②

SMC-TR-93-47

AEROSPACE REPORT NO.
TR-93(3940)-6

Broadband RF Spectrum from Electrostatic Discharges on Spacecraft

Prepared by

H. C. KOONS
Space and Environment Technology Center
Technology Operations
The Aerospace Corporation

and

T. S. CHIN
Space Systems Division
Lockheed Missiles and Space Company
Sunnyvale, California

1 May 1993

Prepared for

SPACE AND MISSILE SYSTEMS CENTER
AIR FORCE MATERIEL COMMAND
Los Angeles Air Force Base
P. O. Box 92960
Los Angeles, CA 90009-2960

Engineering and Technology Group

THE AEROSPACE CORPORATION
El Segundo, California

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION UNLIMITED

This report was submitted by The Aerospace Corporation, El Segundo, CA 90245-4691, under Contract No. F04701-88-C-0089 with the Space and Missile Systems Center, P. O. Box 92960, Los Angeles, CA 90009-2960. It was reviewed and approved for The Aerospace Corporation by A. B. Christensen, Principal Director, Space and Environment Technology Center. Capt. R. Mullany was the project officer for the Mission-Oriented Investigation and Experimentation (MOIE) program.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nationals.

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.

ROBERT D. MULLANY, Capt., USAF Aerospace MOIE Monitor	W. KYLE SNEDDON, Capt., USAF MOIE Program Manager

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
TR-93(3940)-6

5. MONITORING ORGANIZATION REPORT NUMBER(S)
SMC-TR-93-47

6a. NAME OF PERFORMING ORGANIZATION
The Aerospace Corporation
Technology Operations

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
Space and Missile Systems Center

6c. ADDRESS *(City, State, and ZIP Code)*
El Segundo, CA 90245-4691

7b. ADDRESS *(City, State, and ZIP Code)*
Los Angeles Air Force Base
Los Angeles, CA 90009-2960

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
F04701-88-C-0089

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE *(Include Security Classification)*
Broadband RF Spectrum from Electrostatic Discharges on Spacecraft

12. PERSONAL AUTHOR(S)
Koons, Harry C. and Chin, Thomas S.

13a. TYPE OF REPORT

13b. TIME COVERED
FROM ________ TO ________

14. DATE OF REPORT *(Year, Month, Day)*
1993 May 1

15. PAGE COUNT
8

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Electrostatic Discharges, Spacecraft, RF Spectrum, MILSTAR, Kapton

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Electromagnetic interference from discharges on spacecraft subject to the charging environment near geosynchronous orbit may interfere with communication systems on the spacecraft. We 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.

20. DISTRIBUTION/AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL

22b. TELEPHONE *(Include Area Code)*

22c. OFFICE SYMBOL

DD FORM 1473, 84 MAR

83 APR edition may be used until exhausted.
All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

PREFACE

We would like to thank W. Chang of Lockheed Missiles & Space Company, Inc. and T. Craven of Loral Space Syst s for discussions of the data; and R. Adamo at SRI, Inc. for his assistance in performin s on the MILSTAR samples. This work was supported by the Space and Missile Syst er of the U. S. Air Force under Contract Nos. F04701-88-C-0089 and F04701-83-C-

CONTENTS

INTRODUCTION 3

DATA 4

AREA SCALING 6

REFERENCES 8

FIGURES

1. Broadband RF discharge spectrum from laboratory and spacecraft measurements. 4
2. A comparison of the spectrum from discharges on the MILSTAR FSSA blanket with linear regression fits to the large and small Mylar samples 6

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 x 4 array. The sample size was 15 x 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-

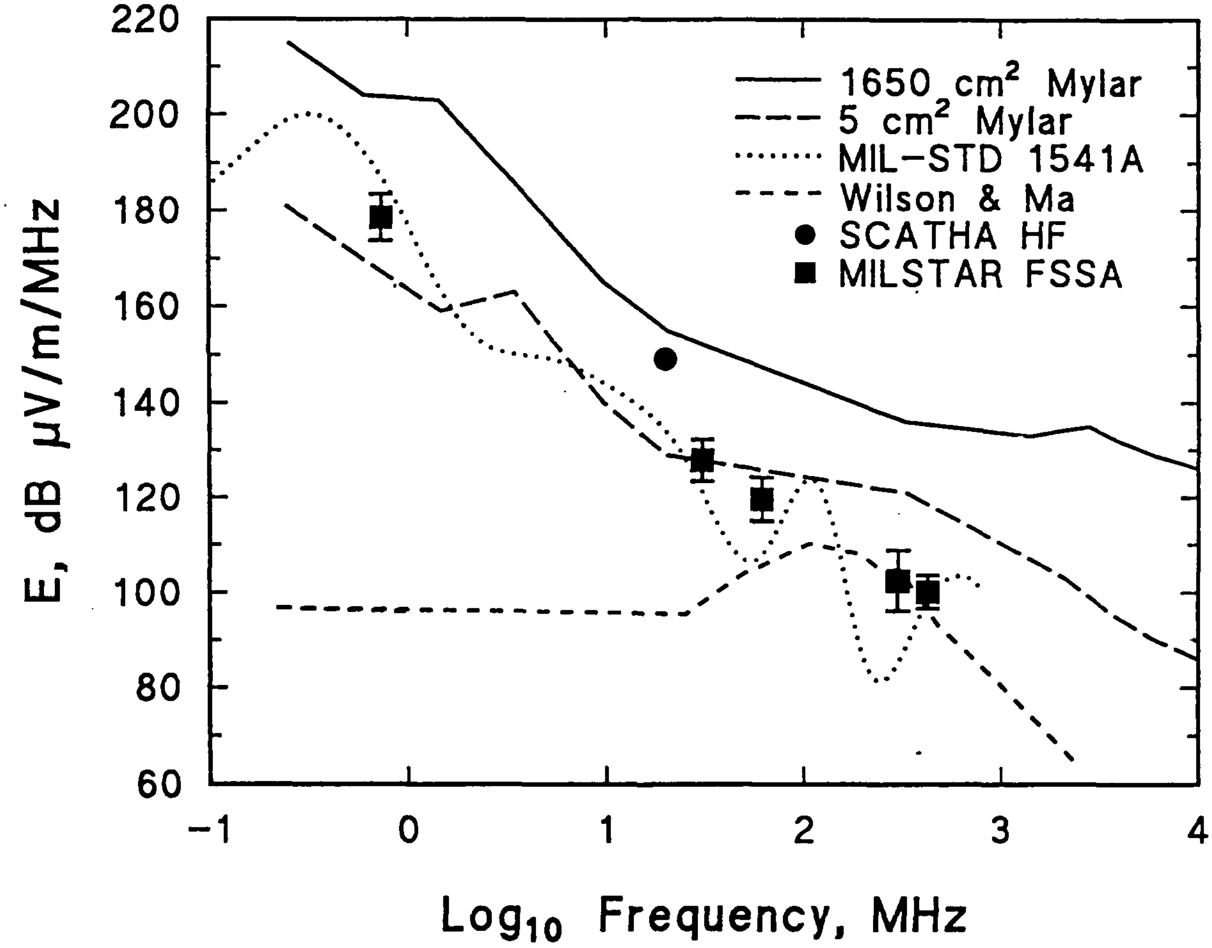

Figure 1. Broadband RF discharge spectrum from laboratory and spacecraft measurements.

sentative of the measurements at LF, HF, and UHF. The error brackets are drawn at ± 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/cm^2. 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 mA.

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 x 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 cm^2 to 1650 cm^2 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 cm^2 and the 1650 cm^2 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 cm^2 sample, $E \propto f^{-0.98}$, and for the 1650 cm^2 sample, $E \propto f^{-0.94}$. Thus, the

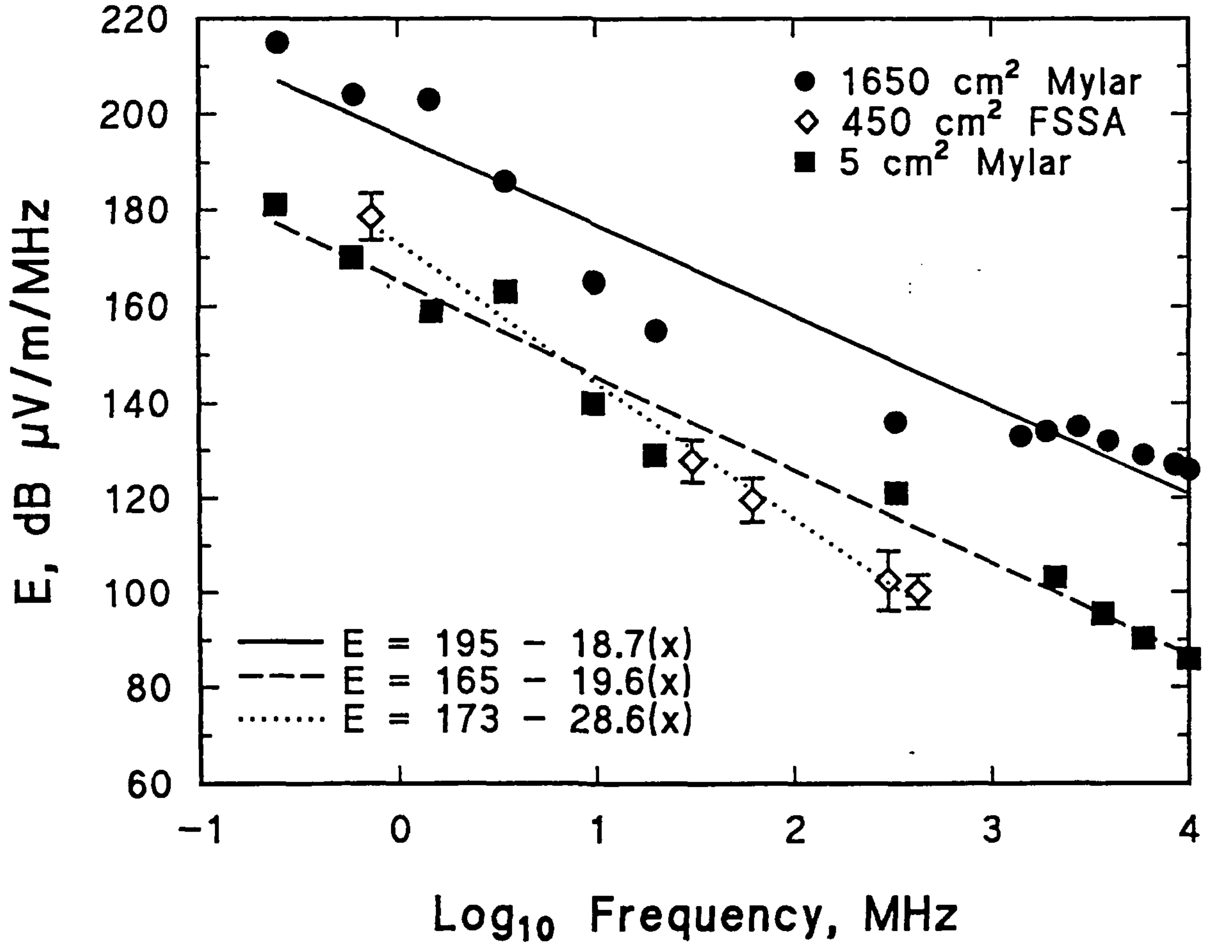

Figure 2. A comparison of the spectrum from discharges on the MILSTAR FSSA blanket with linear regression fits to the large and small Mylar samples.

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.

REFERENCES

1. Fennell, J. F., Koons, H. C., Leung, M. S., and Mizera, P. F., "A Review of SCATHA Satellite Results: Charging and Discharging," ESA-SP-198, European Space Agency, Noordwijk, The Netherlands, 1983.
2. Mullen, E. G., Gussenhoven, M. S., and Garret, H. B., "A Worst-Case Spacecraft Environment as Observed by SCATHA on 24 April 1979," AFGL-TR-81-0231, Air Force Geophysics Laboratory, Hanscom, Mass., 1981.
3. Mizera, P. F. and Boyd, G. "A Summary of Spacecraft Charging Results," Journal of Spacecraft and Rockets, Vol. 20, Sept.-Oct. 1983, pp. 438-443.
4. Robinson, P. A., "Spacecraft Environmental Anomalies Handbook," GL-TR-89-0222, Air Force Geophysics Laboratory, Hanscom, Mass., Aug. 1989.
5. Leung, P. L., "Characteristics of Electromagnetic Interference Generated during Discharge of Mylar Samples," IEEE Transactions on Nuclear Science, Vol. NS-31, Dec. 1984, pp. 1587-1590.
6. Leung, Philip, "Characteristic of Electromagnetic Interference Generated by Arc Discharges," 9th Aerospace Testing Seminar, Los Angeles, CA, Oct. 15-17, 1985, Proceedings, Institute of Environmental Sciences, Mount Prospect, IL, 1986, pp. 40-44.
7. Koons, H. C., "Summary of Environmentally Induced Electrical Discharges on the P78-2 (SCATHA) Satellite," Journal of Spacecraft and Rockets, Vol. 20, No. 5, Sept.-Oct. 1983, pp. 425-431.
8. Wilson, P. F. and Ma, M. T., "Fields Radiated by Electrostatic Discharges," IEEE Transactions on Electromagnetic Compatibility, Vol. 33, No. 1, Feb. 1991, pp. 10-18.
9. Leung, P. and G. Plamp, "Characteristics of RF Resulting from Dielectric Discharges," IEEE Trans. on Nuclear Science, Vol. NS-29, No. 6, dec. 1982, pp. 1610-1614.

TECHNOLOGY OPERATIONS

The Aerospace Corporation functions as an "architect-engineer" for national security programs, specializing in advanced military space systems. The Corporation's Technology Operations supports the effective and timely development and operation of national security systems through scientific research and the application of advanced technology. Vital to the success of the Corporation is the technical staff's wide-ranging expertise and its ability to stay abreast of new technological developments and program support issues associated with rapidly evolving space systems. Contributing capabilities are provided by these individual Technology Centers:

Electronics Technology Center: Microelectronics, solid-state device physics, VLSI reliability, compound semiconductors, radiation hardening, data storage technologies, infrared detector devices and testing; electro-optics, quantum electronics, solid-state lasers, optical propagation and communications; cw and pulsed chemical laser development, optical resonators, beam control, atmospheric propagation, and laser effects and countermeasures; atomic frequency standards, applied laser spectroscopy, laser chemistry, laser optoelectronics, phase conjugation and coherent imaging, solar cell physics, battery electrochemistry, battery testing and evaluation.

Mechanics and Materials Technology Center: Evaluation and characterization of new materials: metals, alloys, ceramics, polymers and their composites, and new forms of carbon; development and analysis of thin films and deposition techniques; nondestructive evaluation, component failure analysis and reliability; fracture mechanics and stress corrosion; development and evaluation of hardened components; analysis and evaluation of materials at cryogenic and elevated temperatures; launch vehicle and reentry fluid mechanics, heat transfer and flight dynamics; chemical and electric propulsion; spacecraft structural mechanics, spacecraft survivability and vulnerability assessment; contamination, thermal and structural control; high temperature thermomechanics, gas kinetics and radiation; lubrication and surface phenomena.

Space and Environment Technology Center: Magnetospheric, auroral and cosmic ray physics, wave-particle interactions, magnetospheric plasma waves; atmospheric and ionospheric physics, density and composition of the upper atmosphere, remote sensing using atmospheric radiation; solar physics, infrared astronomy, infrared signature analysis; effects of solar activity, magnetic storms and nuclear explosions on the earth's atmosphere, ionosphere and magnetosphere; effects of electromagnetic and particulate radiations on space systems; space instrumentation; propellant chemistry, chemical dynamics, environmental chemistry, trace detection; atmospheric chemical reactions, atmospheric optics, light scattering, state-specific chemical reactions and radiative signatures of missile plumes, and sensor out-of-field-of-view rejection.