SEE) program, managed by the Marshall Spaceflight Center, has commissioned and funded a series of software design tools and guidelines documents to aid the spacecraft community. The latest of these efforts is the document reported here, which focuses of high voltage interactions in Low Earth Orbit (LEO).

OVERVIEW

The final document is divided into two parts. The first is the design guidelines proper, which will be briefly outlined below. Additionally, it was felt by the authors as well as by the SEE program that it was advantageous at this time to provide a comprehensive citation of all relevant publications. To this end, the NASA CASI database was extensively searched and a compilation assembled of over 300 relevant publications. These citations, which are provided in the complete CASI format, appear in a separate appendix to the report. Each citation is given a separate page so that header information appears at the top, allowing a quick scan for relevant topics. Additionally, the appendix, like the master guidelines document, was assembled with Microsoft Word as its native format. Conversion to PDF leaves the citations fully searchable.

The guidelines document itself is divided into seven sections, which begin with a brief preface. The remaining six sections are summarized below.

Introduction

The introduction is divided into three subsections. The first introduces the reasons for the current widespread move to high voltage systems, in particular the weight savings to be achieved. A subsection that defines LEO in terms of altitude and latitude follows. While such definitions are somewhat arbitrary, we have made the distinction based of the interactions to be expected. The final subsection introduces the various plasma interactions that are relevant to high voltage systems in LEO.

Environments

The environments section introduces both the ambient and induced environments that spacecraft will experience in LEO. The ambient is further subdivided into the neutral atmosphere and the plasma environment. Basic properties of each are summarized with references to models that may be used to predict environmental properties. The contamination-induced environment is treated with several examples of the changes made to the natural environment by a spacecraft's operations or even by its mere presence.

Plasma Interactions

The fourth section, which reviews the relevant plasma interactions, is the longest in the work. There are two large subsections that deal with current collection and with arcing respectively. The part on current collection begins with an overview of the basic physics with particular attention to the current balance condition and to sheath effects. With this background, we next present the current state of knowledge concerning current collection by structures and the resulting spacecraft charging problem. The next topic treats both ion and electron collection by solar arrays and introduced the engineering challenges posed by snapover and by parasitic power drain. The current collection subtopic ends with brief discussions of collection at high frequencies and of wake effects.

The second major subsection, which covers arcing, opens with an overview of the current state of knowledge of arcing on solar arrays. Lower level subsections deal with initiation mechanisms, arcing thresholds, typical waveforms, system responses to an arc, and damage potential. The arcing section concludes with subtopics on EMI and on structure arcing, which introduces the highly destructive continuous arc.

Mitigation Techniques

The fifth section, on mitigation techniques, is also divided into current collection and arcing. The emphasis is on controlling spacecraft potential. Techniques for preventing the problem in the first place focus on grounding schemes that are more compatible with the plasma environment. When this is not possible, mitigation techniques such as plasma contactors are described. The subsection ends with topics on the encapsulation of solar arrays and on the use of vented enclosures.

The arcing subsection opens with a subtopic dealing with on-orbit detection of arcs. It is followed with an overview of mitigation techniques and lessons learned that are specific to solar arrays.

Modeling

The sixth section, on modeling, is almost entirely concerned with current collection and resulting shifts in spacecraft potential. A wide range of modeling tools are available and are briefly surveyed. Guidelines are presented for their selection and use and an example is provided. The section ends with a discussion of arcing, a stochastic process whose onset is very difficult to predict.

Testing

The final section of the document concerns requirements and guidelines for testing. The discussion covers current collection and arcing and concerns solar arrays as well as material samples.

STATUS

The guidelines have been delivered to the SEE program office, which has submitted them to a number of reviewers. Following receipt of these comments and suggestions, the work will be revised accordingly. The document is expected to be in final form by the end of calendar year 2002. Inquiries concerning access and distribution should be submitted to the SEE program office at the MSFC.