TOWARDS A NEW SURFACE AND INTERNAL CHARGING DESIGN GUIDELINE FOR THE 21ST CENTURY

H. B. Garrett and A. C. Whittlesey
The Jet Propulsion Laboratory
The California Institute of Technology
4800 Oak Grove Dr.
Pasadena, CA 91109
USA
O: 818-354-2644
F: 818-393-4699
Henry.Garrett@jpl.nasa.gov
Albert.C.Whittlesey@jpl.nasa.gov

ABSTRACT

In 2003, Dr. A. R. Frederickson initiated a program to recast and combine the primary guides for mitigating the effects of spacecraft charging. That effort had the ambitious goal of taking the existing NASA guidelines for preventing surface electrostatic charging, NASA-TP-2361 (Purvis et al., 1984), and internal electrostatic charging, NASA-HDBK 4002 (Whittlesey, 1998), and bringing them up to date with recent laboratory and on-orbit findings. With the death of Dr. Frederickson in 2004, that study devolved to the principle authors to complete. This paper will describe the status of those on-going efforts to combine and update the two guidelines with emphasis on the proposed contents and on the differences and similarities between surface and internal charging mitigation techniques. It is planned to have a draft revision ready for review by the spacecraft charging community by the fall of 2005, with 2006 dedicated to implementing reviewers' comments and additions leading to a new, officially approved NASA guideline by the fall of 2006.

INTRODUCTION

Based on extensive laboratory and in-situ data, Dr. A. R. Frederickson proposed that two guides for mitigating the effects of spacecraft charging be updated and combined into a new spacecraft charging handbook. These documents, NASA-TP-2361 (Purvis et al., 1984) and NASA-HDBK 4002 (Whittlesey, 1998), have become the primary handbooks in their respective areas. In fact those authors had long desired to combine the two documents to unify the technical work and to update them with more recent knowledge. Dr. Frederickson, with his intense love of the field and because of his wide ranging research in all aspects of charging would have been the ideal person to implement those dreams. With his death, however, it is left to us to implement his (and our) dream. This paper will briefly describe the two guidelines with emphasis on the differences and similarities between surface and internal charging mitigation techniques. The paper will begin by creating an outline, better described as an overview, for each of the two prior documents. Based upon these two outlines, an outline for the new combined document will be presented that indicates how the two documents will be merged.

OUTLINE FOR TP-2361

Consider first the Purvis, Garrett, Whittlesey, and Stevens document: "Design Guidelines for Assessing and Controlling Spacecraft Charging Effects", NASA-TP-2361 (1984). The table of contents for TP-2361, shown in italics here, forms a reasonable outline of the document. However, TP-2361 deliberately limited its discussions to charging of the outer surfaces of spacecraft based on knowledge at the time. Although it may initially appear plausible that surface voltages can be determined by monitoring charge flows between the outer surface and space plasma, in reality electrical charge deposited anywhere inside the spacecraft also contributes to the charging potentials on its surfaces. The importance of internal charging as a contribution to surface potentials is one reason that TP-2361 needs to be updated and combined with handbook 4002 which specifically addresses internal charging.

TABLE 2. TP-2361 Table of Contents

Contents of TP-2361

Section 1.0, the introduction of TP-2361, describes how spacecraft charging can affect spacecraft operations and spacecraft reliability from the viewpoint of the spacecraft user or designer. There are two primary concerns: a) high surface voltages may distort scientific measurements of the space environment, and b) high voltages can produce violent electrical pulsed-discharges that disturb or destroy portions of the spacecraft. These remain the primary concerns to this day and this section requires only minor changes.

Section 2.0 describes analytical modeling techniques for determining the surface voltages produced by interactions between the spacecraft surfaces and space plasma. It also describes some of the pulsed discharges that had been measured in laboratory testing. Extensive testing since 1984 has provided a much more complete description of the discharge pulsing that may happen on spacecraft. Furthermore, the description of how pulsed discharges couple electrical signals into sensitive systems on the spacecraft needs to be rewritten including more recent references to the literature in the electromagnetic compatibility. This part of the effects on spacecraft is still a work in progress and we are presently uncertain if we can produce an improved product here.

Section 3.0 describes how spacecraft design features can be used to minimize the bad effects of spacecraft charging. Basically, one uses the modeling techniques developed in section 2.0 to minimize the development of high voltages and to minimize the coupling of pulsed discharge signals into sensitive circuits by choosing spacecraft design details that minimize both surface voltage and coupling. Section 3.0 needs be updated with data and models developed since 1984. Additionally, there is a need for "cookbook" design rules to provide a baseline/guideline for design approaches, especially if one is blessed with a mass or power margin, and doesn't have to conflict with thermal control issues.

Section 4.0 describes how one might test and analyze a spacecraft for charging concerns prior to flight. Its emphasis is on minimizing the pulse discharge threat to sensitive systems. Improved testing procedures for both pulsed discharge and material charging have been developed since 1984 and will be incorporated into the new document.

Section 5.0 describes how one might monitor charging and pulsed discharging on a spacecraft, and how one might develop protection systems to minimize both effects. Again, further information is available since 1984.

The overall structure of TP-2361 provided by sections 1.0 through 5.0 appears very reasonable to this day. However, more extensive data has been developed since 1984 that should be included in an updated document. Furthermore significant flaws are inherent in some of the modeling methods (section 2.0) in TP-2361 that require correction. These corrections produce substantial changes in the way that spacecraft should be designed (section 3.0) and tested (section 4.0).

Finally, there are a few other areas that can be improved. The 4002 document provided guidelines, specifically a plot of Earth regions where charging is/may be an issue. We (these authors) have previously computed and presented a "manager's chart" describing regions (altitude and inclination orbits) where surface charging can be an issue. It will be incorporated in the new document. One area of specific interest since 1984 is the use of higher voltage solar arrays and new design accommodations needed to avoid spacecraft charging disasters. Although still a work in progress, the new document will incorporate as much material about this issue as possible.

OUTLINE FOR HDBK-4002

The table of contents for Handbook 4002 is included below in italics for reference in Table 2. Fortunately, Handbook 4002 has an overall structure that can easily be overlaid onto the structure of TP-2361. In particular, HDBK-4002 chapters 1 through 3 satisfy the format requirements for handbook documents and, although they do not relate to any part of TP-2361, will also be required for the new handbook. Chapter 4 in HDBK-4002 corresponds closely to chapter 2 in TP-2361. It describes the physical processes of charging and pulsed discharging by materials and components inside a spacecraft. Internal charging and pulsed discharging are physically similar to surface charging and pulsed discharging with only minor distinctions. The new handbook will bring together these two chapters, 4 and 2, with the addition of newer data into one chapter that covers the physics of charging and pulsed discharging both inside and outside a spacecraft. The new data on the physics of charging and discharging has dramatically improved compared to the data as described in HDBK-4002 and TP-2361.

Chapter 5 in HDBK-4002 corresponds to the combination of chapters 3 and 4 in TP-2361. Chapter 5 describes how charging and discharging affect a variety of spacecraft components. In addition it describes how one tests for the charging and discharging properties of such components. However, improved knowledge of the physics of charging and discharging causes will require changes in many of the descriptions in chapter 5. The distinctions between design practices and testing procedures as is done in TP-2361 will be maintained. Therefore the information in chapter 5 of HDBK-4002 will be split into two chapters in the new handbook, and new data entered in these two chapters.

The existing 4002 document was constrained by page/document limits. A document of this sort must be small enough to be manageable, but we do expect to incorporate more internal charging material in the new document.

TABLE 2. HDBK-4002 Table of Contents

Table of Contents of HDBK-4002

1. SCOPE
- *1.1 Scope*
- *1.2 Purpose*
- *1.3 Applicability*

2. APPLICABLE DOCUMENTS
- *2.1 General*
- *2.2 Government documents*
- *2.3 Order of precedence*

3. ACRONYMS

4. INTRODUCTION AND BACKGROUND TO SPACE PLASMA CHARGING
- *4.1 Physical concepts*

4.2 Plasma
4.3 Penetration
4.4 Charge deposition
4.5 Conductivity
4.6 Breakdown voltage
4.7 Dielectric constant
4.8 Shielding density
4.9 Electron fluxes (fluences) at breakdown
4.10 Electron environment
4.11 Units
4.12 Additional Information
5. PROCESSES AND DESIGN GUIDELINES
5.1 Processes
5.2 Design guidelines
6. NOTES
6.1 General comments
6.2 Sample material list

The table of contents for HDBK-4002 describes a number of specific spacecraft components. In contrast, TP-2361 generally avoids discussion of charging and discharging phenomena for particular components at the surface of spacecraft. By incorporating the descriptive philosophy of HDBK-4002 for internal components into the analysis and design at the surface of spacecraft, it is anticipated that an improved analysis and design (relative to that in TP-2361) for surface components such as high voltage solar arrays and antennas will be attained. These have become important problems for spacecraft, and will be addressed in the proposed new handbook, at least by reference to recent published work. The unfortunate separation arbitrarily imposed in the past between surface phenomena and internal phenomena caused the spacecraft community to overlook these important surface problems (arrays, antennas, others) until they began occurring on spacecraft after 1984.

OUTLINE FOR NEW SPACECRAFT CHARGING GUIDELINES HANDBOOK

Based on the preceding discussion, the list of chapter topics for the new handbook will be as in Table 3. Note that this synthesis includes the important components of both documents. A major objective of the new handbook should be to provide a "one stop shop" for surface and internal charging—a goal which Table 3 addresses.

Other ideas for this new document include possible separation of the "physics" of the phenomenon from the practical and specific design and test guidelines that will be present in the new document. Further, the document will continues to be a work in progress until it is published. Also, the size of the information tables and graphs will be an editing decision. It is impractical to provide all possible plasma spectra for all conceivable mission trajectories (GEO, LEO, polar, jovian, etc.), but some examples will be provided. Similarly, it is desirable to provide specific material parameters and to present specific design options but again, space certainly will not permit placing totally comprehensive tables of material properties. Similar other practicalities will guide the writing of the new document.

TABLE 3. Table of Contents for the new Spacecraft Charging Guidelines Handbook

Spacecraft Charging Guidelines Handbook

1 INTRODUCTION
2 APPLICABLE DOCUMENTS
3 ACRONYMS
4 INTRODUCTION TO THE PHYSICS OF CHARGING AND DISCHARGING
4.1 Physical Concepts.
4.1.1 Plasma.
4.1.2 Penetration
4.1.3 Charge Deposition
4.1.4 Conductivity
4.1.5 Breakdown Voltage
4.1.6 Dielectric Constant

CONCLUSION

This paper has described a program to recast and combine the primary guides for mitigating the effects of spacecraft charging. The goal will also be to bring them up to date with recent laboratory and on-orbit findings as well as perform an editing consolidation of the existing two documents. The paper has described the status of the efforts to combine and update the two guidelines with emphasis on the proposed contents and on the differences and similarities between surface and internal charging mitigation techniques. Again, it is planned to have a draft revision ready for review by the spacecraft charging community by the fall of 2005, with 2006 dedicated to implementing reviewers' comments and additions leading to a new, officially approved NASA guideline by the fall of 2006. We are delighted that there appears to be a renaissance in the understanding of spacecraft charging, its effects, and its mitigation. There are many groups who have been doing excellent work in this field and we have high expectations for the papers delivered at this conference.

ACKNOWLEDGEMENTS

The impetus for this effort was Dr. A. R. Frederickson. In large part, his life-long efforts to bring together laboratory and in-situ studies into a coherent picture of spacecraft charging phenomena has made this possible. It is to him and his memory that we dedicate this talk and hope he looks down on our efforts with pride (HBG and ACW). This research was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

REFERENCES

1) Purvis, C. K., Garrett, H. B., Whittlesey, A. C., and Stevens, N. J., "Design Guidelines for Assessing and Controlling Spacecraft Charging Effects", NASA-TP-2361, September, 1984.

2) Whittlesey, A., "Avoiding On-Orbit ESD Anomalies Due to Internal Charging Effects", NASA-HDBK-4002, February 17, 1999.