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DEVELOPMENT OF AUTOMATED ELECTROMAGNETIC COMPATIBILITY
TEST FACILITIES AT MARSHALL SPACE FLIGHT CENTER

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ABSTRACT

This is the second report concerning efforts to automate the
electromagnetic compatibility (EMC) test facilities at Marshall Space
Flight Center. The goal of the project is to integrate a battery of nine
standard tests by means of desktop computer-controller in order to
provide near real-time data assessment, store the data acquired during
testing on flexible disk and provide computer production of the certi-
fication report.

Principal improvements and additions which were made to the facility
during the period covered by this report are:

(1) integration of newly acquired equipment into the instrument
suite,

(2) refinement of transducer and cable correction factors,

(3) provisions for plotting test limits on the spectrum
analyzer and oscilloscope displays and obtaining hardcopy
record of these displays during testing,

(4) incorporation of a computer-controlled antenna turntable
into the facility,

(5) installation of computer-controlled relays to automate much
of the changeover between transducers, amplifiers and
measurement instruments during testing,

(6) development of programs to recover the data acquired during
testing and produce the EMC certification report.

INTRODUCTION

An interim report on this project was prepared in August, 1985 and is cited as reference [1]. The principal considerations in determining electromagnetic compatibility (EMC), the documents which specify EMC requirements for Shuttle and Spacelab payload equipment, and the goals for an automated EMC test facility at MSFC are all discussed in [1].

At the time of the interim report, the facility was capable of performing automated EMC tests; however, the interconnection of amplifiers and signal sources and the positioning of antennas had to be accomplished manually. Programmable instruments (oscilloscope, pulse generator, power meter and rf voltmeter) required to automate additional tests had not been delivered. Further, only a rudimentary program had been written for recovery of the test data from flexible disk.

This report describes improvements and refinements to the facility which have been accomplished since the interim report. In the interest of completeness, some of the details of the EMC test facility and of the EMC test procedures discussed in [1] will be repeated here.

OBJECTIVES

The objectives in automating the EMC test facility at MSFC are:

(1) to realize the increased accuracy and precision possible with digital instrumentation,

(2) to achieve a facility in which the entire battery of standard EMC tests can be performed with a minimum of intervention by the Test Engineer,

(3) to reduce significantly the time required to perform the tests and record the data,

(4) to utilize the computer-controller to perform near real-time analysis of the test data,

(5) to provide for mass storage of the test data,

(6) to provide for production of the Test Engineer's certification report by the computer-controller, and

(7) to advance the state of EMC testing at MSFC for possible integration with comprehensive test analysis systems (such as SCATS) when such systems become available.

EMC TEST PROCEDURES

The instrument suite and the controller programs have been designed to certify EMC for Spacelab and Shuttle paylod equipment as set forth in MSFC-SPEC-521A [2] (See Table 1). Since the test requirements of [2] include all four general types of EMC tests (conducted emission, radiated emission, conduted susceptibility and radiated susceptibility) and are consistent with the standard military EMC requirements of MIL-STD-461B [3], the facility may be readily adapted to certify other EMC requirements. Refer to [1] for further details of the EMC requirements of [2] and of the EMC test procedures.

The layout of the EMC test facility at MSFC is shown in Figures 1, 2 and 3; a functional block diagram is provided in Figure 4. The principal instruments, signal sources and transducers are listed in Tables 2 and 3. The measurement techniques used in this facility are derived essentially from MIL-STD-462 [4]. A shielded enclosure (locally called a screen room) serves to eliminate environmental factors and to attenuate ambient electromagnetic fields. Some questions concerning the measurement techniques will be addressed later in this report.

Table 1. EMC Requirements for Shuttle
and Spacelab Payload Equipment [2].

EMISSIONS   SUSCEPTIBILITY

CONDUCTED (CE)   CONDUCTED (CS)

* dc Power Bus Ripple   * dc Power Bus Ripple
    (30 Hz - 20 kHz)   (30 Hz - 50 kHz)

* dc Power Bus rf   * dc Power Bus rf
    (20 kHz - 50 MHz)   (50 kHz - 400 MHz)

* Power Bus Transients   * Power Bus Transients

RADIATED (RE)   RADIATED (RS)

* Electric Field   * Electric Field
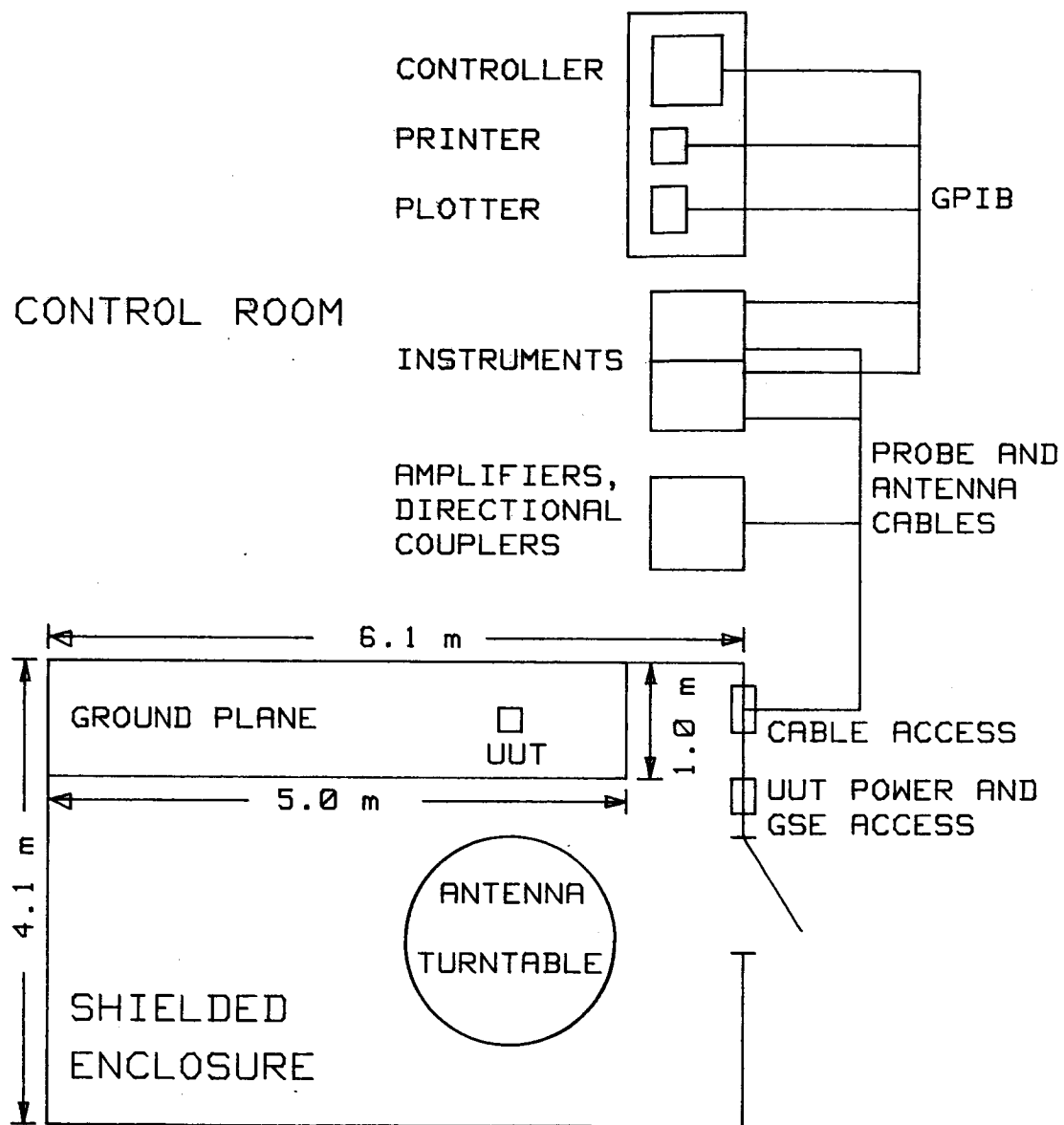   (14 kHz - 10 GHz)   (14 kHz - 10 GHz)

* ac Magnetic Field
    (20 Hz - 50 kHz)

Figure 1. Layout of EMC Test Facility at MSFC.
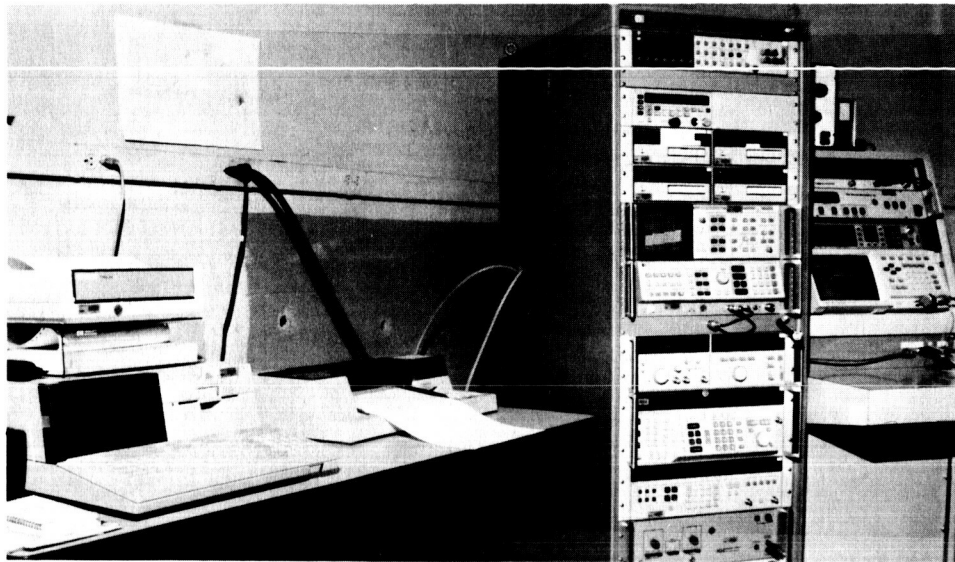
Figure 2. EMC Test Facility (Control Room).

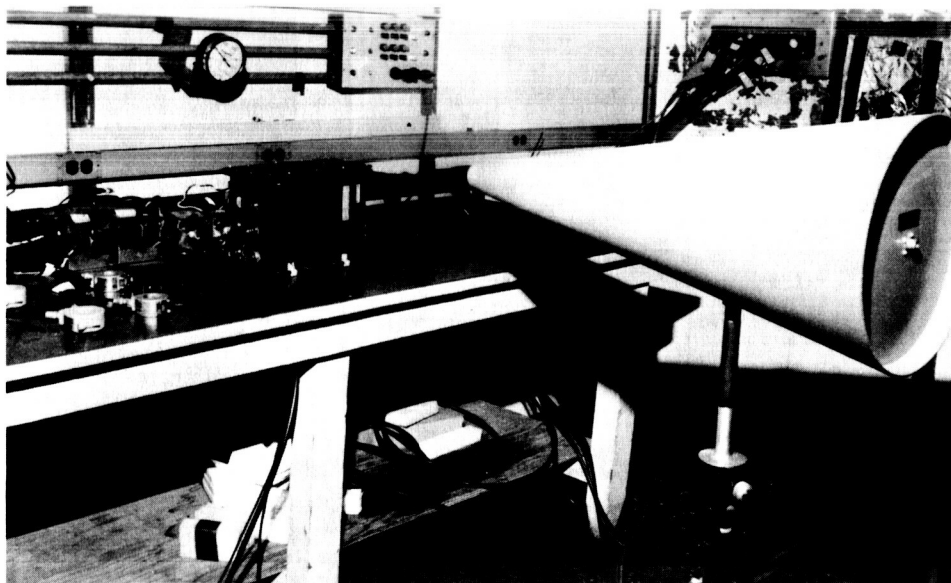Figure 3. EMC Test Facility (Inside Shield Enclosure).

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                          │   UUT    │
                          └──────────┘

        ┌───────┬──────────────────────────────────────┐
        │ TURN- │                                        │
        │       │            TRANSDUCERS                 │
        │ TABLE │                                        │
        ├───────┤                                        │
        │       │                                        │
        ├───────┼──────────────────────────────────────┤
        │ ACTU- │                                        │
        │       │           RELAY  NETWORK               │
        │ ATORS │                                        │
        └───────┴──────────────────────────────────────┘


              ┌──────────────┐      ┌──────────────────┐
              │   SIGNAL     │      │   MEASUREMENT    │
              │              │      │                  │
              │   SOURCES    │      │   INSTRUMENTS    │
              └──────────────┘      └──────────────────┘

     GPIB

  ┌──────────────┬───────────┐    ┌──────────┐ ┌───────────┐
  │              │   DISK    │    │          │ │           │
  │ CONTROLLER   │           │    │ PRINTER  │ │  PLOTTER  │
  │              │  DRIVE    │    │          │ │           │
  └──────────────┴───────────┘    └──────────┘ └───────────┘
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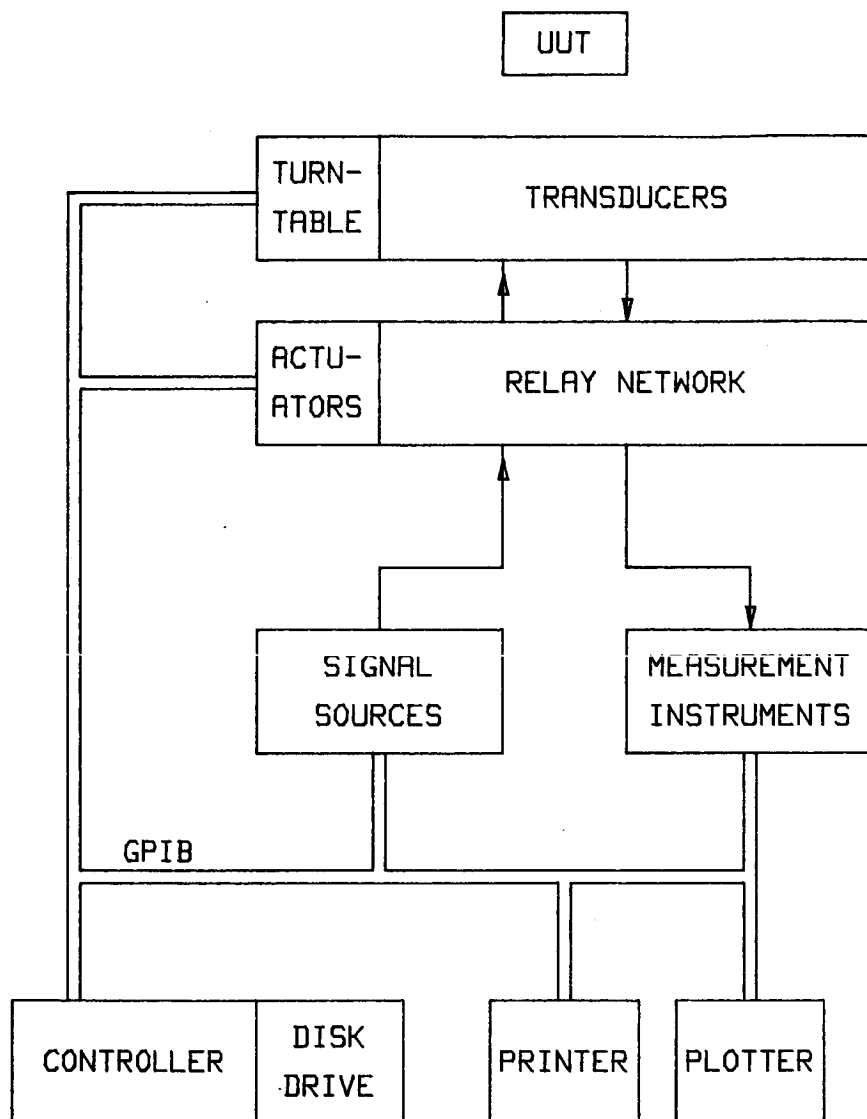
Figure 4.   Block Diagram of EMC Test Facility.

Table 2. Principal Test Instruments

CONDUCTED EMISSIONS

    30 Hz -   50 MHz   Spectrum Analyzer (HP 8566A)
    Transient   Digitizing Oscilloscope (HP 54200A)

RADIATED EMISSIONS

    All Bands   Spectrum Analyzer (HP 8566A)

CONDUCTED SUSCEPTIBILITY

    30 Hz -   50 kHz   Synthesizer/Function Generator (HP 3325A)
                             Digital Voltmeter (HP 3455A)
    50 kHz - 400 MHz   Synthesized Signal Generator (HP 8662A)
                             True rms rf Level Meter (Racal-Dana 9303)
    Transient   *RFI Transient Generator (Solar Model 6254-5)
                             Digitizing Oscilloscope (HP 54200A)

RADIATED SUSCEPTIBILITY

    14 kHz -   1 GHz   Synthesized Signal Generator (HP 8662A)
     1 GHz -   2 GHz   add Frequency Doubler (HP 11721A)
     2 GHz -   15 GHz   Synthesized Signal Generator (HP 8672A)
    14 kHz - 220 MHz   *Field Strength Meter (IFI Model EFS-1)
    220 MHz -   15 GHz   Power Meter (HP 438A)

                *Indicates non-programmable instrument

Table 3. Transducers

CONDUCTED EMISSIONS

30 Hz - 20 kHz	Current Probe (Electrometrics PCL-10)
20 kHz - 50 MHz	Current Probe (Empire Devices CP-105)
Transient	Direct connection to Orbiter Impedance Simulation Network

RADIATED EMISSIONS

14 kHz - 20 MHz	E-Field Rod Antenna (EMCO 3301)
20 MHz - 200 MHz	Biconical Antenna (EMCO 3104)
200 MHz - 1 GHz	Conical Log Spiral Antenna (Singer 93490-1)
1 GHz - 10 GHz	Conical Log Spiral Antenna (Singer 93492-2)
20 Hz - 50 kHz	Magnetic Field Pick-up Coil (EMCO 7604)

CONDUCTED SUSCEPTIBILITY

30 kHz - 50 kHz	Isolation Transformer
50 kHz - 400 MHz	Capacitor
Transient	Direct Connection to Injection Point

RADIATED SUSCEPTIBILITY

14 kHz - 220 MHz	Antenna (IFI EFG-2)
220 MHz - 1 GHz	Conical Log Spiral Antenna (Singer 93940-1)
1 GHz - 10 GHz	Conical Log Spiral Antenna (Singer 93941-2)
13 GHz - 15 GHz	Standard Gain Horn (Sci.-Atlanta SGH 12.4)

AUTOMATION OF TEST PROCEDURES

The principal test instruments listed in Table 2, the antenna turn-table and the relay actuators are all programmable and are controlled via an IEEE Std-488 general purpose interface bus (GPIB). The GPIB is managed by a computer-controller (HP 9826) with internal VDT and flexible disk drive. A dot-matrix ink jet printer and an X-Y plotter are also attached to the GPIB (Figures 1 and 4).

Controller Program

The controller program is written in high-speed programming language (HPL 2.1). The organization of the program is shown in Figure 5. The concept of the controller program is outlined in [1]. Features of the controller program are:

(1) a comprehensive set of VDT cues which keep the Test Engineer abreast of the progress of the test,

(2) near real-time tabular and/or graphical display of test results,

(3) flexibility which permits modification of many test procedures by the Test Engineer, and

(4) mass storage of test data.

VDT Cues

Despite efforts to maximize the use of programmable equipment, some operations must be accomplished manually. The controller program presents VDT cues which clearly describe the required manual operation to the Test Engineer at the appropriate time, then suspends execution until the Test Engineer acknowledges that the operation has been performed. In addition, the VDT annunciates the significant parameters (frequency, signal level, etc.) of each phase of the test.

Data Display

During data collection for emissions tests, emission limits (from [2]) are displayed on the spectrum analyzer or oscilloscope. At the end of each test phase, the Test Engineer may opt to make a hardcopy record (X-Y plot) of the display. Cable corrections, bandwidth factors and antenna factors are then applied, and reduced data are made available to the Test Engineer. Emission limits are plotted on graphical products, and data which exceed limits are flagged on tabular products.
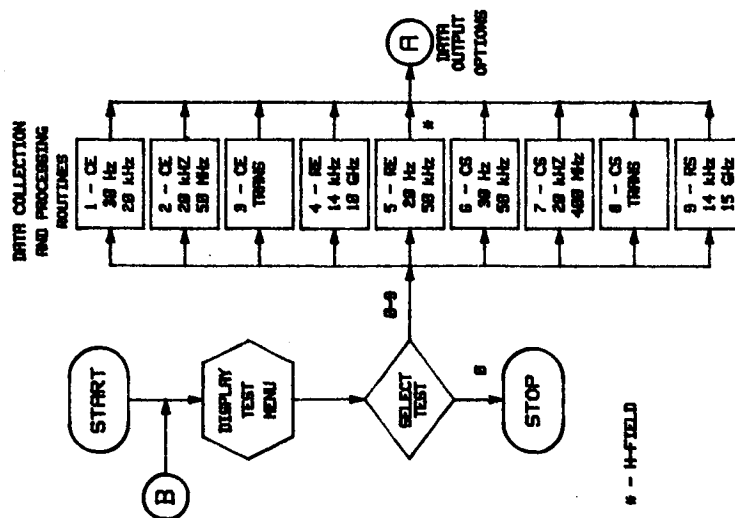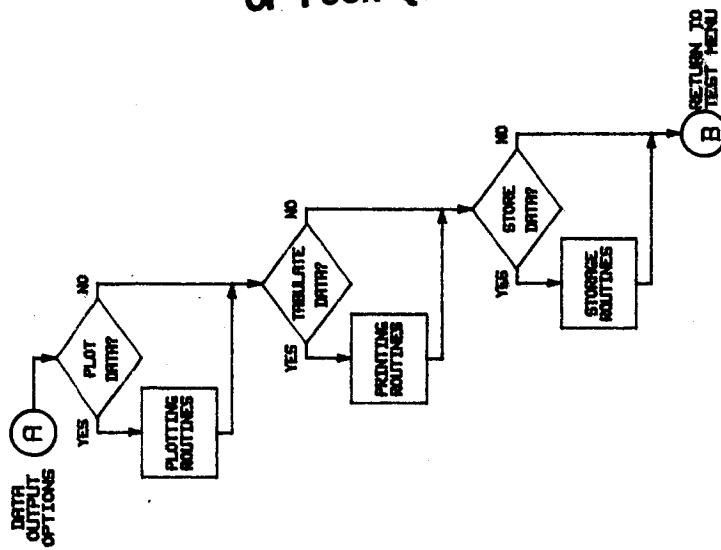
Figure 5.   Organization of Controller Program.

During susceptibility testing, requirements from [2] for injected
voltage or incident field intensity are annunciated on the VDT. The
controller applies cable corrections and transducer factors, and computes
the source levels required to achieve the required injected voltage or
incident field level at the UUT. These limits are enforced on the signal
sources by the controller unless overridden by the Test Engineer. After
each phase of susceptibility testing, a tabular display of the injected
voltage or incident field intensity at each frequency (or time increment
for transient tests) is made available. In addition, a hardcopy record
of the oscilloscope display is available during transient susceptibility
testing.

Flexibility

Following each phase of each test, the Test Engineer may opt to
repeat the test. In most cases the Test Engineer can alter test para-
meters such as signal levels, frequency range, etc., a feature which is
particularly useful in determining threshold of susceptibility.

Data Storage

The Test Engineer has the option to store the reduced data from each
phase of each test on flexible disk. This option is presented after the
option to review data, thus inappropriate data need not be retained. In
addition to the electrical data, such information as UUT designation,
date and Test Engineer's commentary is also stored.

Certification Report

The computer-controller is also used as a special-purpose word
processor to produce the Test Engineer's certification report. The Test
Engineer must respond to VDT prompts to enter administrative details such
as report date, manufacturer and identification of the UUT, requirements
and operating documents for the UUT, etc. This information, along with
reduced test data recovered from flexible disk, is integrated with stan-
dard report sentences and phrases to produce the certification report.

Program Code

The programs described above have not been reproduced here.
Inquiries concerning program codes may be directed to:

      Mr. Jimmy W. Rees
      Code ET-45
      Marshall Space Flight Center, AL 35812
      (205-544-1305).

COMMENTS AND RECOMMENDATIONS

General

The facility described in this report can be used to perform accurately and effectively the EMC tests required by MSFC-SPEC-521A for Shuttle and Spacelab payload equipment. The controller program provides flexibility in setting test parameters which will permit adaptation of the facility to other EMC tests which are derived from MIL-STD-461B and MIL-STD-462. A particular feature of this facility, which is not widely available in automated EMC test facilities, is the capability of determining and documenting threshold of susceptibility. The capability of direct production of the Test Engineer's certification report using data acquired during EMC testing is also a unique feature of this facility.

Measurement Technique

Even though high quality, modern digital instruments are used throughout the test facility, the measurement techniques for certifying EMC of Shuttle and Spacelab payload equipment is derived directly from MIL-STD-462, a document prepared nearly twenty years ago. Questions concerning the measurement techniques involve:

(1) failure to account for or manage reverberation within the shielded enclosure,

(2) location of the UUT within the shielded enclosure during tests,

(3) failure to test for directional radiated emissions or aspect-dependent radiated susceptibility.

A significant amount of work has been done in the last ten years, paticularly by the National Bureau of Standards (NBS), to investigate and improve EMC test chambers and measurement techniques. Reference [5] provides an excellent survey and bibliography of that work. It is recommended that NASA/MSFC undertake a review of modern EMC test chambers and measurement techniques and incorporate the findings into specifications for EMC certification of spacecraft and payload equipment.

Test Chamber

The shielded enclosure provides protection from the elements and reduction of ambient electromagnetic fields; however, it is inevitable that there will be reverberation of the electromagnetic field within a shielded enclosure. Reverberation must be managed within a shielded

enclosure, and its effect on EMC measurements must be considered. The use of Crawford (TEM) cell [6] and/or a mode-stirred reverberation chamber [7] should be considered as replacements for the shielded enclosure. In the meantime, it is recommended that anechoic material be placed appropriately within the shielded enclosure to reduce reverberation levels.

UUT Location

In the MSFC facility, the UUT is placed on a relatively small ground plane (1 m along the narrow dimension) approximately 0.5 m from the wall of the shielded enclosure. This placement of the UUT in what is essentially a corner reflector environment will have a problematic effect on radiated and incident electromagnetic fields in the vicinity of the UUT. It is recommended that the ground plane be relocated to the center of the shielded enclosure and/or that the wall of the enclosure be lined with anechoic material.

UUT Orientation

At present, all radiation tests are conducted with the antenna or magnetic pick-up coil at one location and with the UUT in a fixed orientation. This procedure will fail to detect the presence of directional radiation and will fail to reveal aspect-dependent susceptibility. Narrow slotted apertures, such as may exist between a metal equipment case and its cover plates, are known to create directional propagation of electromagnetic energy. This directional propagation may result in directional emission from the equipment or in coupling of energy incident from a given direction into the equipment. It is recommended that radiation testing be conducted with the antenna or magnetic pick-up coil in each of several positions laterally around the UUT. This would necessitate placement of the UUT in the center of the shielded enclosure, which is consistent with the previous recommendation. Alternativly, it is recommended that the UUT be rotated in the horizontal plane during testing.

Utilization of Test Data

The data stored on flexible disk during testing is presently used only for computer generation of the Test Engineer's certification report. While this is an important administrative convenience, other important uses of this data are possible. One potentially very significant application of EMC test data is in mission planning.

If each item of payload equipment for a given mission is certified in a facility with similar data collection and storage capabilities, then the data from all such tests can be used to generate a computer model for EMC of the entire payload. Some of the uses of an EMC model are obvious: certify EMC for the entire payload, substantiate waivers of particular

requirements for particular items, and schedule activities during the mission. As an simplified example, some item of equipment which fails to meet a particular EMC emission requirement, might be scheduled for operation only when other equipment with a corresponding susceptibility is not in use. This would preclude costly re-design of an item of equipment to meet what is, at least for that mission, an arbitrary EMC requirment.

It is recommended that NASA/MSFC investigate the creation of a computer EMC model, either as a separate entity or as part of a more comprehensive payload model. It will be necessary to establish a standard format for EMC data storage; the present format, which was created by the author with only a vague notion of intended use of the data, is not recommended as a standard format.

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