NASA's Technical Handbook for Avoiding On-Orbit ESD Anomalies Due to Internal Charging Effects

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Abstract:

This paper describes NASA-HDBK-4002, "Avoiding Problems Caused by Spacecraft On-Orbit Internal Charging Effects". The handbook includes a description of internal charging and why it is of concern to spacecraft designers. It also suggests how to determine when a project needs to consider internal spacecraft charging, it contains an electron penetration depth chart, rationale for a critical electron flux criterion, a worst-case geosynchronous electron plasma spectrum, general design guidelines, quantitative design guidelines, and a typical materials characteristics list. Appendices include a listing of some environment codes, electron transport codes, a discussion of geostationary electron plasma environments, a brief description of electron beam and other materials tests, and transient susceptibility tests. The handbook will be in the web page: http://standards.nasa.gov.

A prior document, NASA TP2361 "Design Guidelines for Assessing and controlling Spacecraft Charging Effects", 1984, is in use to describe mitigation techniques for the effects of surface charging of satellites in space plasma environments. HDBK-4002 is meant to complement 2361 and together, the pair of documents describe both cause and mitigation designs for problems caused by energetic space plasmas.

1. What is Internal Charging?

In contrast to the better known "surface charging", internal charging is an accumulation of electrons that penetrate to the interior of a satellite. The key distinction is that surface electrostatic discharges (ESDs) are often loosely coupled to the interior victim circuits. This handbook is concerned about electrons with sufficient energy to deposit close to a victim circuit so that a resultant ESD arcs directly to a victim circuit (Fig. 1). The implicit assumption is that the spacecraft is a cage, and circuits outside of the cage are protected from surface ESDs. By this definition, electrons must have enough energy to penetrate the spacecraft shell. The shell of most satellites varies from a thin layer of thermal blankets, to a more robust 100+ mils of aluminum or equivalent. (Protons are not usually considered a cause of internal charging problems.) Electrons with a range of energies in excess of 100 keV (capable of penetrating 3 mils of aluminum or equivalent protection) or 1 MeV (about 80 mils protection) (Figure 2) and higher can cause internal charging. In Earth geosynchronous orbits (GEO), the flux above 3 MeV is generally too low to be of concern.

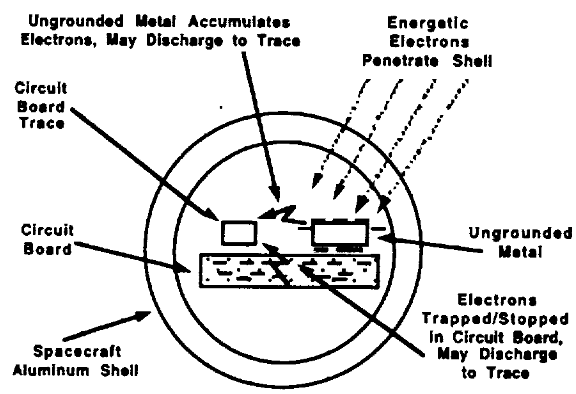

Figure 1. Illustrating Internal Charging

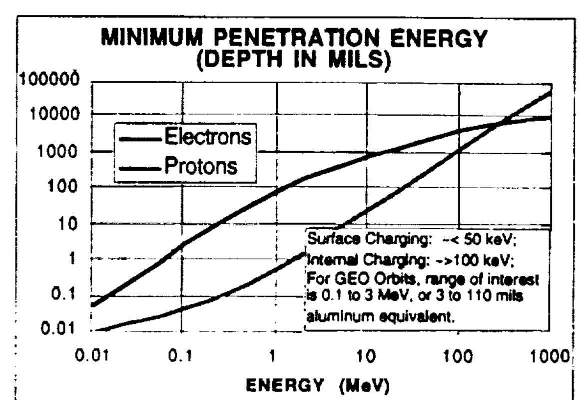

Figure 2. Penetration Depth Curves (Depth in mils of aluminum vs electron energy, MeV)

2. What Satellites Need Internal Charging Protection?

Whether a satellite does or does not need protection from internal charging depends on the energetic electron environment, the degree of shielding, the amount of materials that can accumulate charge, the charge leakage rate, and the sensitivity of the victim circuit. In short, it is not an easy answer. However, there is user experience from on-orbit analysis of various satellites' on-orbit anomalies and there is quantitative data from the CRRES satellite's experiments. These sources imply that the internal charging anomaly threshold is $2x10^{10}$ electrons per square centimeter accumulated over a 10-hour period (equivalent to $5x10^5/cm^2$-s average). An additional safety factor is not specified in the NASA Handbook.

The handbook presents a simple screening method to determine at the start of a project whether internal charging should be considered. The environments where internal charging can be a problem include regions of Jupiter, Saturn, and Earth. A chart has been prepared to serve as an initial screen for circular Earth orbits (Fig. 3). The chart is very simplified and includes numerous assumptions about the environment, victim sensitivity, etc., but provides a quick idea whether internal charging may be of concern. A few common satellite types are noted on this chart for perspective.

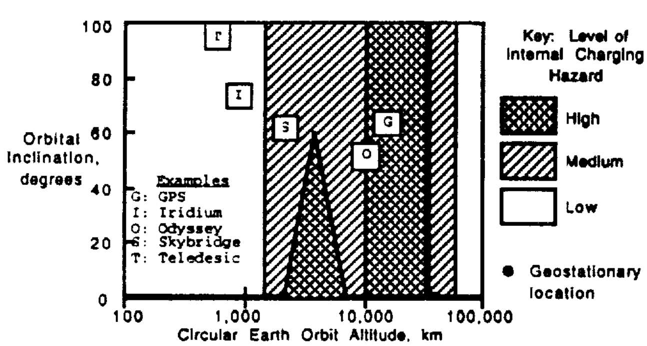

Figure 3. Internal Charging Hazard Regions (GEO ~36,000 km altitude)

3. What is a Worst-Case Electron Environment?

To do an analytic assessment of spacecraft internal charging, the environment must be specified. Then that environment can be used in a particle transport code (using the spacecraft geometry data) to determine the flux into candidate electron accumulation regions (dielectrics and ungrounded metals, such as radiation spot shields, etc.). Fig. 3 shows a few of the typical Earth user orbits. The handbook presents a "worst-case" (greater than 95%-ile) electron integral spectrum for GEO that was derived by first doing a quick screen for high environment days using GOES E>2 MeV data, and then using Los Alamos satellite data to determine an energy spectrum. That result is shown in Fig. 4. Fig. 4 also presents the often-used NASA AE8min electron spectrum for comparison (it was selected to be 200 degrees E longitude, which provides the highest amplitude). As can be seen, the AE8min spectrum, designed to be a long-term average, is substantially lower and is inadequate for internal charging analyses. Internal charging has roughly a 10-hour time scale and the AE8 is on the order of a year. Other orbit environments are not part of the handbook.

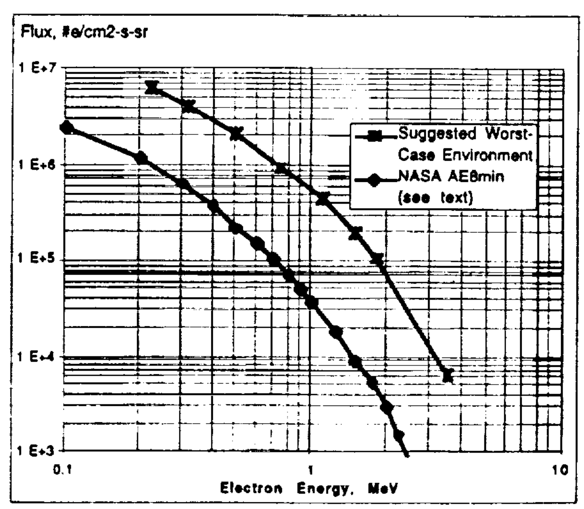

Figure 4. Suggested Worst-Case GEO Electron Environment and NASA AE8min Compared

4. What is Proper Design Against Internal Charging Problems?

Having determined that there may be a problem, the question becomes what to do about it. Conceptually there are simple design ideas to prevent the problem. The practical problem is that materials with the requisite characteristics often do not exist, so the designer usually must resort to solutions that are not simple, or that require mass or extra circuit elements, etc. For example, remembering Figure 3, the most simple is to choose an orbit that is not in a region of concern. Secondly, a simple way to avoid any problems is to prevent the accumulation of charge: use dielectrics that are leaky (10^9 ohm-cm, and grounded, is good enough) and assure that there are no floating conductors in the satellite. Dielectrics are a problem because dielectrics with other desirable characteristics (Teflon, Kapton, FR4 circuit boards, etc.) are more resistive than is desirable for internal charging. Conductors are a problem because of numerous floating items (radiation spot shields, capacitor cans, transformer cores, etc.) and even wiring that may become disconnected from a circuit due to switching at both ends. The simple solution of placing lots of aluminum or equivalent shielding over the whole satellite may add too much mass. To summarize, there is no simple solution to the internal charging problem for a satellite in a potentially hazardous environment. The solution must come from several design features used together, with assumption of risk.

A short list of design suggestions is given here: keep everything inside a grounded Faraday Cage; shield as much as possible ... 110 mils of aluminum (grounded) is usually sufficient for GEO orbits; ground all metallic elements that are not related to ground by virtue of being in a circuit; assure that all circuitry has a chassis ground reference; ground all radiation spot shields; filter ESD-sensitive circuits (to a level of 20 pF and 20 kV if possible); provide a bleed path to ground for all but the smallest size conductors; ground all conductive layers of thermal blankets; protect dielectrics and circuits to the level of 10^{10} e/cm^2 per 10 hours; screen all circuits and protect if they are Class 1 ESD-sensitive (per MIL-STD-883, Method 3015); keep dielectric fields below 100 V/mil.

5. Other Information in the Handbook

The Handbook also contains a representative list of spacecraft materials and their ESD parameters; a listing and brief description of various electron transport codes; additional descriptions of the Earth's plasma environment; an example of a simple internal charging analysis; descriptions of material testing for charging behavior; a list of data sources for plasma environments; and a bibliography with annotations.

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