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Broadband RF Spectrum from Electrostatic Discharges on Spacecraft

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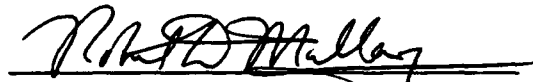
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This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.



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PREFACE

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INTRODUCTION

Various aspects of the space environment can cause anomalous behavior of components on spacecraft. The plasma environment (especially around geosynchronous orbit) can differentially charge materials on the surface of a vehicle.^{1,2,3} Spacecraft anomalies attributable to the resulting electrostatic discharges have been known to cause command errors, spurious signals, phantom commands, degraded sensor performance, part failure, and even complete mission loss.⁴ Electromagnetic interference from the resulting discharges may also interfere with communication systems on the spacecraft. Although many measurements of the properties of discharges have been made in space and in the laboratory, few have included the complete electromagnetic spectrum in the radio-frequency (RF) range. The purpose of this report is to compare new measurements of the RF spectrum from the Kapton blanket from the backside of the MILSTAR spacecraft's flexible substrate solar array (FSSA) with other space and laboratory data so that they will be more readily available for the analysis of spacecraft systems. The data may be used to estimate the effects of EMI from discharges on spacecraft systems operating in the frequency range from 100 kHz to 10 GHz.

DATA

Figure 1 shows the broadband RF spectra of electrostatic discharges from 100 kHz to 10 GHz from a variety of different measurements. The original data have been converted to a standard distance of one meter. The MILSTAR Flexible Substrate Solar Array (FSSA) data were obtained from discharge measurements performed by Stanford Research Institute for Lockheed Missiles & Space Company, Inc. on a Kapton blanket sample from the backside of the solar array for the MILSTAR satellite. The blanket sample would cover eight solar cells arranged in a 2×4 array. The sample size was 15×30 cm (450 cm^2). About 20% of the Kapton blanket was covered on the inside by copper metallization. The data shown in Fig. 1 are from a series of tests on the sample at an electron beam energy of 20 keV and a beam current of 5 nA/cm^2 . They are repre-

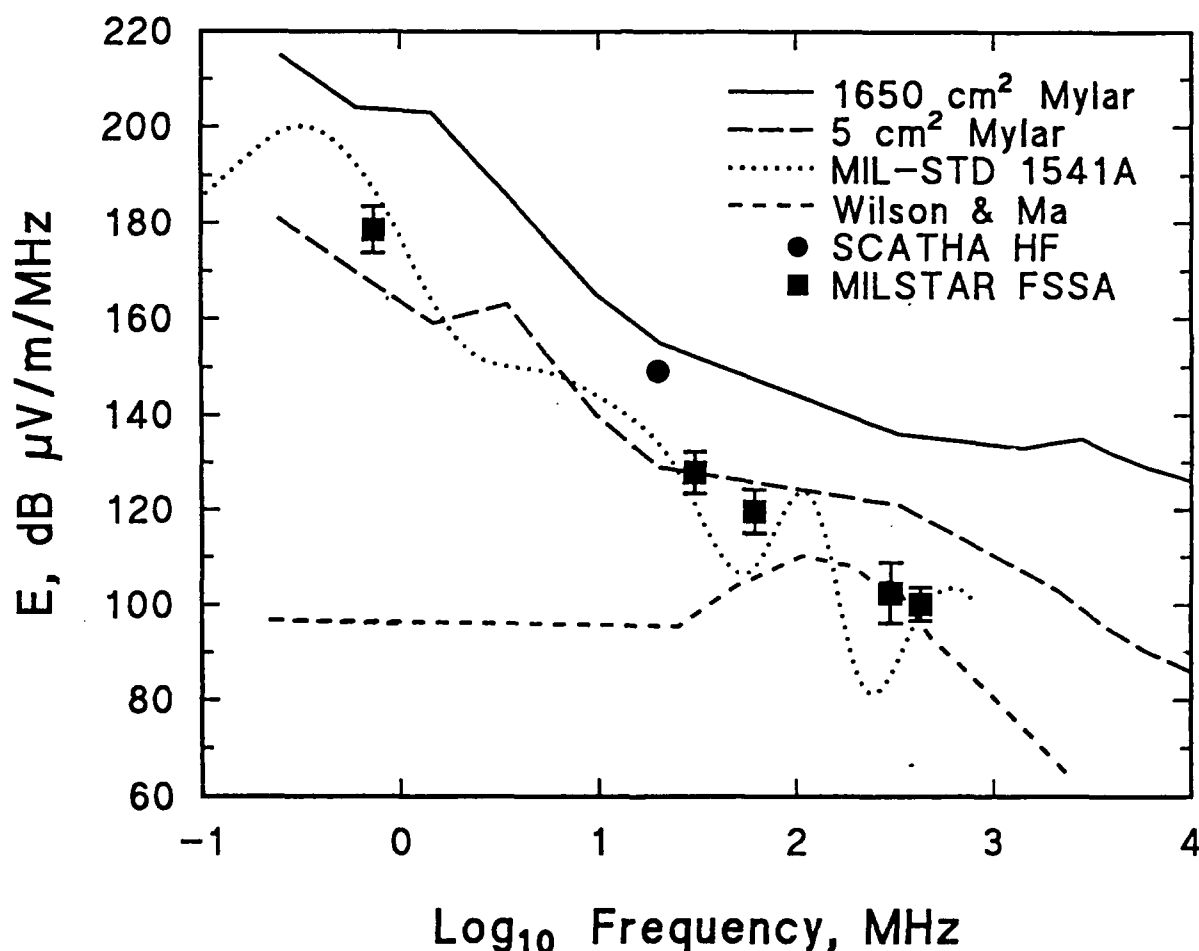


Figure 1. Broadband RF discharge spectrum from laboratory and spacecraft measurements.

sentative of the measurements at LF, HF, and UHF. The error brackets are drawn at $\pm$ one standard deviation for a sample of 14 or 15 discharges at each frequency.

The solid curve and the long-dashed curve are the spectra measured by Leung for two different-sized samples of Mylar.^{5,6} The Mylar samples were irradiated by a 20-keV electron beam with a current density of 2 to 5 nA/cm². The peak pulse current was typically 150 A and the pulse width was 230 ns.

The measurement in Fig. 1 identified by the circle was made by the RF analyzer aboard the SCATHA spacecraft during a period when electron-beam experiments were being performed on the vehicle.⁷ It is not known what material was discharging. The RF analyzer was tuned to 20 MHz with a bandwidth of 4 kHz. The peak power was measured to be -83 dBm. The electron beam was operating at 3 keV and 6 nA.

The dotted curve is the RF spectrum of a MIL-STD-1541A spark gap.⁶ According to MIL-STD-1541A, the spark gap is to be established at a level of 10 kV, and the energy in the spark should be greater than 2×10^{-3} W-s.

The short-dashed curve is the spectrum measured by Wilson and Ma using a commercially available ESD simulator and a target.⁸ The target was an 8-mm-diameter brass ball. For the spectrum shown in Fig. 1, the voltage was 4 kV. The peak current was 26 A with an approximate rise time of 0.9 ns and a width of about 2 ns. The short rise time and narrow width of this pulse account for the low electric-field levels below 10 MHz.

The data shown in Fig. 1 can be used to evaluate the possibility of EMI to spacecraft receivers from electrostatic discharges on spacecraft. However, the data from Wilson and Ma are not representative of spacecraft materials and should not be used in this application.

AREA SCALING

Because the test samples used in the laboratory are often much smaller than the area of dielectric materials on spacecraft surfaces, it is important to determine how the spectra and intensities on such small samples scale to the spectra and intensities from larger samples. Leung measured the dependence of the peak discharge current on the area of the test sample for five sample sizes of Mylar from 5 cm² to 1650 cm² and found that the peak current varied as the area to the 0.4 power.⁶ The solid and dashed lines in Fig. 2 are the best-fitting straight lines to the electric-field spectra of the 5 cm² and the 1650 cm² Mylar samples, respectively, as obtained by a linear-regression analysis. These fits were made over the entire frequency range of Leung's measurements. For the 5 cm² sample, $E \propto f^{-0.98}$, and for the 1650 cm² sample, $E \propto f^{-0.94}$. Thus, the

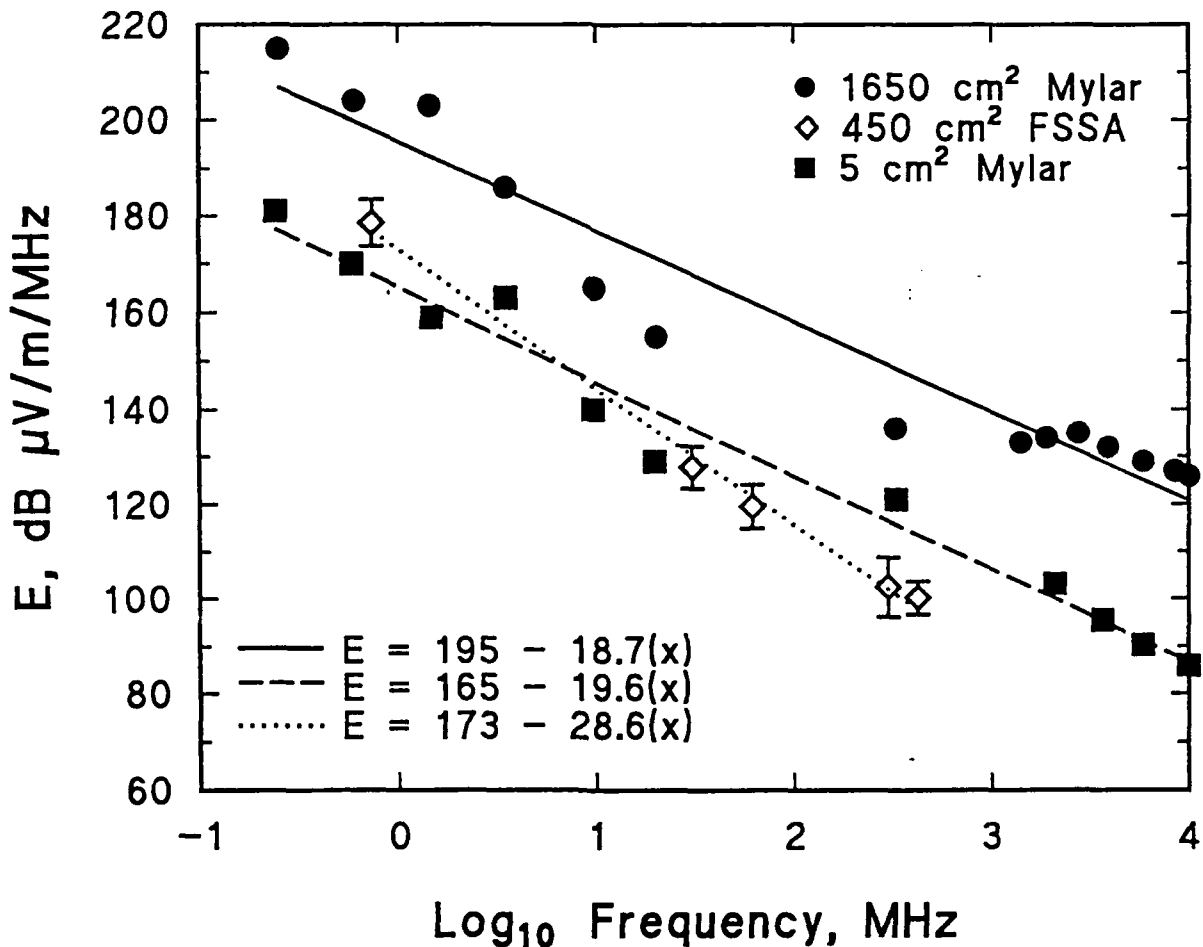


Figure 2. A comparison of the spectrum from discharges on the MILSTAR FSSA blanket with linear regression fits to the large and small Mylar samples.

electric field is very nearly inversely proportional to the frequency over the entire frequency range. The dotted line in Fig. 2 is the best-fitting line for the MILSTAR FSSA Kapton sample for which we find that $E \propto f^{-1.48}$. Leung has published fits to the Mylar data for the frequency range below 30 MHz.⁵ At those frequencies, he finds that for the small sample, $E \propto f^{-1.5}$, and for the large sample, $E \propto f^{-1.8}$.

From Fig. 2, we find that the electric-field intensity from the large Mylar sample is 30 dB greater than the electric-field intensity from the small sample. The ratio, then, is 32. Since the ratio of the areas is 330, the electric field scales as area to the 0.6 power.

The electric-field intensity from the MILSTAR FSSA Kapton blanket is not in accord with the area scaling for the Mylar. If the electric-field intensity was independent of the material, the intensity from the FSSA blanket would be about 23 dB higher than the intensity from the small Mylar sample. Instead, at frequencies above 10 MHz, it is actually lower than that from the small Mylar sample. Leung and Plamp have shown that the peak current and the pulse width of discharges are a function of beam energy and differ between Kapton and Mylar.⁹ Thus, many factors must be taken into account when estimating the electric-field intensity from electrostatic discharges.

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