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PERSPECTIVES ON THE DISTRIBUTIONS OF ESD BREAKDOWNS FOR SPACECRAFT CHARGING APPLICATIONS

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ABSTRACT

Electrostatic discharge (ESD) continues to pose significant risks to space missions despite decades of intense study. Tabulated values of material breakdown strength used in spacecraft charging models are often based on cursory measurements that may not be relevant to a given mission. Materials physics offers insight into the relevant variables that affect breakdown and how to address them experimentally for spacecraft applications. Measured distributions of ESD data across several test configurations, taken together, begin to provide an understanding of how to estimate the likelihood of ESD events as a function of acquired charge over a spacecraft's mission lifetime. We discuss how consequences of these results apply to spacecraft charging modelling and design considerations.

1. INTRODUCTION

Electrostatic discharge (ESD) can cause serious upsets or failures to space assets and continues to pose a challenge to spacecraft designers and modellers [1]. It is critical to mitigate the risk of ESD for mission success, especially as mission lifetimes increase, components become more compact and sensitive, and spacecraft venture into more extreme space environments.

Spacecraft charging effects mitigation standards offer guidelines for spacecraft modellers to design spacecraft systems to be immune to the effects of expected ESD pulse characteristics and frequencies. These guidelines refer to tabulated and estimated values of breakdown voltages, but also emphasize the importance of testing while offering only limited guidance on how to test and even less as to how to interpret the results [2-12].

2. MATERIALS PHYSICS PERSPECTIVE

Dielectric breakdown is a complicated, stochastic, process. In the cases of sensitive missions and/or extreme charging environments the concept of dielectric strength may not be well approximated by a constant value.

Physical models of conductivity and breakdown in insulating materials are driven by electronic defect energies and densities, temperature, applied electric field, the time over which a given set of conditions persists, and the history of the materials (aging) [13]. Assuming static, intrinsic, defect energies and densities, the breakdown strength may vary significantly with extrinsic conditions such as temperature and charging rate. One should also beware of aging effects, contamination, or even variations in manufacturing as any of these can significantly alter charging properties [14-15].

It is impossible to perfectly simulate both flight conditions and durations on the ground; however, considering mission conditions and possible changes in material properties can guide accelerated test methods. Taken together, tests such as the following begin to predict how materials' likelihood for dielectric breakdown can change with different conditions.

First, establish a nominal room temperature breakdown field using voltage step-up to breakdown tests with a moderate ramp rate. Standard test configurations subject samples to up to 500 V/s [2, 4]. Not only is this charging rate much higher than any realistic operational condition encountered by spacecraft, but accuracy and precision suffer as a result. Charging rates of even tens of volts per second result in significantly increased accuracy and precision [16].

Given a baseline, voltage step-up tests at different temperatures or at different ramp rates can be done to determine the dependencies of the material [13]. For example, static voltage endurance time (SVET) experiments hold a sample below its nominal breakdown voltage and measure the time to breakdown. Results can be fit to empirical or physical models in order to extrapolate the results to the comparatively very slow ramp rates and much longer times typical of spacecraft missions [13, 17].

Arcing tolerances and risks will depend on individual spacecraft or systems and space environments. Therefore modellers will have to ask themselves how much risk they can tolerate and how much testing is feasible given budget and time constraints.

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3. CONCLUSION

In summary we offer the following considerations when selecting breakdown thresholds for use in models.

- Handbook values are not wrong, but they were often developed for different applications (*e.g.*, breakdown tests in oil with a pin electrode at 500V/s).

- Define your mission parameters and requirements then tailor ESD tests, together with materials and components, to be as close to worst case flight conditions as possible.

- Taken together, SVET tests, plus tests at different ramp-rates and temperatures, can be used to more accurately estimate material behaviours.

- Breakdown is not well characterized by as single number. Consider a probability distribution that depends not only on the material, but the conditions it is subjected to over time [13, 17]. The acceptable probability need to be determined by considering mission objectives and tolerances.

- Physics-based or even well-chosen empirical models can estimate behaviour of materials for times and conditions not achievable with testing [13, 17].

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