JSC-CR-06-070

DEPARTMENT OF DEFENSE

JOINT SPECTRUM CENTER

ANNAPOLIS, MARYLAND
21402-5064

SPACE VEHICLE RF ENVIRONMENTS

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Marshall Space Flight Center
Electromagnetic Environmental Effects and Electrical Integration Branch
Huntsville, AL 35812

JSC Project Engineer

Richard Chatfield

AUGUST 2006

CONSULTING REPORT

Prepared by

Lloyd Apirian and Philip Baummer

Alion Science and Technology
Under Contract to
Department of Defense

This report was prepared by Alion Science and Technology under Contract DCA100-00-C-4012 in support of the DoD Joint Spectrum Center in Annapolis, Maryland.

This report has been reviewed by the following Alion personnel:

PHILIP F. BAUMMER
Project Manager, Alion

SCOTT D. WILEY
Division Manager, Alion

This report is approved for publication.

For DAVID A. GAINES, Lt Col, USAF
Chief, Applied Engineering Division
Joint Spectrum Center

ROBERT M. WILLIAMS, JR.
Technical Director
Joint Spectrum Center

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From – To)*
08-2006	Consulting Report	

4. TITLE AND SUBTITLE
Space Vehicle RF Environments

5a. CONTRACT NUMBER
DCA100-00-C-4012

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Apirian, Lloyd, and Baummer, Philip

5d. PROJECT NUMBER
P2375

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) AND ADDRESS(ES)

Joint Spectrum Center
Applied Engineering Division (JSC/J8)
2004 Turbot Landing
Annapolis, MD 21402-5064

8. PERFORMING ORGANIZATION REPORT NUMBER

JSC-CR-06-070

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

National Aeronautics and Space Administration
Marshall Space Flight Center
Electromagnetic Environmental Effects and Electrical Integration Branch
Huntsville, AL 35812

10. SPONSOR/MONITOR'S ACRONYM(S)

NASA

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited. August 2006.

13. SUPPLEMENTARY NOTE

14. ABSTRACT
Marshall Space Flight Center (MSFC) requested that the Joint Spectrum Center evaluate the radio frequency (RF) environments for a space vehicle in orbit. This request was made in response to MSFC concerns about potential degradation to space vehicle operations due to electromagnetic effects from communications-electronics emitters in the environment that operate between 2 MHz and 40 GHz. MSFC will use the Joint Spectrum Center results to evaluate RF-hardening requirements for systems/subsystems and payloads aboard a space vehicle. Data used in this report was current as of May 2006.

15. SUBJECT TERMS
Marshall Space Flight Center, National Aeronautics and Space Administration, RF Environment Definitions, Space Vehicle

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Richard Chatfield
U	U	U	SAR	16	**19b. TELEPHONE NUMBER** *(include area code)* (410) 293-2617 DSN 281-2617

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std. Z39.18

EXECUTIVE SUMMARY

Marshall Space Flight Center (MSFC) requested that the Joint Spectrum Center evaluate the radio frequency (RF) environments for a space vehicle in orbit at an altitude of 100 nmi with inclinations of 57º and 90º. This request was made in response to MSFC concerns about potential degradation to space vehicle operations due to electromagnetic environmental effects from communications-electronics emitters operating between 2 MHz and 40 GHz.

For the on-orbit altitude and inclinations of interest, the Joint Spectrum Center identified multiple environmental emitters capable of equaling or exceeding an MSFC-selected electric field strength level of 5 volts per meter. MSFC will use the analysis results to evaluate RF hardening requirements for systems/subsystems and payloads aboard a space vehicle.

TABLE OF CONTENTS

Figures

Tables

GLOSSARY

EIRP	Effective Isotropic Radiated Power
JETS	Joint Equipment, Tactical, and Space
MSFC	Marshall Space Flight Center
RF	Radio Frequency
RLOS	Radio Line of Sight
V/m	Volts per Meter

BACKGROUND

Marshall Space Flight Center (MSFC) requested that the Joint Spectrum Center evaluate the radio frequency (RF) environments for a space vehicle in orbit at an altitude of 100 nmi with inclinations of 57º and 90º. This request was made in response to MSFC concerns about potential degradation to space vehicle operations due to electromagnetic environmental effects from communications-electronics emitters operating between 2 MHz and 40 GHz.

For the on-orbit altitude and inclinations of interest, the Joint Spectrum Center identified multiple environmental emitters capable of equaling or exceeding an MSFC-selected electric field strength level of 5 volts per meter (V/m). The MSFC will use the analysis results to evaluate RF hardening requirements for systems/subsystems and payloads aboard a space vehicle.

OBJECTIVE

The objective of this task was to identify environmental emitters capable of equaling or exceeding an electric field strength level of 5 V/m at the exterior of a space vehicle for MSFC-specified on-orbit parameters.

APPROACH

The analysis approach used was a modified version of the approach developed in fiscal year 2000 for a Space Shuttle RF environments task in support of Johnson Space Center.[1] For a space vehicle, flight profiles were developed based on discussions between the Joint Spectrum Center and the MSFC.

[1] Philip Baummer, *Radio-Frequency Environments for Space Shuttle Launch, Landing, and On-Orbit Scenarios*, JSC-CR-00-059, Annapolis, MD: Joint Spectrum Center, October 2000.

Based on the flight profiles, environmental emitters were identified from an extensive in-house collection of worldwide frequency assignment data, shown in Table 1. Identified environmental emitters were limited to those which:

- operate between 2 MHz and 40 GHz
- operate within radio line of sight (RLOS) of a space vehicle flight profile

Note: The data sources listed in Table 1 are not all-inclusive for emitters throughout the world. Internationally, nations are not required to register their spectrum usage if it will not interfere with usage in another nation and protection from another nation's usage is not desired. There are emitters in operation in the world that are not reported in any generally available database.

Table 1. Sources of Environmental Emitter Data

Database	Type of Frequency Assignment
ARFA/MRFL	US assignments in NATO Europe; Foreign NATO assignments between 100 – 156, 225 – 400, and 960 – 1215 MHz
CDF	Canadian non-military assignments above 30 MHz
EOB	Frequency data for foreign emitters - obtained using intelligence methods
FCC	US assignments to state and local government, and private industry
FRRS	US assignments to military departments, unified commands, and DoD frequency coordinators
GMF	US assignments to the Federal government
ITU/IFL	Assignments registered with the ITU by member nations
JETS	US/foreign frequency assignments for satellites and earth stations
RA	Assignments, worldwide, of interest to radio astronomers
ARFA/MRFL:	Allied Radio Frequency Agency/Master Radio Frequency List
CDF:	Canadian Data File
EOB:	Electronic Order of Battle
FCC:	Federal Communications Commission
FRRS:	Frequency Resource Record System
GMF:	Government Master File
ITU/IFL:	International Telecommunication Union/International Frequency List
JETS:	Joint Equipment, Tactical, and Space
NATO:	North Atlantic Treaty Organization
RA:	Radio Astronomy

To ensure the accuracy of subsequent calculations, identified environmental emitters were subjected to a validation process that flagged potential problems with crucial emitter technical characteristics (i.e., transmit power, antenna gain, pulsewidth, pulse repetition frequency, duty cycle, and effective isotropic radiated power [EIRP]). When necessary, emitter technical characteristics were compared to parametric data from a collection of in-house sources, shown in

Table 2. In some cases, this validation process resulted in modifications to the technical characteristics of environmental emitter data.

Table 2. Sources of Technical Parametric Data

Source	Type of Data
JETS	US civil and military systems
Technical Library	US civil and military systems

Once the environmental emitter data were collected and validated, calculations were performed to determine average and peak electric field strength levels at the exterior of an orbiting space vehicle. Environmental emitters that produced both average and peak electric field strength levels less than the 5 V/m threshold were eliminated from future consideration.

ASSUMPTIONS

Critical assumptions regarding the operation of environmental emitters and the effect of signal propagation between environmental emitters and a space vehicle used when calculating electric field strength levels are as follows:

- environmental emitters operate at maximum EIRP – maximum transmit power, maximum antenna gain, maximum duty cycle and zero circuit or line loss
- environmental emitter signals propagate under antenna far-field conditions
- environmental emitter signals propagate RLOS under free-space conditions (no signal attenuation due to atmospheric conditions, such as oxygen or water vapor absorption)
- signals from multiple environmental emitters do not illuminate a space vehicle simultaneously
- signals from multiple co-frequency environmental emitters do not have a cumulative effect on electric field strength levels at a space vehicle.

SPACE VEHICLE FLIGHT PROFILES AND ELECTRIC FIELD STRENGTH CALCULATION POINTS

Two on-orbit flight profiles for a space vehicle were developed based on discussions between the Joint Spectrum Center and MSFC. The first orbit profile was for a space vehicle operating at an altitude of 100 nmi with an inclination of 57º. The second orbit profile was for a space vehicle operating at an altitude of 100 nmi with an inclination of 90º. Based on these parameters, a space vehicle was assumed to pass over the Earth regions identified in Figure 1.

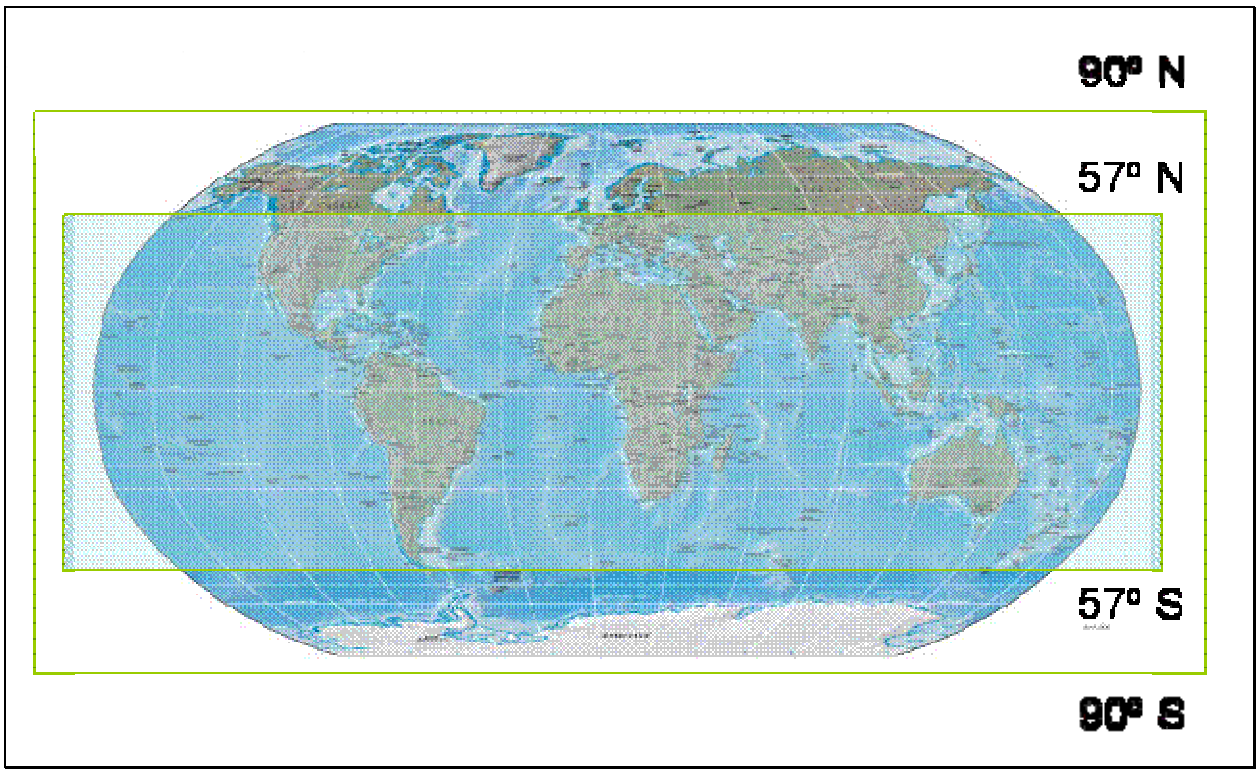

Figure 1. Space Vehicle On-Orbit Areas of Operation

For each orbit profile, electric field strength levels were calculated from all environmental emitters that could be within RLOS of a space vehicle. The distance used to calculate the electric field strength level depended on the location of the environmental emitter. For a space vehicle orbit inclined at 57º, emitters located between 57º N and 57º S had electric field strength levels calculated assuming a space vehicle was passing directly overhead (i.e., closest approach of a space vehicle to an emitter). This equated to a space vehicle altitude of 100 nmi. For all

other emitters, electric field strength level calculations assumed the smallest possible slant range between an emitter and a space vehicle.

For a space vehicle orbit inclined at 90º, all emitters had electric field strength levels calculated assuming a space vehicle was passing directly overhead.

RESULTS

Histogram plots are provided of average electric field strength levels versus frequency and peak electric field strength levels versus frequency. Average electric field strength calculations assumed the maximum transmitter power for non-pulsed emitters and the highest possible average power (i.e., largest duty cycle times maximum transmitter power) for pulsed emitters. Peak electric field strength calculations assumed maximum transmitter power for both non-pulsed and pulsed emitters. Average and peak electric field strength calculations also assumed the smallest possible distance between an emitter and an orbiting space vehicle. The radius of movement was considered for mobile emitters when determining this distance.

In addition, each average and peak plot represents a composite of all the electric field strength levels calculated to equal or exceed 5 V/m for environment emitters within RLOS of an orbiting space vehicle. Of the four plots provided, Figures 2 and 3 correspond to a space vehicle in a 57º inclined orbit, while Figures 4 and 5 correspond to a space vehicle in a 90º inclined orbit.

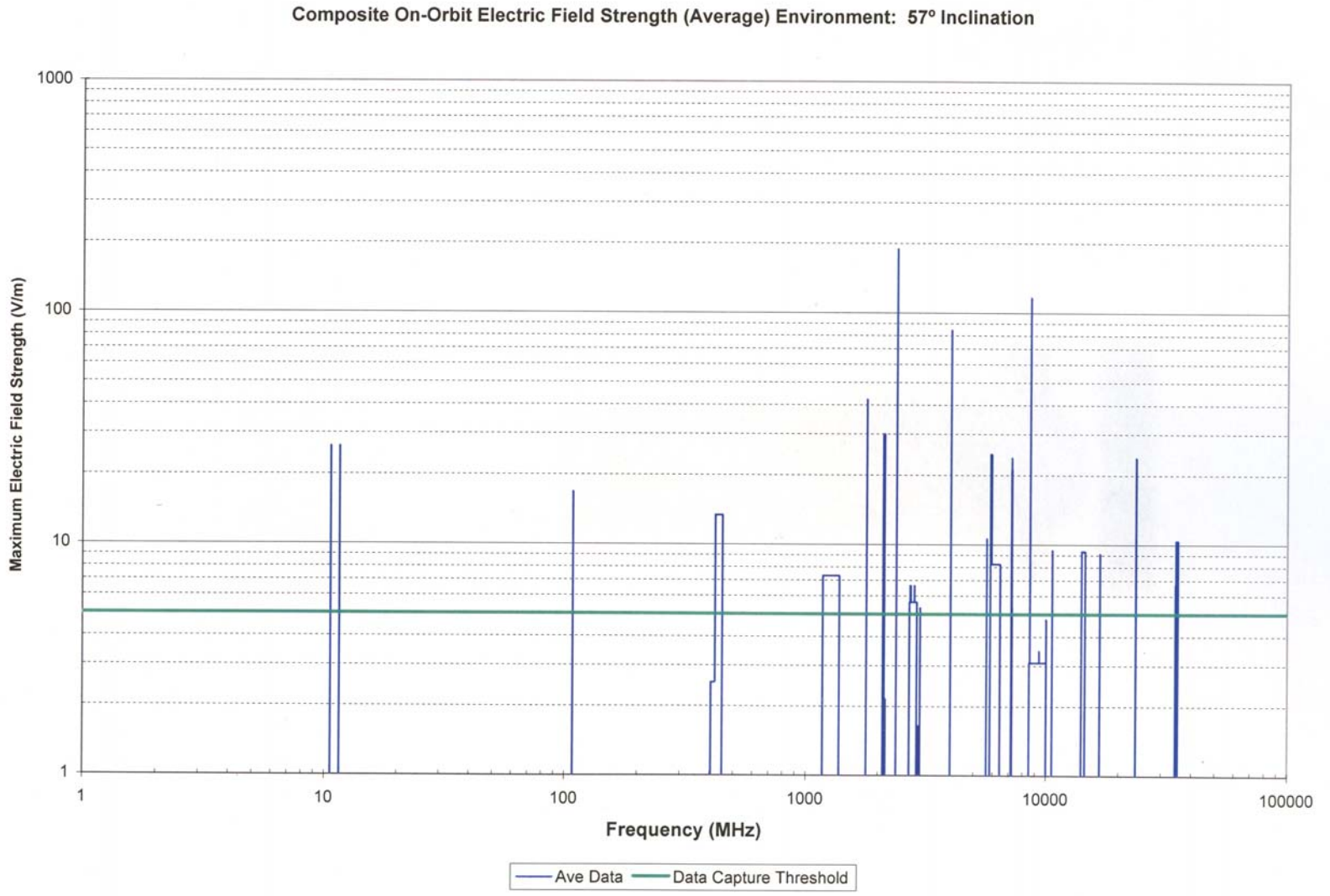

Figure 2. Composite On-Orbit Electric Field Strength (Average) Environment: 57º Inclination

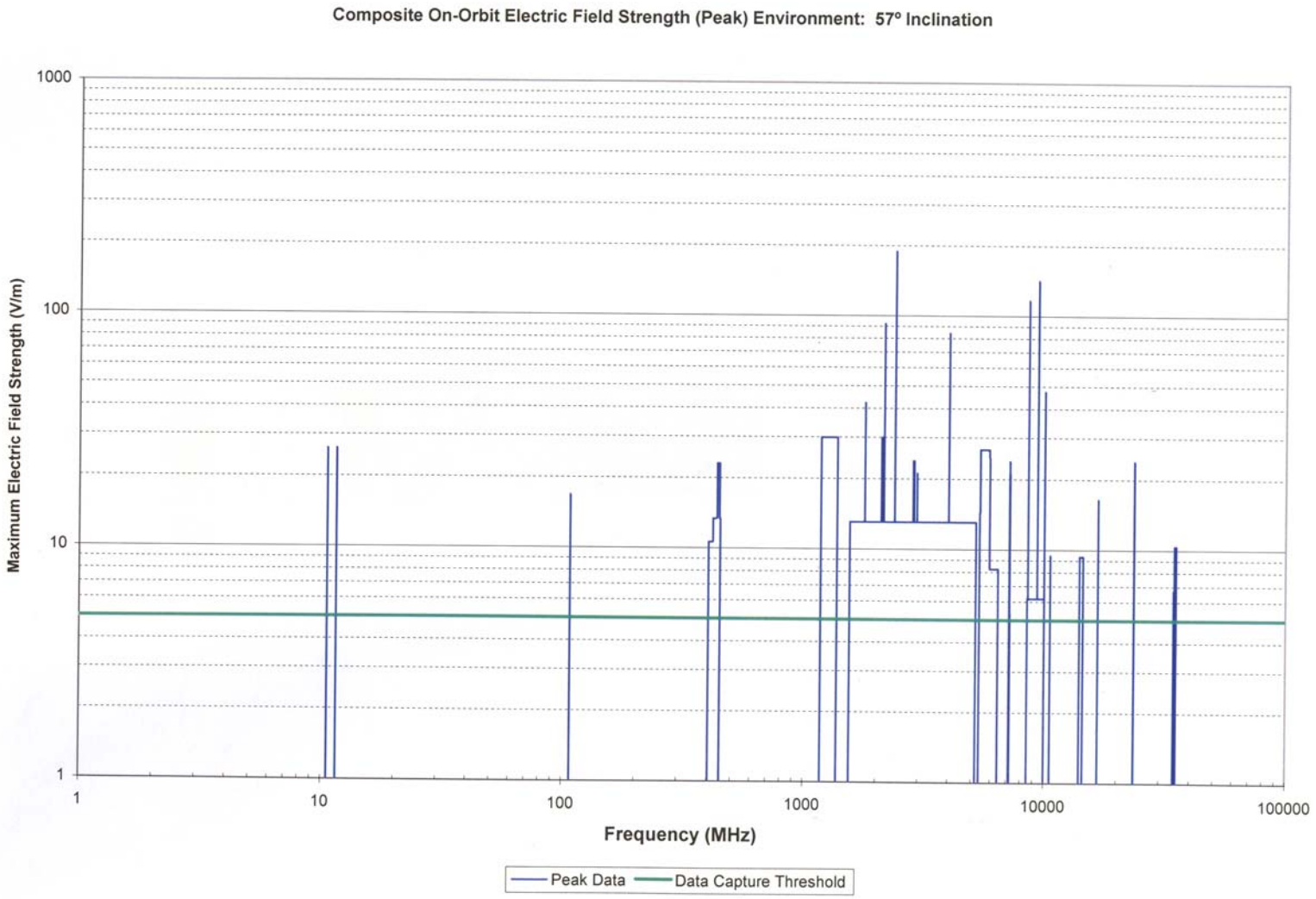

Figure 3. Composite On-Orbit Electric Field Strength (Peak) Environment: 57º Inclination

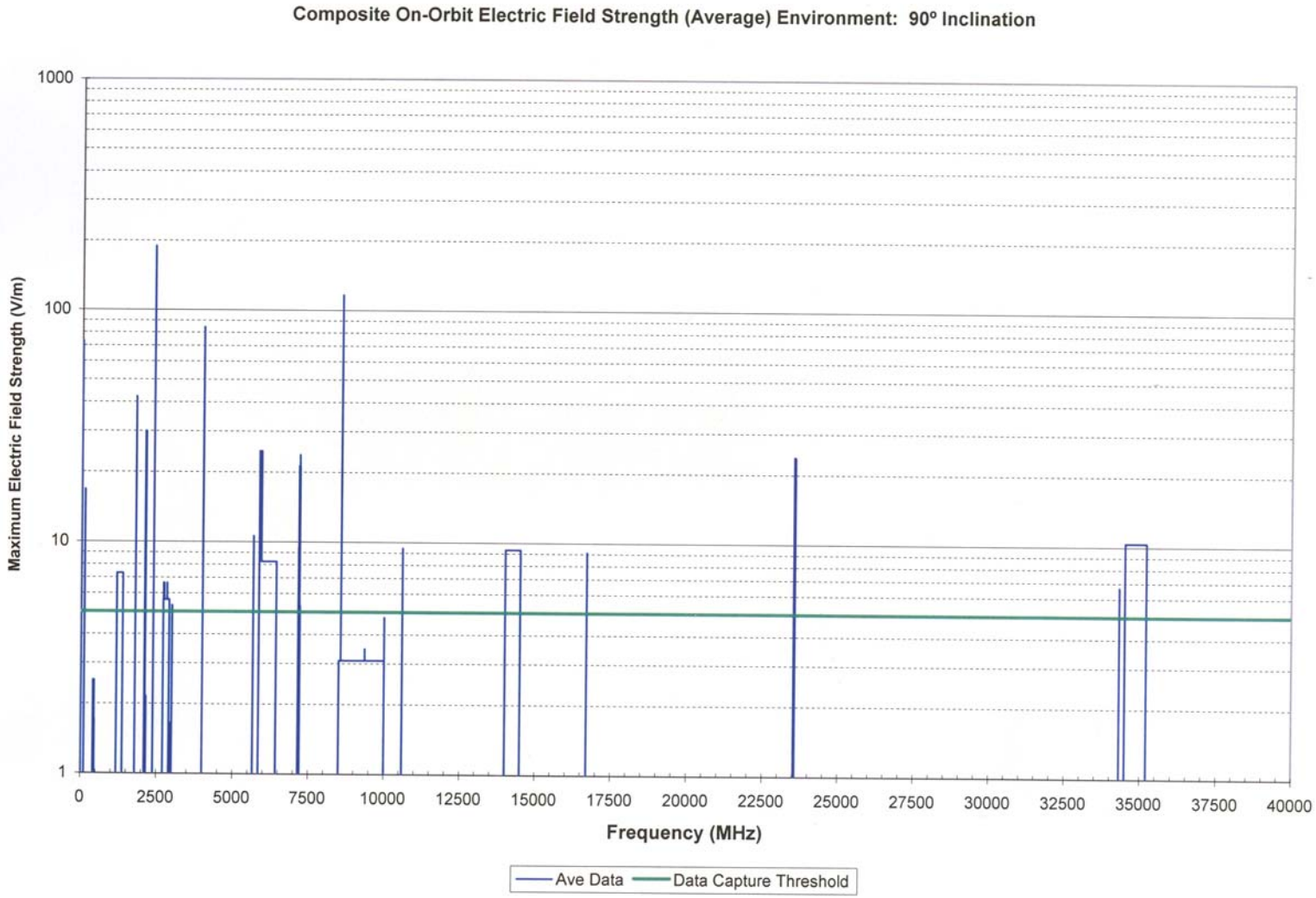

Figure 4. Composite On-Orbit Electric Field Strength (Average) Environment: 90º Inclination

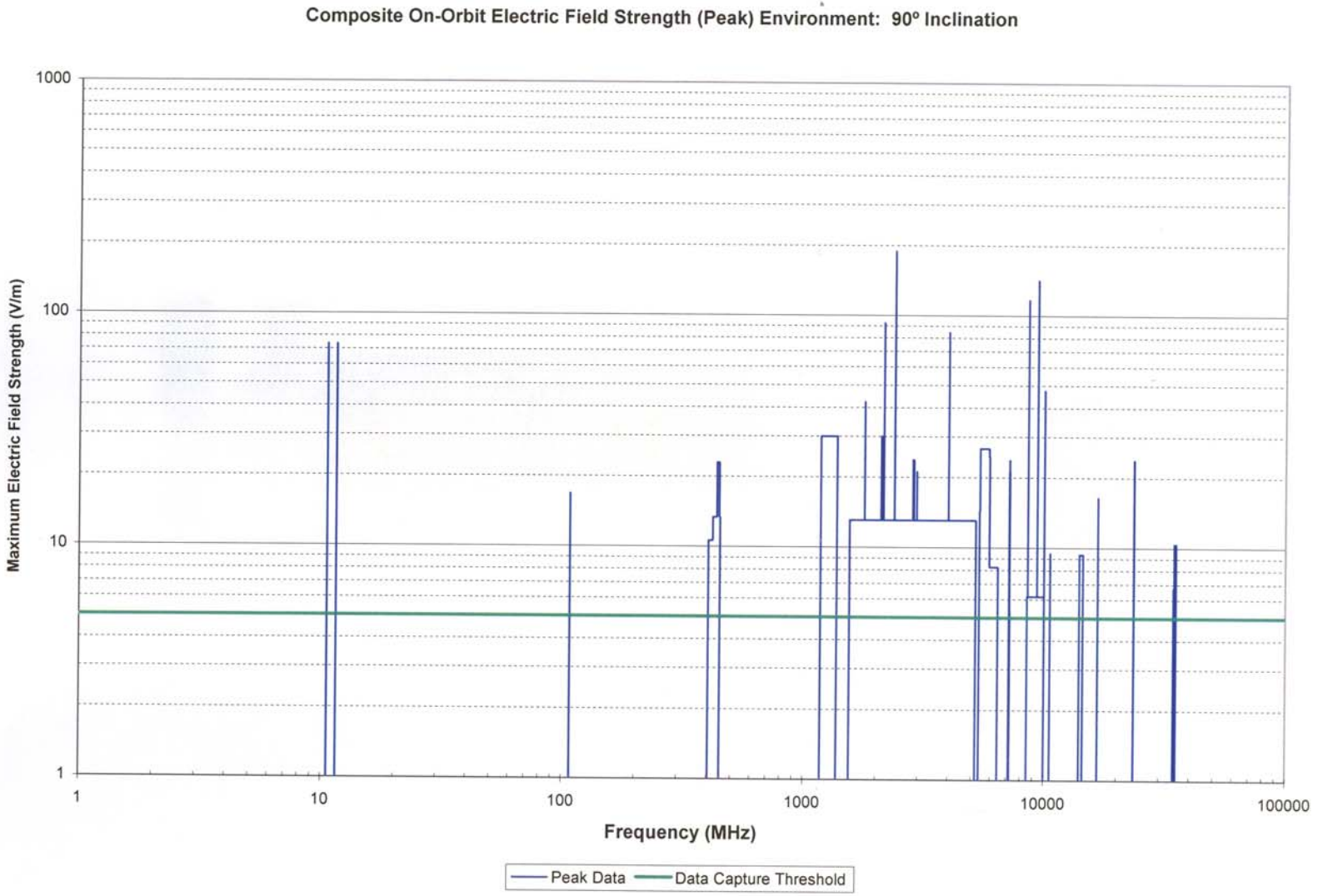

Figure 5. Composite On-Orbit Electric Field Strength (Peak) Environment: 90º Inclination

DISTRIBUTION LIST FOR
Space Vehicle RF Environments
JSC-CR-06-070

	No. of Copies
External	
National Aeronautics and Space Administration Marshall Space Flight Center Electromagnetic Environmental Effects and Electrical Integration Branch Attn: Tony Clark/EI24 Huntsville, AL 35812	5
Internal	
J8/Richard Chatfield	1
DSS/Philip Baummer	1
DSS/Lloyd Apirian	1
DPS/Library	5
DPSC	Camera-Ready and pdf