**NASA BOEING 757 HIRF Test Series
Low Power On-the-Ground Tests**

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Summary

The data acquisition phase of a program intended to provide data for the validation of computational, analytical, and experimental techniques for the assessment of electromagnetic effects in commercial transports; for the checkout of instrumentation for following test programs; and for the support of protection engineering of airborne systems has been completed. Funded by the NASA Fly-By-Light/Power-By-Wire Program, the initial phase involved on-the-ground electromagnetic measurements using the NASA Boeing 757 and was executed in the LESLI Facility at the USAF Phillips Laboratory.

The major participants in this project were LLNL, NASA Langley Research Center, Phillips Laboratory, and UIE, Inc. The tests were performed over a five week period during September through November, 1994. Measurements were made of the fields coupled into the aircraft interior and signals induced in select structures and equipment under controlled illumination by RF fields. A characterization of the ground was also performed to permit ground effects to be included in forthcoming validation exercises.

This report and the associated test plan that is included as an appendix represent a definition of the overall on-the-ground test program. They include descriptions of the test rationale, test layout, and samples of the data. In this report, a detailed description of each executed test is provided, as is the data identification (data id) relating the specific test with its relevant data files. Samples of some inferences from the data that will be useful in protection engineering and EM effects mitigation are also presented.

The test plan which guided the execution of the tests, a test report by UIE Inc., and the report describing the concrete pad characterization are included as appendices.

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1.0 Introduction

The NASA Fly-by-Light / Power-by-Wire (FBL/PBW) program was initiated to develop technology for a future generation of commercial transport aircraft. Studies have shown that an all-electric aircraft (PBW) could have substantial benefits in terms of weight and maintenance costs over today's aircraft that rely on hydraulic and pneumatic controls. However, one major concern regarding the all-electric aircraft is the potential for conducted and radiated electromagnetic susceptibility of its electronic controls. A way to potentially alleviate this problem (and save weight at the same time) is to route all control and signal information over optical fiber control links (FBL) that are inherently easier to harden against the electromagnetic environment (EME).

Since electro-optic devices and electronic digital computers will still be required, a major objective of the FBL/PBW program is to develop tools and techniques for predicting the electromagnetic environment and for assessing the survivability of the modern aircraft using such equipment in the electromagnetic environment. The EME includes both externally generated high intensity radiated fields (HIRF) and internally-generated radiated or conducted emissions.

The EME effects assessment tools and techniques must ultimately be accepted by industry and the FAA regulatory body to be useful. Therefore, an important aspect of the program is to validate these tools and techniques to the satisfaction of this community. Here, validation is a demonstration of the utility, and a proof of the accuracy of the tool or technique during the execution of its intended role. As part of this exercise, a series of aircraft tests, specifically, low power on-the-ground tests at frequencies up to 1 GHz and fly-by tests using three RF radiators in the HF, VHF and UHF ranges, have been conducted under NASA Langley Research Center sponsorship. This report describes the on-the-ground tests, which include those used for generating data for code validation as well as those which might support the development of protection engineering guidelines. It also contains a description of the output data, their format, and their identifying features.

2.0 Objectives

2.1 The NASA B-757 HIRF Test Series

The primary thrust of this aircraft test program, both on-the-ground and fly-by, is to develop a library or database of experimental results that were obtained using techniques as close to the "scientific method" as possible. This data can then be used for the validation of computational, analytical and experimental techniques for the assessment of electromagnetic effects in commercial transports and for the support of protection engineering of airborne systems. The on-the-ground tests provided a checkout of instrumentation for following test programs.

This report provides a roadmap for the test series and its associated data so that specific tests, test conditions, and the resulting data can be related and identified.

The data library is necessarily limited in size and scope by cost and time constraints, but nonetheless is expected to provide a reasonable database for validation exercises involving computer codes as well as analytical and experimental techniques. As an example, this exercise will "validate" the physics kernel of the code, its numerical algorithms, and its overall ability to provide the "right" answer. Of possibly equal importance, the data can help to establish the limits of applicability of a code, the validity of approximations and extensions which can enlarge its applicability, and the resources such as computer time and memory required to attain various levels of accuracy. Similar statements can be made regarding the analytical and experimental techniques.

2.2 On-the-Ground Test Objectives

There were four objectives and four test series for the on-the-ground tests. The first test series generated data for the library which will be used directly for coupling code validation. For this objective, discrepancies and uncertainties between measurement and model were to be minimized or at least understood and quantized. These tests used dipole antennas, so the antenna can be included in the model, thus eliminating the uncertainty in the exact form of the wave entering the problem space.

The second test series exercised the equipment that will be used for the fly-by tests. The third test series provided more data for validation of the codes and for the development of protection engineering guidelines. This series also provided information to support the fly-by tests such as that relating to resonances near the fly-by frequencies and the coupling variation due to uncertainties in aspect angle or the position of interior objects. The fourth test series involved a continuing study of stirred frequency techniques.

The first and third test series are the primary subject of this report. The fly-by test equipment check and the stirred frequency or statistical electromagnetics tests are not described.

3.0 Test Organization and Facilities

3.1 Organization

The organization for the ground tests is shown in Figure 3-1. The Phillips Laboratory provided

Figure 3-1. Organization for the execution of the On-the-Ground Test Series

the test environment including the LESLI facility and its associated instrumentation, data processing of the data, and detailed test planning prior to execution. United International Engineering provided support in the execution of the tests and associated functions. LLNL was responsible for test planning and management of its execution. NASA was the funding agency with overall program management of FBL/PBW program as well as responsibility for development and emplacement of the sensors and other equipment on board the airplane. Figure 3-1 represents the various participants and lines of responsibility. The solid lines indicate the formal lines of responsibility while the dashed lines indicate the informal communication channel during the execution of the tests.

3.2 Test Aircraft

The primary test object for the HIRF Test Series was the NASA/Eastern (Boeing) 757-200. The onboard certificate identifies the aircraft as a Boeing 757-225, Serial Number 22191 with the 225 denoting the specific configuration requested by the original sole owner (Eastern Airlines). With the exception of the intrusion of the HIRF probes and data acquisition system, the aircraft was maintained in a typical airline passenger configuration (passenger seats, overhead baggage compartments, galleys and lavatories) during the duration of the test series. In the following, this aircraft is referred to as the B-757, NASA B-757, NASA 757, etc., for convenience.

3.3 On-the-Ground Test Facility

The on-the-ground tests were conducted at the U.S. Air Force Phillips Laboratory (PL) Large Electromagnetic System-Level Illuminator (LESLI) test facility. The LESLI facility is operated and maintained by the PL/WSR. This facility consists of concrete pad, a two-wire rhombic antenna supported by a non-conducting line attached to wooden poles, a source shack housing power amplifiers, and a data acquisition and control trailer (DAS). Figure 3-2 is a sketch of the aircraft in the LESLI facility with the rhombic radiators in the deployed configuration. These radiators were lowered and stowed during other test configurations, e.g., dipole tests to be described later.

Figure 3-2. Sketch of the LESLI facility with the rhombic deployed and aircraft emplaced

Figure 3-3 is an overhead plan view showing the LESLI facility, the circular concrete pad with 92 meter diameter, and the aluminum sheet that serves as a conducting ground plane in the near vicinity of the rhombic feedpoint, and the relative positions of the rhombic radiating wires as used during the on-the-ground test series. The insertion or feedpoint of the rhombic radiators was located about three meters from the edge of the concrete pad.

Figure 3-3. LESLI Facility with rhombic radiator and ground plane

All tests carried out in the LESLI made use of the data acquisition system in place in the facility. Since the tests were stepped CW over the frequency range of interest, vector automatic network analyzers (VANA) were used throughout. Figure 3-4 is an organizational layout of the data acquisition and processing system for a signal channel of data. In practice, a two channel system was employed.

A low-level RF signal was generated in the source shack by a VANA under computer control from the DAS. It was amplified to the desired level by one of the two power amplifiers in the source shack, and this high-level RF signal was used to generate the required fields in the test volume by driving the appropriate radiator (rhombic or dipole).

Responses to the generated fields were sensed by a probe (voltage or current) or field sensor. The resultant electrical signals were sent on Heliax, 50 ohm coaxial cable to a fiber optic transmitter,

converted to optical signals, transmitted to a fiber optic receiver in the source shack, converted back to electrical signals, and delivered to the data processing system for final processing, QC, and generation of hard and soft copies for the user.

Figure 3-4. CW data acquisition and processing flow

3.4 The On-the-Ground Test Series Coordinate Systems Care should be taken throughout this report as the coordinate systems and their associated directions may differ when referring to different measurements. This was a result of using pre-established coordinate systems for electromagnetic measurement facilities, geometry descriptions provided by airplane manufacturers, and lack of hard coordination between the teams performing the test planning and

execution. The coordinate systems are summarized here to stress the importance of the issue rather than waiting for the section in which the particular measurement is described. The following can serve as a reference with details later in the text.

The main differences occur when referring to:

- 1) the rhombic radiator on the LESLI pad and locations on the pad,
- 2) dipole radiators in isolation as when measuring their radiated fields (field mapping),
- 3) the position of the dipole antenna and its associated reference sensor when measuring aircraft responses to dipole excitation
- 4) positions and locations of physical structures within the aircraft based on the aircraft manufacturers drawings and their datum
- 5) coordinated directions for field components within the aircraft.

Figure 3-5 is a summary of the systems used in defining the coordinates and directions in various parts of this report. The following is a brief description of the systems with an indication of the section in which the system is first referred.

Figure 3-5a is a repeat of Figure 3-3 and is an overhead plan of the LESLI facility showing the extent of the concrete pad, the aluminum ground plane, and the relative position of the rhombic radiating wires as used during the on-the-ground test series. (Sect. 3.3). The coordinate system is a right-hand one in which positive "X" is looking down the wires from the origin, in a westerly direction. Positive "Y" is up (vertical), and positive "Z" is orthogonal to "X" in a northerly direction. Objects located on the test pad, e.g., the aircraft, were positioned with the respect to this system.

Figure 3-5b depicts the coordinate system for the dipole antennas standing alone, as when measuring their radiated fields. (Sect. 6.3.3). The origin is on the ground directly below the antenna center or feedpoint. The system is similar to the LESLI facility in that positive "X" is in a direction from the antenna towards the measurement point (all field measurements were with positive "X"), Positive "Y" is up (vertical), and positive "Z" is orthogonal to "X" and "Y" in a right-hand sense.

Figure 3-5c shows the coordinate system which was used to position the dipole antennas for excitation of the aircraft. (Sect. 6.4.3). In this case, the system is with respect to the aircraft. The origin is a point on the test pad directly below the nose. In this right-hand system, the positive "X" direction is forward of the aircraft and parallel to the fuselage. The positive "Y" direction is up, and the positive "Z" direction to starboard of the aircraft.

Figure 3-5d shows the coordinate directions used for defining the on-board measurements. (Sect. 4.1). These are used to define the components of the electric and magnetic fields.

Figure 3-5e shows the coordinate system used by the manufacturer in defining the geometry of the aircraft in their drawings. It is used here to define the location of physical objects in the aircraft when necessary. (Sect. 4.2). This information will be used in creating the computer models to be used in modeling.

Figure 3-5. A summary of the coordinate systems used in this report

4.0 On-Board Sensor Systems

The sensors for the on-the-ground tests were fitted into the aircraft prior to its arrival at the LESLI facility. Some of the sensors were removed for the flight to Kirtland AFB, and were reinstalled for the tests. The suite of 12 sensors were to sample fields, cable currents and voltages in three aircraft areas and the exterior of the fuselage. The internal measurements were in the cockpit, electronics bay (E-bay) and cabin, while the external measurement involved field sensing at a single point on the aircraft skin. During the remainder of this report, the external sensor is included in the cabin sensor suite.

4.1 Cockpit Sensors

Figure 4-1 depicts the various sensor locations in the cockpit. Also shown in Figure 4-1 is the coordinate system used in the definition of vector directions in the interior of the airplane. Note that this definition (x, y, z) is different than that used for the definition of vector directions associated with the primary radiators, namely the rhombic and dipoles.

Figure 4-1. Cockpit sensors

There were five sensors in the cockpit. All of these sensors were mounted onto the same sensor box that was fabricated by NASA LaRC and is referred to as the ATOPS box. The box was a cube, 12 inches on a side, was constructed of welded aluminum and was mounted on a metal pedestal (14 inches square by 18 inches high). The ATOPS box had three orthogonal faces on which were placed Prodyn AD-60 D-dot sensors as well as a face with a feed-through connector to which was appended an external two foot long, AWG#10 Bus Bar wire that was routed vertically. In the following, this wire will be referred to as the "climbing wire".

In addition, a Prodyn I-320 current probe was used on the climbing wire just outside of the box. This probe was also used to measure current on the starboard side window heater cable in a select test at point CP12 to be referred to later. The geometry of emplacement of the ATOPS box and its pedestal in the cockpit is shown in Figure 4-2 and a sketch of the ATOPS box with conceptual AD-60 probes is shown in Figure 4-3. A picture of the ATOPS box emplaced in the cockpit is shown in Figure 4-4.

Figure 4-2. ATOPS box and pedestal in cockpit with coordinates

Figure 4-3. ATOPS box with conceptual representation of E field sensors (d-dot)

4.2 Electronics Bay Sensors

There were three sensors emplaced in the electronics bay as shown in Figure 4-5. A Prodyn AD-60 electric field probe was used to measure the vertical (z-directed) electric field near the floor within the bay (see Figure 4-6). A Prodyn I-320 current probe was placed on a power line within the E-bay which was used for energizing the cockpit windshield heater. The third measurement in the electronics bay was made inside a Collins VHF-700 transceiver box. In the remainder of this report, this unit will often be referred to as the LRU or RC-7 box or unit. The unit had been modified by LLNL to permit the measurement of the voltage on an internal power line pin. The unit was connected to the avionics bus during the low power RF stepped frequency tests.

Figure 4-4. ATOPS box on pedestal in cockpit

Figure 4-5. Electronics bay sensors

Figure 4-6. Electronics bay electric field (d-dot) sensor

4.3 Cabin Sensors

There were four sensors in the cabin area as shown in Figure 4-7. One of these was an AD-60 electric field sensor (D-dot sensor) mounted on top of the EME instrumentation rack (Figure 4-8). The EME rack and its power conditioning unit contained the data acquisition system for the fly-by experiments and was only used during the fly-by instrumentation checkout phase of the ground tests. This phase is not a subject of this report but suffice it to say that the system was not powered but otherwise was maintained in its fly-by configuration during the ground tests.

Figure 4-7. Cabin sensors

Figure 4-8. Electric field sensor (d dot) on the EME rack and close-up

A second sensing device in the cabin was a long-wire that consisted of a 20 foot length of AWG#12 wire supported from the ceiling of the aircraft cabin by phenolic stand-offs. The stand-offs provided a 12 inch clearance from any metal aircraft parts. The picture in Figure 4-9a shows the supports (seen as vertical, dark colored structures spaced at uniform intervals) and the long wire (seen at the bottom of the supports). The picture in Figure 4-9b shows the first support that has an attached,

a) Long wire with dielectric supports and coaxial cable feed

b) Long wire feed point

Figure 4-9. The cabin long wire with dielectric supports and coaxial cable feed

4.4 Summary of Test Points and Measured Parameters

Table 4-1 summarizes the test point designation, the parameter being measured, and the location of each of the test points in the aircraft.

Table 4-1. Test Points, Measured Parameters and Locations		
Test Point	Measured Parameter	Description
CP1	Vertical Field E_z	E_z measured at ATOPS box in cockpit
CP2	Horiz.1 Field E_x	E_x (parallel to aircraft axis) measured at ATOPS box
CP3	Horiz.2 Field E_y	E_y (perpendicular to aircraft axis) measured at ATOPS box
CP4	Wire Current	Current on "climbing wire" at ATOPS box
CP5	Wire Voltage	Voltage at "climbing wire"
CP12	Wire Current	Current on side window heater wire
EB1	Vertical Field E_z	E_z (vertical) measured in E-bay
EB2	LRU Voltage	Voltage measured in power supply section of LRU (RC-7)
EB3	Cable Current	Current measured on power cable from windshield heater
C1	Vertical Field E_z	E_z (vertical) measured atop the instrumentation rack in the cabin
C2	Wire Current	Cable current on the coaxial cable connected to the "long wire" in the cabin
C3	Voltage	Feedpoint voltage of the long wire in the cabin
C4	Field (Ext. Antenna)	Voltage measured at the feedpoint of the external blade antenna

4.5 Sensor/Cable/Fiber Optic Transmitter Identifications

The data acquisition system setup for the test series used the conceptual scheme of Figure 3-4, but for the purposes of expediency and efficiency employed two fiber optic transmitters (NanoFast) and two network analyzers (Hewlett Packard HP 8753C). This permitted simultaneous acquisition of two aircraft data channels. The block diagram for the system is shown in Figure 4-11. The sensors and their respective cabling to the F-O transmitters are not shown. The radiator and its reference in the figure were either the rhombic or dipole radiators with their associated reference probe.

The RF signal used in the tests was generated by using the RF output of the network analyzer and amplifying this signal to a level in the range of 100 to 200 watts. This was accomplished by passing the signal through one of two Amplifier Research RF amplifiers depending on the frequency range. For this test system, the ranges were defined as 0.3 to 100 MHz (AR 250L220) and 100 MHz to 1 GHz (AR 200W/1000M7). This arrangement is shown in Figure 4-11. The two network analyzer measurement system involved the use of two F-O transmitters each having four input ports which could be remotely switched and a single output port.

Table 4-2 relates the test points, the variables measured, the location, the specific probe and its Heliac cable designation, and the designation of the F-O transmitter port to which the cable was attached. Retention of the information regarding the precise setup is important because the data recorded in the VANAs are, in effect, voltages or ratios of voltages at the VANA terminals. Knowledge of the system setup permits the use of sensor and cable calibrations as well as fiber link characteristics, to back out the actual variable of interest. Thus, using the effective transfer function of the measurement system, one can gain access to a variable in a remote position (say an electric field strength) having measured a voltage at the terminals of the measurement system. Discussion of such calibration procedures is carried out in the discussion of pretest activities and the actual calibration data for the each element in the data acquisition system is identified.

grounded metal strip on which is mounted a coaxial connector for the 50 ohm semi-rigid coaxial cable. The feedthrough connector serves as the feedpoint for the long wire. A feedpoint voltage measurement was made on this cable as shown in Figure 4-9b. A current sensor to measure shield current was also installed on the semi-rigid coaxial cable at a position where the cable emerged from behind the wall panel at the floor of the cabin (Figure 4-10).

Figure 4-10. Current sensor on cable in cabin

The fourth sensor referred to as a cabin sensor was the VHF-L (left) antenna which is part of the normal complement of external antennas for the NASA aircraft. It was located on the upper surface of the fuselage. This antenna was primarily intended to provide a strong signal to be used as a trigger for the fly-by test instrumentation but also provided a measurement of the external field (perturbed by the aircraft).

Figure 4-11. Aircraft test system using two network analyzers

Table 4-2. Test Point, Cable, Sensor and Fiber Optic Transmitter Designations

Test Point	Measured Parameter	Location	Cable Desig.	Probe/Sensor	XMTR Input	Comments
CP1	Vertical Field E_z	Cockpit	T1C3	AD60	NF50	
CP2	Horiz.1 Field E_x	Cockpit	T1C1	AD60	NF20	
CP3	Horiz.2 Field E_y	Cockpit	T1C2	AD60	NF52	
CP4	Wire Current	Cockpit	T1C4	P132	NF53	
CP5	Wire Voltage	Cockpit	T2C1	APRB	NF51	
EB1	Vertical Field E_z	E-bay	T2C2	AD60	NF21	
EB2	LRU Voltage	E-bay	T2C4	APRB	NF22	
EB3	Cable Current	E-bay	T2C3	P134	NF23	
C1	Vertical Field E_z	Cabin	T3C2	AD60	NF50	Second Set
C2	Wire Current	Cabin	T3C4	P133	NF51	Second Set
C3	Voltage	Cabin	T3C3	APRB	NF20	Second Set
C4	Field (Ext. Antenna)	Cabin	T3C1	APRB	NF21	Second Set
CP12	Wire Current (side window heat wire)	Cockpit	T1C4	P132	NF53	

In Table 4-2, the ports on the F-O transmitters are denoted NF## with the 50 and 20 series denoting the two transmitters, respectively. Given the desire to record 12 channels, the cabling attachment to the F-O transmitters would have to be changed at least once during a series of tests. Thus ports NF20, NF21, NF50 and NF51 were used in each run with different cables attached. CP12 refers to a specific test which was executed during the program and which required the movement of one of the probes in the earlier series.

5.0 Creating the Electromagnetic Environment

The electromagnetic environment for the test object - the NASA B-757 - was generated in the LESLI facility. We have already discussed how the RF driver signal for radiators was produced - a VANA test signal was amplified in RF amplifiers to the 100 to 200 watt level. To produce the electromagnetic fields illuminating the B-757 as it sat on the LESLI concrete pad, the amplified RF signal was used to drive a radiator. For the purposes of this program, two separate radiators were used - the rhombic radiator as shown in Figures 3-2 and 3-3 and a dipole. In the following we describe the ground plane and the two distinct radiating structures.

5.1 Ground Plane

The concrete surface forming the pad in the LESLI facility was used in an unaltered state as the ground surface. It was originally planned that a conducting ground plane composed of interlocking metal plates would be used. This would permit accurate knowledge of the ground parameters and reduce the uncertainties in the aircraft's environment. A portable runway system owned by the US Army that could cover in excess of 15,000 sq. ft. with approximately 1100 panels was located, inspected, and integrated into plans. However, military operational conflicts ultimately made such a ground plane unavailable and other plans for conducting ground planes proved impractical. Thus, the tests were reconfigured to use the unaltered concrete ground for which there was little information regarding constitutive parameters or the density and location of reinforcing materials. Since the parameters were unknown, and the concrete/aggregate/rebar/soil was not precisely describable, a measurement of the parameters was needed. A brief description of the method and the data is provided in Section 6.3.5 and the details are provided in NASA Contractor Report 4674 (Poggio et al., 1995).

6.0 The Low Power On-the-Ground Test Series

The tests conducted during the low power on-the-ground test program were governed by the test matrix presented in the test plan [Poggio et al., 1994] which is reproduced in Appendix A, for convenience. In that document the purpose of each test was defined and the test was described. Every attempt was made to adhere to that plan but in some cases tests were abandoned either because they were deemed not useful or because time restraints precluded their successful completion in view of other tests that were planned. The tests were not necessarily executed in the order presented in the test matrices but were carried out in a manner which maximized throughput by always striving for full usage of both channels in data acquisition and minimization of down-time for system reconfiguration.

6.1 A Tabulation of the Executed Tests

The following tables describe the tests which were executed. Table 6-1 contains the test point abbreviated name, the parameters measured at each test point, and a location description.

Table 6-1. Test Points and Measured Parameters

CP1	Vert. Field	E_z measured at ATOPS box in cockpit
CP2	Horiz.1 Field	E_x (parallel to aircraft axis) measured at ATOPS box in cockpit
CP3	Horiz.2 Field	E_y (transverse to aircraft axis) measured at ATOPS box in cockpit
CP4	Wire Current	Current on "climbing wire" at ATOPS box
CP5	Wire Voltage	Voltage at "climbing wire"
EB1	Field	E_z (vertical) measured in E-bay
EB2	LRU Voltage	Voltage measured in power supply section of LRU
EB3	Cable Current	Current measured on power cable from windshield heater
C1	Field	E_z (vertical) measured atop the instrumentation rack in the cabin
C2	Wire Current	Cable current on the coaxial cable connected to the "long wire" in the cabin
C3	Voltage	Feedpoint voltage of the long wire in the cabin
C4	Field	Voltage measured at the feedpoint of the external blade antenna
CP12	Wire Current	Cockpit;; current measured on copilot's side window heater wire; uses same channel as CP4; occasional use only

Tables 6-2 a, b, and c define the abbreviations used in the following tables.

Table 6-2a. Xmit Ant	
D	Dipole
R	Rhombic

Table 6-2b. Polarization	
V	Vertical
H	Horizontal

Table 6-2c. Probe or Sensor	
AD-60	D-Dot or E field probe
I-320	Current Probe
Ext. Antenna	External VHF blade antenna
Climbing Wire	vertical wire on ATOPS Box
Voltage Probe (also RC7)	voltage measurement in LRU
Long Wire	voltage measurement in cabin

Table 6-3 contains a description of the meaning of the letter designators for the notes in the following tables.

Table 6-3. Notes	
A	Predictions of field coupling; transmit antenna in computational volume
B	Thin wire coupling
C	Aircraft external field measurement
D	Typical coupling into a representative critical LRU in the E-bay
E	Variations in coupling with frequency
G	Predictions of field coupling; plane wave incident
G2	E-bay hatch cover electrically sealed with conducting tape to assess leakage at seam
G3	E-bay hatch cover open to assess energy leakage
G4	Negative pressure door sealed with conductive tape to assess change from normal state
H	Predictions of thin wire coupling; plane wave incident
I	Calibration of aircraft external field measurement, plane wave incident
J	Typical coupling into a representative critical LRU in the E-bay, plane wave incident
J1	VHF circuit breaker pulled (out)
J2	VHF circuit breaker engaged (in)
K	Repeatability
L	Resolution element effects. "Small box" is a plastic box (3"x3"x4") wrapped in conducting copper tape) located on the sensor box.
L1	Small box placed on lower port edge of the aft side of ATOPS Box with long axis parallel to floor
L2	Small box placed on upper starboard edge of the aft side of ATOPS Box with long axis perpendicular to floor
M	Stirring effects caused by people. Remove small box
M1	Pilot and copilot, personnel in seats 3c, 3d, 2b, and 3b
N	Cockpit Window model
N1	Current probe on heater wire at copilot's side window with cable toward window and forward
O	Effect of cable loads on cavity absorption. AWG #20 wire 3 feet long with 213 Ω resistor at ground end on ATOPS Box.
O1	Free end of wire on pilot's seat
O2	Free end of wire to top of jump seat
P	Angular sensitivity. Movement to 5° will be performed if measurements at 10° indicate strong sensitivity
Q	Effect of aircraft static grounding wire
R	Repeatability (angular)
S1	Cockpit seats in mid position as compared to normal full forward in all other tests
T	Measurement noise floors
U	Ambient noise measurement
V	Instrumentation Noise Measurements: Strongest and weakest channels observed over the test series are chosen. Probe is replaced by matched load and noise signals recorded.
X1	No cables connected to the other three ports of the respective F-O transmitter to avoid crosstalk
Z	Aluminum foil cover on all cockpit windows

Tables 6-4 through 6-16 are a tabulation of the thirteen test series which were performed. Most of the data in these tables are extracted directly from the Test Plan, Appendix A. Also included in the tables are specific identifications of sensors, cables, date and time of acquisition, and remarks for each test for later reconstruction of the test environment, if necessary.

A brief description of each table follows:

- Table 6-4. Test Series AN -Ambient noise measurements.
- Table 6-5. Test Series A - Dipole measurements, horizontal polarization from 23 to 28 MHz. **NOTE:** Tests A101 and A102 were added to the test matrix to better understand the effects of seat placement.
- Table 6-6. Test Series B - Dipole measurements, horizontal polarization from 23 to 28 MHz.
- Table 6-7 Test Series C - Dipole measurements, vertical polarization from 150 to 200 MHz. **NOTE:** Tests C104, 204, 404, and C109 were added to the test matrix to investigate the effects of cross-talk in the instrumentation
- Table 6-8 Test Series D - Dipole measurements, horizontal polarization from 150 to 200 MHz.
- Table 6-9 Test Series E - Dipole measurements, vertical polarization from 350 to 500 MHz. **NOTE:** Test E004 was a repeat measurement to increase the signal to noise response of the data.
- Table 6-10. Test Series F- Dipole measurements, horizontal polarization from 350 to 500 MHz. **NOTE:** Tests F008 and F010 were added to the test matrix to investigate the effects of cross-talk in the instrumentation.
- Table 6-11. Noise Floor Measurements- in which the sensors were replaced by a 50Q Load and the noise contributed by the instrumentation measured.
- Table 6-12. Test Series J - Rhombic measurements, nose-on from 0.3 MHz to 1 GHz. **NOTE:** Test J05 was added to the test matrix as a vertical wire variation to investigate instrumentation loading, and Tests J026, J028, and J029 were added to investigate coupling into the aircraft with the cargo bay door sealed with copper tape.
- Table 6-13. Test Series K - Rhombic measurements, wing-on from 0-.3 MHz to 1 GHz. **NOTE:** Tests K16 through K22 (variations with people in various positions in the aircraft) were dropped because this experiment had been accomplished in Test Series J. Tests K007 and J024 were added to the test matrix after the aircraft returned to the nose-on orientation to investigate the effects of circuit breaker configurations.
- Table 6-14. Test Series Z - Rhombic measurements, nose-on from 0.3 MHz to 1 GHz. **NOTE:** This entire test series was added to the test matrix to study various issues which arose during the test period.
- Table 6-15. Rhombic Horizontal Polarization - Rhombic in horizontal polarization measurements, nose-on from 0.3 MHz to 1 GHz. **NOTE:** This entire test series was added to the test matrix to provide analysts with data pertaining to the aircraft's lowest order resonances.
- Table 6-16. Test Series WF - Rhombic measurements, nose-on from 0.3 MHz to 1 GHz with the aircraft windshield covered with aluminum foil. **NOTE:** This entire test series was added to study the effect of the a/c windshield as a major POE.

Table 6-4. Test Series AN - Ambient Noise Measurements

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
AN1	CP1	Vert. Field	AD60 #35	0.3 - 1000				U	T1C3/P5	9-23/10:55	REF1 = MGL-6 for H _z at (-1.525, 3, -7.475)
AN2	CP2	Horiz.1 Field	AD60 #32	0.3 - 1000				U	T1C1/GTC4	9-23/10:55	REF2 = MGL-6 for H _z at (-1.525, 3, -7.475)
AN3	EB3	Cable Current	I-320 #34	0.3 - 1000				U	T2C3/P7	9-23/12:45	REF2 = MGL-6 for H _z at (-1.525, 3, -7.475)
AN4	C4	Field	Ext. antenna	0.3 - 1000				U	T3C1/P1	9-23/13:30	REF2 = MGL-6 for H _z at (-1.525, 3, -7.475)

Table 6-5. Test Series A - Dipole (Horizontal, 23 - 28 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
A1	CP1	Vert. Field	AD-60 #35	23 - 28	D	H	Dipole // to a/c axis	A	T1C3/P5	9-26/14:39	Note: Seats aft, see A101
A2	CP2	Horiz.1 Field	AD-60 #32	23 - 28	D	H	Dipole // to a/c axis	A	T1C1/GTC4	9-26/14:39	Note: Seats aft, see A102
A3	CP3	Horiz.2 Field	AD-60 #36	23 - 28	D	H	Dipole // to a/c axis	A	T1C2/GTC1	9-26/ 1. 12:45 2. 13:07	1. Repeat run for jump at 25 MHz 2. Grad rise at 75.5 MHz
A4	CP4	Wire Current	I-320 #32	23 - 28	D	H	Dipole // to a/c axis	B	T1C4/GTC3	9-26/13:56	
A5	CP5	Wire Voltage	Climbing Wire	23 - 28	D	H	Dipole // to a/c axis	B	T2C1/GTC2	9-26/15:35	
A6	EB1	Field	AD-60 #34	23 - 28	D	H	Dipole // to a/c axis	A	T2C2/P6	9-26/12:05	
A7	EB2	LRU Voltage	RC7	23 - 28	D	H	Dipole // to a/c axis	D	T2C4/GTC5	9-26/13:07	down to noise at about 25.5 MHz & back out at about 26.5 MHz 22
A8	EB3	Cable Current	I-320 #34	23 - 28	D	H	Dipole // to a/c axis	B	T2C3/P7	9-26/13:56	
A9	C1	Field	AD-60 #33	23 - 28	D	H	Dipole // to a/c axis	A	T3C2/P2	9-26/10:34	
A10	C2	Wire Current	I-320 #33	23 - 28	D	H	Dipole // to a/c axis	B	T3C4/P3	9-26/10:57	
A11	C3	Voltage	Long Wire	23 - 28	D	H	Dipole // to a/c axis	B	T3C3/P4	9-26/10:34, 10:57	
A12	C4	Field	Ext. Ant	23 - 28	D	H	Dipole // to a/c axis	C	T3C1/P1	9-26/15:35	
A13	Weak Signal Line	LRU Voltage	RC7	23 - 28	D	H	Dipole // to a/c axis	V	T2C4/GTC5	9-26/16:26	Weak signal, 50 ohm load on cable at RC7
A14	Strong Signal Line	Voltage	Long Wire	23 - 28	D	H	Dipole // to a/c axis	V	T3C3/P4	9-26/16:08	Strong signal, 50 ohm on cable at LW
A101	CP1	Field	AD-60 #35	23 - 28	D	H	Dipole // to a/c axis	V	T1C3/P5	9-26/15:03	Seats forward
A102	CP2	Field	AD-60 #32	23 - 28	D	H	Dipole // to a/c axis	V	T1C1/GTC4	9-26/15:03	Seats forward

Table 6-6. Test Series B - Dipole (Vertical, 23 - 28 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
B1	CP1	Vert. Field	AD-60 #35	23 - 28	D	V	front, left of a/c	A	T1C3/P5	9-23/14:20	
B2	CP2	Horiz.1 Field	AD-60 #32	23 - 28	D	V	front, left of a/c	A	T1C1/GTC4	9-23/15:26	Copilot seat in aft post'n
B3	CP3	Horiz.2 Field	AD-60 #36	23 - 28	D	V	front, left of a/c	A	T1C2/GTC1	9-23/15:05	
B4	CP4	Wire Current	I-320 #32	23 - 28	D	V	front, left of a/c	B	T1C4/GTC3	9-23/15:26	
B5	CP5	Wire Voltage	climbing wire	23 - 28	D	V	front, left of a/c	B	T2C1/GTC2	9-23/14:40	
B6	EB1	Field	AD-60 #34	23 - 28	D	V	front, left of a/c	A	T2C2/P6	9-26/8:09	App 15.5 dB dip at 25.5 MHz
B7	EB2	LRU Voltage	RC7	23 - 28	D	V	front, left of a/c	D	T2C4/GTC5	9-23/15:48	
B8	EB3	Cable Current	I-320 #34	23 - 28	D	V	front, left of a/c	B	T2C3/P7	9-23/14:30	
B9	C1	Field	AD-60 #33	23 - 28	D	V	front, left of a/c	A	T3C2/P2	9-26/8:09	
B10	C2	Wire Current	I-320 #33	23 - 28	D	V	front, left of a/c	B	T3C4/P3	9-26/7:45	
B11	C3	Voltage	Long Wire	23 - 28	D	V	front, left of a/c	B	T3C3/P4	9-26/7:45	
B12	C4	Field	Ext. Ant.	23 - 28	D	V	front, left of a/c	C	T3C1/P1	9-23/14:40, 15:05	
B13	C1	Field	AD-60 #33	25.7 - 26	D	V	1% BW, 1000 pts	E	T3C2/P2	9-26/8:40	1000 points
B14	Weak Signal Line	LRU Voltage	RC7	23 - 28	D	V	front, left of a/c	V	T2C4/GTC5	9-26/9:00	50 ohm load on cable at RC7
B15	Strong Signal Line	Voltage	Long Wire	23 - 28	D	V	front, left of a/c	V	T3C3/P4	9-26/9:22	50 ohm load on cable at LW

Table 6-7. Test Series C - Dipole (Vertical, 150 - 200 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
C1	CP1	Vert. Field	AD-60 #35	150 - 200	D	V	front, left of a/c	A	T1C3/P5	9-27/9:31	
C2	CP2	Horiz.1 Field	AD-60 #32	150 - 200	D	V	front, left of a/c	A	T1C1/GTC4	9-27/12:55	
C3	CP3	Horiz.2 Field	AD-60 #36	150 - 200	D	V	front, left of a/c	A	T1C2/GTC1	9-27/10:19	
C4	CP4	Wire Current	I-320 #32	150 - 200	D	V	front, left of a/c	B	T1C4/GTC3	9-27/10:47	
C5	CP5	Wire Voltage	climbing wire	150 - 200	D	V	front, left of a/c	B	T2C1/GTC2	9-27/9:58	
C6	EB1	Field	AD-60 #34	150 - 200	D	V	front, left of a/c	A	T2C2/P6	9-27/1:15	
C7	EB2	LRU Voltage	Voltage Probe	150 - 200	D	V	front, left of a/c	D	T2C4/GTC5	9-27/10:19	
C8	EB3	Cable Current	I-320 #34	150 - 200	D	V	front, left of a/c	B	T2C3/P7	9-27/10:47	
C9	C1	Field	AD-60 #33	150 - 200	D	V	front, left of a/c	A	T3C2/P2	9-27/1:38	
C10	C2	Wire Current	I-320 #33	150 - 200	D	V	front, left of a/c	B	T3C4/P3	9-27/12:15, 1:15	
C11	C3	Voltage	Long Wire	150 - 200	D	V	front, left of a/c	B	T3C3/P4	9-27/9:31	
C12	C4	Field	Ext. antenna	150 - 200	D	V	front, left of a/c	C	T3C1/P1	9-28/9:58	
C13	C1	Field	AD-60 #33	171 - 173	D	V	1% BW, 1000 pts	E	T3C2/P2	9-27/1:51	
C14	Weak Signal Line	Wire Current	I -320 #32	150 - 200	D	V	front, left of a/c	V	T104/GTC3	9-27/2:25	50 ohms on cable at connection to I-320
C15	Strong Signal Line	Voltage	Long Wire	150 - 200	D	V	front, left of a/c		T3C3/P4	9-27/2:25	50 ohms on cable at connection to LW
C109	C1	Field	AD-60 #33	150 - 200	D	V	front, left of a/c		T3C2/P2	9-27/3:12	Path variation test-compare to C9
C111	C3	Voltage	Long Wire	150 - 200	D	V	front, left of a/c		T3C3/P4	9-27/3:12	Path variation test-compare to C11
C104	CP4	Wire Current	I 320 #32	150 - 200	D	V	front, left of a/c	V	T104/GTC3	9-29/7:33	Study instrumentation noise- 50 ohm on input 53 of F-O xmtr; possible crosstalk
C204	CP4	Wire Current	I 320 #32	150 - 200	D	V	front, left of a/c	V	T104/GTC3	9-28/7:53	More instrumentation noise- 50 ohm on input 53 of F-O xmtr, disconnect others
C304	CP4	Wire Current	I 320 #32	150 - 200	D	V	front, left of a/c	V	T104/GTC3	9-28/8:07	Same as C204 but T1C4 connected to NF53 & 50 ohm on sensor end of T1C4
C404	CP4	Wire Current	I 320 #32	150 - 200	D	V	front, left of a/c	V	T104/GTC3	9-28/8:21	Rerun weak signal with no cables attached to other F-O ports

Table 6-8. Test Series D - Dipole (Horizontal, 150 - 200 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
D1	CP1	Vert. Field	AD-60 #35	150 - 200	D	H	Dipole // to a/c axis	A	T1C3/P5	9-28/10:59	
D2	CP2	Horiz.1 Field	AD-60 #32	150 - 200	D	H	Dipole // to a/c axis	A	T1C1/GTC4	9-28/10:59	
D3	CP3	Horiz.2 Field	AD-60 #36	150 - 200	D	H	Dipole // to a/c axis	A	T1C2/GTC1	9-28/9:49	
D4	CP4	Wire Current	I-320 #32	150 - 200	D	H	Dipole // to a/c axis	B	T1C4/GTC3	9-28/10:13	
D5	CP5	Wire Voltage	climbing wire	150 - 200	D	H	Dipole // to a/c axis	B	T2C1/GTC2	9-28/12:51	
D6	EB1	Field	AD-60 #34	150 - 200	D	H	Dipole // to a/c axis	A	T2C2/P6	9-28/9:22	
D7	EB2	LRU Voltage	Voltage Probe	150 - 200	D	H	Dipole // to a/c axis	D	T2C4/GTC5	9-28/9:49	
D8	EB3	Cable Current	I-320 #34	150 - 200	D	H	Dipole // to a/c axis	B	T2C3/P7	9-28/10:13	
D9	C1	Field	AD-60 #33	150 - 200	D	H	Dipole // to a/c axis	A	T3C2/P2	9-28/9:00	
D10	C2	Wire Current	I-320 #33	150 - 200	D	H	Dipole // to a/c axis	B	T3C4/P3	9-28/9:22	
D11	C3	Voltage	Long Wire	150 - 200	D	H	Dipole // to a/c axis	B	T3C3/P4	9-28/9:00	
D12	C4	Field	Ext. antenna	150 - 200	D	H	Dipole // to a/c axis	C	T3C1/P1	9-28/12:51	
D13	Weak Signal Line	Wire Current	I-320 #33	150 - 200	D	H	Dipole // to a/c axis	V	T3C4/P3	9-28/1:34	
D14	Weak Signal Line	LRU Voltage	Voltage Probe	150 - 200	D	H	Dipole // to a/c axis	V	T2C4/GTC5	9-28/1:34	

Table 6-9. Test Series E - Dipole (Vertical, 350 - 500 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
E1	CP1	Vert. Field	AD-60 #35	350 - 500	D	V	front, left of a/c	A	T1C3/P5	9-29/1:31	
E2	CP2	Horiz.1 Field	AD-60 #32	350 - 500	D	V	front, left of a/c	A	T1C1/GTC4	9-29/1:31	
E3	CP3	Horiz.2 Field	AD-60 #36	350 - 500	D	V	front, left of a/c	A	T1C2/GTC1	9-29/2:48	
E4	CP4	Wire Current	I-320 #32	350 - 500	D	V	front, left of a/c	B	T1C4/GTC3	9-29/11:13	
E5	CP5	Wire Voltage	climbing wire	350 - 500	D	V	front, left of a/c	B	T2C1/GTC2	9-29/10:16	
E6	EB1	Field	AD-60 #34	350 - 500	D	V	front, left of a/c	A	T2C2/P6	9-29/10:16	
E7	EB2	LRU Voltage	Voltage Probe	350 - 500	D	V	front, left of a/c	D	T2C4/GTC5	9-29/10:48	
E8	EB3	Cable Current	I-320 #34	350 - 500	D	V	front, left of a/c	B, X1	T2C3/P7	9-29/8:43	
E9	C1	Field	AD-60 #33	350 - 500	D	V	front, left of a/c	A	T3C2/P2	9-29/9:30	
E10	C2	Wire Current	I-320 #33	350 - 500	D	V	front, left of a/c	B, X1	T3C4/P3	9-29/8:43	
E11	C3	Voltage	Long Wire	350 - 500	D	V	front, left of a/c	B	T3C3/P4	9-29/9:30	
E12	C4	Field	Ext. antenna	350 - 500	D	V	front, left of a/c	C	T3C1/P1	9-29/2:09	
E13	C1	Field	AD-60 #33	427 - 432	D	V	1% BW, 1000 pts	E	T3C2/P2	9-29/11:35	
E004	CP4	Wire Current	I-320 #32	350 - 500	D	V	front, left of a/c	B	T1C4/GTC3	9-29/2:09	Repeat E4 with gain to 24 for better noise ratio

Table 6-10. Test Series F - Dipole (Horizontal, 350 - 500 MHz)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
F1	CP1	Vert. Field	AD-60 #35	350 - 500	D	H	Dipole // to a/c axis	A	T1C3/P5	9-28/2:43	
F2	CP2	Horiz.1 Field	AD-60 #32	350 - 500	D	H	Dipole // to a/c axis	A	T1C1/GTC4	9-28/2:43	
F3	CP3	Horiz.2 Field	AD-60 #36	350 - 500	D	H	Dipole // to a/c axis	A	T1C2/GTC1	9-28/3:29	
F4	CP4	Wire Current	I-320 #32	350 - 500	D	H	Dipole // to a/c axis	B	T1C4/GTC3	9-28/3:52	
F5	CP5	Wire Voltage	climbing wire	350 - 500	D	H	Dipole // to a/c axis	B	T2C1/GTC2	9-28/4:40	
F6	EB1	Field	AD-60 #34	350 - 500	D	H	Dipole // to a/c axis	A	T2C2/P6	9-28/5:04	
F7	EB2	LRU Voltage	Voltage Probe	350 - 500	D	H	Dipole // to a/c axis	D	T2C4/GTC5	9-28/3:29	
F8	EB3	Cable Current	I-320 #34	350 - 500	D	H	Dipole // to a/c axis	B	T2C3/P7	9-28/3:52	
F9	C1	Field	AD-60 #33	350 - 500	D	H	Dipole // to a/c axis	A	T3C2/P2	9-28/5:04	
F10	C2	Wire Current	I-320 #33	350 - 500	D	H	Dipole // to a/c axis	B	T3C4/P3	9-28/3:07	
F11	C3	Voltage	Long Wire	350 - 500	D	H	Dipole // to a/c axis	B	T3C3/P4	9-28/4:40	
F12	C4	Field	Ext. antenna	350 - 500	D	H	Dipole // to a/c axis	C	T3C1/P1	9-28/3:07	
F13	C2	Wire Current	I-320 #33	350 - 500	D	H	Dipole // to a/c axis	V	T3C4/P3	9-29/7:19	
F14	EB3	Cable Current	I-320 #34	350 - 500	D	H	Dipole // to a/c axis	V	T2C3/P7	9-29/7:19	
F008	EB3	Cable Current	I-320 #34	350 - 500	D	H	Dipole // to a/c axis	B	T2C3/P7	9-29/8:00	Repeat of F8 because of crosstalk
F010	C2	Wire Current	I-320 #33	350 - 500	D	H	Dipole // to a/c axis	B	T3C4/P3	9-29/8:00	Repeat of F10 because of crosstalk

Table 6-11. Noise Floor Measurements - Rhombic

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
NO1	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	Nose Incident	T	T1C3/P5	9-30/7:28 9:28	
NO2	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	Nose Incident	T	T1C1/GTC4	9-30/7:38 9:28	
NO3	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	Nose Incident	T	T1C2/GTC1	9-30/7:57 8:48	
NO4	CP4	Wire Current	I-320 #32	0.3 - 1000	R	V	Nose Incident	T	T1C4/GTC3	9-30/8:10 8:29	
NO5	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	Nose Incident	T	T2C1/GTC2	9-30/7:43 9:09	
NO6	EB1	Field	AD-60 #34	0.3 - 1000	R	V	Nose Incident	T	T2C2/P6	9-30/10:47 10:29	
NO7	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	Nose Incident	T	T2C4/GTC5	9-30/7:57 8:48	
NO8	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	Nose Incident	T	T2C3/P7	9-30/8:10 8:29	
NO9	C1	Field	AD-60 #33	0.3 - 1000	R	V	Nose Incident	T	T3C2/P2	9-30/11:40 10:06	
NO10	C2	Wire Current	I-320 #33	0.3 - 1000	R	V	Nose Incident	T	T3C4/P3	9-10/10:47 10:27	
NO11	C3	Voltage	Long Wire	0.3 - 1000	R	V	Nose Incident	T	T3C3/P4	9-30/11:00 10:06	
NO12	C4	Field	Ext. antenna	0.3 - 1000	R	V	Nose Incident	T	T3C1/P1	9-30/7:43 9:09	

Table 6-12. Test Series J - Rhombic (Nose Incident and Related Tests)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
J1	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	nose incident, AM	G	T1C3/P5	10-4/7:34 7:18	Deleted - malfunction of network analyzer; see J20
J2	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	nose incident, AM	G	T1C1/GTC4	10-4/7:34 7:18	Deleted - malfunction of network analyzer; see J21
J3	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	nose incident, AM	G	T1C2/GTC1	10/4/7:54 8:01	Deleted - malfunction of network analyzer; see J22
J4	CP4	Wire Current	I-320 #32	0.3 - 1000	R	V	nose incident	H	T1C4/GTC3	10-3/3:21 3:08	
J5	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	nose incident	H	T2C1/GTC2	10-3/3:57 4:28	
J6	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	small box	L, L1	T1C3/P5	10-4/1:19 1:02	
J7	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	small box	L, L1	T1C1/GTC4	10-4/1:19 1:02	
J8	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	small box	L, L1	T1C2/GTC1	10-4/1:40 1:48	
J9	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	move small box	L, L2	T1C3/P5	10-4/2:22 2:09	
J10	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	move small box	L, L2	T1C1/GTC4	10-4/2:22 2:09	
J11	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	move small box	L, L2	T1C2/GTC1	10-4/2:40 2:49	
J12	CP1	Vert. Field	AD-60 #35	800 - 900	R	V	1% BW, 1000 pts	E	T1C3/P5	10-3/4:50	
J13	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	person in left seat	M	T1C3/P5	10-4/8:47 8:33	
J14	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	person in left seat	M	T1C1/GTC4	10-4/9:47 8:33	
J15	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	person in left seat	M	T1C2/GTC1	10-4/9:07 9:16	
J16	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	persons in both seats	M	T1C3/P5	10-4/9:39 9:27	
J17	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	persons in both seats	M	T1C1/GTC4	10-4/9:39 9:27	
J18	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	persons in both seats	M	T1C2/GTC1	10-4/9:59 10:07	

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
J19	CP12	Heater Current	I-320 #32	0.3 - 1000	R	V	new probe position	N, N1	T1C4/GTC3	10-4/3:21 3:15	
J20	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	repeatability, PM	K	T1C3/P5	10-3/1:55 1:41	
J21	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	repeatability, PM	K	T1C1/GTC4	10-3/1:55 1:41	
J22	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	repeatability, PM	K	T1C2/GTC1	10-3/2:34 2:54	
J23	EB1	Field	AD-60 #34	0.3 - 1000	R	V	nose incident	G	T2C2/P6	10-3/2:34 2:54	
J24	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	nose incident	J, J1	T2C4/GTC5	10-3/3:21 3:08	
J25	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	nose incident	H	T2C3/P7	10-3/3:57 4:28	
J26	EB1	Field	AD-60 #34	0.3 - 1000	R	V	nose incident	G2	T2C2/P6	10-5/9:46 10:03	
J27	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	nose incident	G2	T2C4/GTC5	10-5/9:30 9:13	
J28	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	nose incident	G2	T2C3/P7	10-5/8:44 9:02	
J29	EB1	Field	AD-60 #34	0.3 - 1000	R	V	nose incident	G3	T2C2/P6	10-4/4:47 4:02	
J30	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	nose incident	G3	T2C4/GTC5	10-5/7:03 7:24	
J31	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	nose incident	G3	T2C3/P7	10-5/8:06 7:38	
J32	C1	Field	AD-60 #33	0.3 - 1000	R	V	nose incident	G	T3C2/P2	10-5/10:56 10:37	
J33	C2	Wire Current	I-320 #33	0.3 - 1000	R	V	nose incident	H	T3C4/P3	10-5/1:21 1:41	
J34	C3	Voltage	Long Wire	0.3 - 1000	R	V	nose incident	H	T3C3/P4	10-5/10:56 10:37	
J35	C4	Field	Ext. antenna	0.3 - 1000	R	V	nose incident	I	T3C1/P1	10-5/1:21 1:41	
J36	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	move a/c 10° off axis	P	T1C3/P5	10-6/5:34 8:53	
J37	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	move a/c 10° off axis	P	T1C1/GTC4	10-6/8:34 8:53	
J38	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	move a/c 10° off axis	P	T1C2/GTC1	10-6/9:23 9:17	
J39	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	move a/c 5° off	P	T1C3/P5	10-6/10:45 11:00	

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
J40	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	move a/c 5° off	P	T1C1/GTC4	10-6/10:45 11:00	
J41	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	move a/c 5° off	P	T1C2/GTC1	10-6/11:20 11:13	
J005	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	nose incident	H	T2C1/GTC2	10-4/3:42 3:51	
J026	EB1	Field	AD-60 #34	0.3 - 1000	R	V	nose incident; negative press door sealed	G2, G4	T2C2/P6	10-11/7:46 8:04	
J027	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	nose incident; negative press door sealed	G2, G4	T2C4/GTC5	10-11/8:27 8:16	
J028	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	nose incident; negative press door sealed	G2, G4	T2C3/P7	10-11/8:58 9:19	

Table 6-13. Test Series K - Rhombic (Side Incident and Related Tests)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
K1	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	side incident	G	T1C3/P5	10-6/2:28 2:46	
K2	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	side incident	G	T1C1/GTC4	10-7/8:57 5:45	
K3	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	side incident	G	T1C2/GTC1	10-6/3:21 3:10	
K4	CP4	Wire Current	I-320 #32	0.3 - 1000	R	V	side incident	H	T1C4/GTC3	10-6/3:43 4:02	
K5	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	side incident	H	T2C1/GTC2	10-7/7:30 7:02	
K6	EB1	Field	AD-60 #34	0.3 - 1000	R	V	side incident	G	T2C2/P6	10-6/3:21 3:10	
K7	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	side incident	J	T2C4/GTC5	10-6/3:43 4:02	
K8	EB3	Cable Current	I-320 #34	0.3 - 1000	R	V	side incident	H	T2C3/P7	10-7/7:30 7:52	
K9	C1	Field	AD-60 #33	0.3 - 1000	R	V	side incident	G	T3C2/P2	10-7/8:57 8:45	
K10	C2	Wire Current	I-320 #33	0.3 - 1000	R	V	side incident	H	T3C4/P3	10-7/9:37 9:56	
K11	C3	Voltage	Long Wire	0.3 - 1000	R	V	side incident	H	T3C3/P4	10-6/2:28 2:46	
K12	C4	Field	Ext. antenna	0.3 - 1000	R	V	side incident	I	T3C1/P1	10-7/9:37 9:56	
K13	C3	Voltage	Long Wire	0.3 - 1000	R	V	repeatability, side incident	K	T3C3/P4	10-7/10:49 10:37	
K14	C3	Voltage	Long Wire	0.3 - 1000	R	V	move bodies in cabin, side inc	M, M1	T3C3/P4	10-7/2:59 2:41	
K15	EB3	Field	AD-60 #34	0.3 - 1000	R	V	repeatability, side inc	K	T2C2/P6	10-6/12:53 1:21	
K23	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	add parasitic wire, side inc	O, O1	T2C1/GTC2	10-7/1:53 1:47	
K24	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	add parasitic wire, side inc	O, O2	T2C1/GTC2	10-7/2:11 2:18	
K25	CP12	Heater current	I-320 #32	0.3 - 1000	R	V	new probe position, side	N	T1C4/GTC3	10-7/10:49 10:37	
K26	C3	Voltage	Long Wire	0.3 - 1000	R	V	add static ground, side	Q	T3C3/P4	10-6/3:31 3:46	

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
K27	CP1	Vert. Field	AD-60 #3	0.3 - 1000	R	V	return to nose incident	R	T1C3/P5	1010/10:02 9:51	
K28	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	return to nose incident	R	T1C1/GTC4	1010/10:02 9:51	
K29	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	return to nose incident	R	T1C2/GTC1	10-10/9:15 9:35	
K30	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	5 degrees from nose-on	S1	T1C3/P5	10-10/7:32 7:52	
K31	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	5 degrees from nose-on	S1	T1C1/GTC4	10-10/7:32 7:52	
K32	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	5 degrees from nose-on	S1	T1C2/GTC1	1010/8:10 8:05	
K007	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	side incident	J	T2C4/GTC5	10-6/4:41 4:29	
J024 brkr in	EB2	LRU Voltage	Voltage Probe	0.3 - 1000	R	V	nose incident	J, J2	T2C4/GTC5	10-10/9:15 9:35	

Table 6-14. Test Series Z - Rhombic (System State Effects - Circuit Breakers)

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
Z1	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	nose incident	G	T1C3/P5		Repeat of J1 (or J20) Circuit breaker closed
Z2	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	nose incident	G	T1C1/GTC4		Repeat of J2 (or J21) Circuit breaker closed
Z3	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	nose incident	G	T1C2/GTC1		Repeat of J3 (or J22) Circuit breaker closed
Z4	CP4	Wire Current	I-320 #32	0.3 - 1000	R	V	nose incident	H	T1C4/GTC3		Repeat of J4 Circuit breaker closed
Z5	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	nose incident	H	T2C1/GTC2		Repeat of J5 Circuit breaker closed
Z6	CP12	Heater Current	I-320 #32	0.3 - 1000	R	V	new probe position	N, N1	T1C4/GTC3		Repeat of J19 Circuit breaker closed
Z7	EB1	Field	AD-60 #34	0.3 - 1000	R	V	nose incident	G	T2C2/P6		Repeat of J23 Circuit breaker closed
Z8	C1	Field	AD-60 #33	0.3 - 1000	R	V	nose incident	G	T3C2/P2		Repeat of J32 Circuit breaker closed
Z9	C2	Wire Current	I-320 #33	0.3 - 1000	R	V	nose incident	H	T3C4/P3		Repeat of J33 Circuit breaker closed
Z10	C3	Voltage	Long Wire	0.3 - 1000	R	V	nose incident	H	T3C3/P4		Repeat of J34 Circuit breaker closed
Z11	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	add parasitic wire	O, O1	T2C1/GTC2		Repeat of K23 Circuit breaker open; compare to J5
Z12	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	add parasitic wire	O, O2	T2C1/GTC2		Repeat of K24 Circuit breaker open; compare to J5
Z13	C3	Voltage	Long Wire	0.3 - 1000	R	V	add static ground	Q	T3C3/P4		Repeat of K26 Circuit breaker open; compare to J34
Z14	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	nose incident, AM	G	T1C1/GTC4		Repeat of J2 Circuit breaker open

Table 6-15. Horizontal Polarization

Test #	Test Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes
HP1	CP1	Vert. Field	AD-60 D-Dot	2 - 30	R	H	Nose-on	A
HP2	CP2	Horiz.1 Field	AD-60 D-Dot	2 - 30	R	H	Nose-on	A
HP3	CP3	Horiz.2 Field	AD-60 D-Dot	2 - 30	R	H	Nose-on	A
HP4	CP4	Wire Current	I-320 Probe	2 - 30	R	H	Nose-on	B
HP5	CP5	Wire Voltage	climbing wire	2 - 30	R	H	Nose-on	B
HP6	EB1	Field	AD-60 D-Dot	2 - 30	R	H	Nose-on	A
HP7	EB2	LRU Voltage	Voltage Probe	2 - 30	R	H	Nose-on	D
HP8	EB3	Cable Current	I-320 Probe	2 - 30	R	H	Nose-on	B
HP9	C1	Field	AD-60 D-Dot	2 - 30	R	H	Nose-on	A
HP10	C2	Wire Current	I-320 Probe	2 - 30	R	H	Nose-on	B
HP11	C3	Voltage	Long Wire	2 - 30	R	H	Nose-on	B
HP12	C4	Field	Ext. antenna	2 - 30	R	H	Nose-on	C
HP13	Weak Signal Line			2 - 30	R	H	Nose-on	V
HP14	Strong Signal Line			2 - 30	R	H	Nose-on	V

Table 6-16. Test Series WF - Window Shielded/Unshielded

Test #	Test Point	Measured Parameter	Probe or Sensor	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Configuration	Notes	Cable ID	Acquisition Date/Time	Remarks
WF1	CP1	Vert. Field	AD-60 #35	0.3 - 1000	R	V	nose-on	Z	T1C3/P5	10-11/12:57 12:33	
WF2	CP2	Horiz.1 Field	AD-60 #32	0.3 - 1000	R	V	nose-on	Z	T1C1/GTC4	10-11/12:57 12:33	
WF3	CP3	Horiz.2 Field	AD-60 #36	0.3 - 1000	R	V	nose-on	Z	T1C2/GTC1	10-11/1:19 1:39	
WF4	CP4	Wire Current	I-320 #32	0.3 - 1000	R	V	nose-on	Z	T1C4/GTC3	10-11/1:59 1:52	
WF5	CP5	Wire Voltage	climbing wire	0.3 - 1000	R	V	nose-on	Z	T2C1/GTC2	10-11/2:07 2:15	
WF6	EB3	Cable Current	I-320	0.3 - 1000	R	V	nose-on	Z	T2C3/P7	10-11/1:19 1:39	
WF7	CP12	Heater current	I-320 #32	0.3 - 1000	R	V	nose-on	Z	T1C4/GTC3	10-11/2:38 2:31	

6.2 Relating Data File Names to Experiment Test Numbers

The data collected during the course of the experimental program were recorded to data files with file names which allow the identification of a specific test from the test matrix (Tables 6-4 through 6-16). File names also identify characteristics retarding the sweep parameters. File names are in the form:

a###j&&&

where the first letter is a sweep designator and the number ### is a sweep number. The second letter represents a specific test series within the test matrix and the number &&& identifies the test within the test series. Leading zeros have been omitted in Tables 6-4 through 6-16, except where they are used to indicate a test was repeated or added to the matrix.

The test team provided a sweep designation scheme, proved effective in other LESLI test efforts, which conveyed information regarding the frequency span and number of points in the sweep, as well as other details. The scheme is presented in Table 6-17.

Table 6-17. Sweep Designation Definitions					
SWEEP DESIGNATION	F min	F max	No. POINTS	COMMENTS	TEST NUMBER
a	300 kHz	100 MHz	932	NORMAL RHOMBIC SWEEP	J1-J41 K1-K29
b	100 MHz	1000 MHz	413	NORMAL RHOMBIC SWEEP	J1-J41 K1-K29
c	23 MHz	28 MHz	1000	DIPOLE SWEEP	all A all B exc B13
d	25.7 MHz	26 MHz	1000	DIPOLE SWEEP	B13
e	150 MHz	200 MHz	1000	DIPOLE SWEEP	all C exc C13 all D
f	171 MHz	173 MHz	1000	DIPOLE SWEEP	C13
g	350 MHz	500 MHz	1000	DIPOLE SWEEP	all E exc E13 all F
h	427 MHz	432 MHz	1000	DIPOLE SWEEP	E13
j	25.85 MHz	25.85 MHz	1	RHOMBIC DWELL	all G
k	172 MHz	172 MHz	1	RHOMBIC DWELL	all H
l	430 MHz	430 MHz	1	RHOMBIC PULSE	all I
m	950 MHz	959 MHz	1000	RHOMBIC SWEEP	J12
n	2 MHz	30 MHz	250	RHOMBIC SWEEP DIFFERENTIAL	all HP
p	1 MHz	100 MHz	50	GROUND PLANE CHARACTERIZATION	Pad Characterization
q	100 MHz	1 GHz	100	GROUND PLANE CHARACTERIZATION	Pad Characterization

The designator "m" is used with test J12. Its data has the form "m###j012". This was an inadvertent oversight that could lead to confusion. The prefix "m" is usually used as a prefix to designate a merged file, i.e., a file that has been created by merging or appending data files for sweeps designated "a" referring to the low frequency data sweep (300 kHz < f < 100 MHz) and files for sweeps designated "b" referring to the high frequency data sweep (100 MHz < f < 1 GHz). Thus, "m" is usually used as a prefix for files that correspond to data over the entire frequency range from 300 kHz to 1 GHz that is composed of parts acquired during different sweeps. Thus, the files "a###j&&&" and "b###j&&&" were merged to produce a single file covering 0.3 MHz to 1 GHz of the form "m###j&&&".

To facilitate the correspondence of data files to specific tests, a tabulation has been created which presents the executed test, by number and some identifying characteristics, and the files associated with that particular test. This information is contained in Tables 6-18 through 6-30.

Table 6-18. Data ID: Test Series AN - Ambient Noise Measurements

Test #	Test Point	Measured Parameter	Low Freq. Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (100 - 1000 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 1000 MHz)
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name
AN1	CP1	Vert. Field	an00an01	an00ref1	bn00an01	bn00ref1	mn00an01	mn00ref1
AN2	CP2	Horiz.1 Field	an00an02	an00ref1	bn00an02	bn00ref1	mn00an02	mn00ref1
AN3	EB3	Cable Current	an01an03	an01ref1	bn01an03	bn01ref1	mn00an03	mn01ref1
AN4	C4	Field	an02an04	an02ref1	bn02an04	bn02ref1	mn02an04	mn02ref2

Table 6-19. Data ID: Test Series A

Test #	Test Point	Measured Parameter	Data (23 - 28 MHz)	Reference (23 - 28 MHz)
			Data File Name	Data File Name
A1	CP1	Vert. Field	c059a001	c059ref1
A2	CP2	Horiz.1 Field	c059a002	c059ref1
A3	CP3	Horiz.2 Field	c056a003	c056ref1
A4	CP4	Wire Current	c058a004	c058ref1
A5	CP5	Wire Voltage	c061a005	c061ref1
A6	EB1	Field	c055a006	c055ref2
A7	EB2	LRU Voltage	c056a003	c056ref1
A8	EB3	Cable Current	c058a008	c058ref1
A9	C1	Field	c053a009	c053ref1
A10	C2	Wire Current	c054a010	c054ref1
A11	C3	Voltage	c054a011	c054ref1
A12	C4	Field	c061a012	c061ref1
A13	Weak Signal Line	LRU Voltage	c063a013	c063ref2
A14	Strong Signal Line	Voltage	c062a014	c062ref2
A101	CP1	Field	c060a101	c060ref1
A102	CP2	Field	c060a102	c060ref1

Table 6-20. Data ID: Test Series B

Test #	Test Point	Measured Parameter	Data (23 - 28 MHz)	Reference (23 - 28 MHz)
			Data File Name	Data File Name
B1	CP1	Vert. Field	c043b001	c043ref1
B2	CP2	Horiz.1 Field	c046c002	c046ref1
B3	CP3	Horiz.2 Field	c045b003	c045ref1
B4	CP4	Wire Current	c046b004	c046ref1
B5	CP5	Wire Voltage	c044b005	c044ref1
B6	EB1	Field	c050b006	c050ref1
B7	EB2	LRU Voltage	c047b007	c047ref2
B8	EB3	Cable Current	c043b008	c043ref1
B9	C1	Field	c050b009	c050ref1
B10	C2	Wire Current	c049b010	c049ref1
B11	C3	Voltage	c049b011	c049ref1
B12	C4	Field	c045b012	c045ref1
B13	C1	Field	d001b013	d001ref1
B14	Weak Signal Line	LRU Voltage	c051b014	c051ref2
B15	Strong Signal Line	Voltage	c052b015	c052ref2

Table 6-21. Data ID: Test Series C

Test #	Test Point	Measured Parameter	Data (150 - 200 MHz) Data File Name	Reference (150 - 200 MHz) Data File Name
C1	CP1	Vert. Field	e004c001	c004ref1
C2	CP2	Horiz.1 Field	e010c002	e010ref2
C3	CP3	Horiz.2 Field	e007c003	e007ref1
C4	CP4	Wire Current	e009c004	e009ref1
C5	CP5	Wire Voltage	e006c005	e006ref1
C6	EB1	Field	e012c006	e012ref1
C7	EB2	LRU Voltage	e007c007	e007ref1
C8	EB3	Cable Current	e009c008	e009ref1
C9	C1	Field	e013c009	e013ref1
C10	C2	Wire Current	e012c010	e012ref1
C11	C3	Voltage	e004c011	c004ref1
C12	C4	Field	e006c012	e006ref1
C13	C1	Field	f002c013	f002ref1
C14	Weak Signal Line	Wire Current	c015c014	c015ref1
C15	Strong Signal Line	Voltage	c015c015	c015ref1
C109	C1	Field	e016c109	c016ref1
C111	C3	Voltage	e016c111	c016ref1
C104	CP4	Wire Current	e017c104	e017ref1
C204	CP4	Wire Current	e018c204	e018ref1
C304	repeat ?	Wire Current	e019c304	e019ref1
C404	CP4	Wire Current	e020c404	e020ref1

Table 6-22. Data ID: Test Series D

Test #	Test Point	Measured Parameter	Data (150 - 200 MHz) Data File Name	Reference (150 - 200 MHz) Data File Name
D1	CP1	Vert. Field	e027d001	e027ref1
D2	CP2	Horiz.1 Field	e027d002	e027ref1
D3	CP3	Horiz.2 Field	e024d003	e024ref1
D4	CP4	Wire Current	e025d004	e025ref1
D5	CP5	Wire Voltage	e029d005	e029ref1
D6	EB1	Field	e022d006	e022ref1
D7	EB2	LRU Voltage	e024d007	e024ref1
D8	EB3	Cable Current	e025d008	e025ref1
D9	C1	Field	e021d009	e021ref1
D10	C2	Wire Current	e022d010	e022ref1
D11	C3	Voltage	e021d011	e021ref1
D12	C4	Field	e029d012	e029ref1
D13	Weak Signal Line	Wire Current	e031d013	e031ref1
D14	Weak Signal Line	LRU Voltage	e031d014	e031ref1

Table 6-23. Data ID: Test Series E

Test #	Test Point	Measured Parameter	Data (350 - 500 MHz)	Reference (350 - 500 MHz)
			Data File Name	Data File Name
E1	CP1	Vert. Field	g024e001	g024ref1
E2	CP2	Horiz.1 Field	g024e002	g024ref1
E3	CP3	Horiz.2 Field	g022e003	g022ref1
E4	CP4	Wire Current	g026e004	g026ref1
E5	CP5	Wire Voltage	g020e005	g020ref1
E6	EB1	Field	g020e006	g020ref1
E7	EB2	LRU Voltage	g022e007	g022ref1
E8	EB3	Cable Current	g014e008	g014ref1
E9	C1	Field	g015e009	g015ref1
E10	C2	Wire Current	g014e010	g014ref1
E11	C3	Voltage	g015e011	g015ref1
E12	C4	Field	g026e012	g026ref1
E13	C1	Field	h001e013	h001ref1

Table 6-24. Data ID: Test Series F

Test #	Test Point	Measured Parameter	Data (350 - 500 MHz)	Reference (350 - 500 MHz)
			Data File Name	Data File Name
F1	CP1	Vert. Field	g002f001	g002ref1
F2	CP2	Horiz.1 Field	g002f002	g002ref1
F3	CP3	Horiz.2 Field	g004f003	g004ref1
F4	CP4	Wire Current	g005f004	g005ref1
F5	CP5	Wire Voltage	g007f005	g007ref1
F6	EB1	Field	g009f006	g009ref1
F7	EB2	LRU Voltage	g004f007	g004ref1
F8	EB3	Cable Current	g005f008	g005ref1
F9	C1	Field	g009f009	g009ref1
F10	C2	Wire Current	g003f010	g003ref1
F11	C3	Voltage	g007f011	g007ref1
F12	C4	Field	g003f012	g003ref1
F13	C2	Wire Current	g012f013	g012ref1
F14	EB3	Cable Current	g012f014	g012ref1
F008	EB3	Cable Current	g013f008	g013ref1
F010	C2	Wire Current	g013f010	g013ref1

Table 6-25. Data ID: Noise Floor Measurements - Rhombic

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz) Data File Name	Low Freq Reference (0.3 - 100 MHz) Data File Name	High Freq Data (100 - 1000 MHz) Data File Name	High Freq Reference (100 - 1000 MHz) Data File Name	Merged Data (0.3 - 1000 MHz) Data File Name	Merged Reference (0.3 - 1000 MHz) Data File Name
NO1	CP1	Vert. Field	a100ni01	a100ref1	b100ni01	b100ref1	m100ni01	m100ref1
NO2	CP2	Horiz.1 Field	a100ni02	a100ref1	b100ni02	b100ref1	m100ni02	m100ref1
NO3	CP3	Horiz.2 Field	a102ni03	a102ref1	b102ni03	b102ref1	m102ni03	m102ref1
NO4	CP4	Wire Current	a103ni04	a103ref1	b103ni04	b103ref1	m103ni04	m103ref1
NO5	CP5	Wire Voltage	a101ni05	a101ref1	b101ni05	b101ref1	m101ni05	m101ref1
NO6	EM1	Field	a105ni06	a105ref1	b105ni06	b105ref1	m105ni06	m105ref1
NO7	EM2	LRU Voltage	a102ni07	a102ref1	b102ni07	b102ref1	m102ni07	m102ref1
NO8	EM3	Cable Current	a103ni08	a103ref1	b103ni08	b103ref1	m103ni08	m103ref1
NO9	C1	Field	a104ni09	a104ref1	b104ni09	b104ref1	m104ni09	m104ref1
NO10	C2	Wire Current	a105ni10	a105ref1	b105ni10	b105ref1	m105ni10	m105ref1
NO11	C3	Voltage	a104ni11	a104ref1	b104ni11	b104ref1	m104ni11	m104ref1
NO12	C4	Field	a101ni12	a101ref1	b101ni12	b101ref1	m101ni12	m101ref1

Table 6-26. Data ID: Test Series J - Rhombic (Nose Incident and Related Tests)

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
J1	CP1	Vert. Field		DROPPED					DROPPED
J2	CP2	Horiz.1 Field		DROPPED					DROPPED
J3	CP3	Horiz.2 Field		DROPPED					DROPPED
J4	CP4	Wire Current	a109j004	a109ref1	b109j004	b109ref1	m109j004	m109ref1	10-3/3:21 3:08
J5	CP5	Wire Voltage	a111j005	a111ref1	b111j005	b111ref1	m111j005	m111ref1	10-3/3:57 4:28
J6	CP1	Vert. Field	a120j006	a120ref1	b120j006	b120ref1	m120j006	m120ref1	10-4/1:19 1:02
J7	CP2	Horiz.1 Field	a120j007	a120ref1	b120j007	b120ref1	m120j007	m120ref1	10-4/1:19 1:02
J8	CP3	Horiz.2 Field	a121j008	a121ref1	b121j008	b121ref1	m121j008	m121ref1	10-4/1:40 1:48
J9	CP1	Vert. Field	a122j009	a122ref1	b122j009	b122ref1	m122j009	m122ref1	10-4/2:22 2:09
J10	CP2	Horiz.1 Field	a122j010	a122ref1	b122j010	b122ref1	m122j010	m122ref1	10-4/2:22 2:09
J11	CP3	Horiz.2 Field	a123j011	a123ref1	b123j011	b123ref1	m123j011	m123ref1	10-4/2:40 2:49
J12	CP1	Vert. Field			b112j012	b112ref1			10-3/4:50
J13	CP1	Vert. Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m116j013	m116ref1	10-4/8:47 8:33
J14	CP2	Horiz.1 Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m116j014	m116ref1	10-4/9:47 8:33
J15	CP3	Horiz.2 Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m117j015	m117ref1	10-4/9:07 9:16
J16	CP1	Vert. Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m118j016	m118ref1	10-4/9:39 9:27
J17	CP2	Horiz.1 Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m118j017	m118ref1	10-4/9:39 9:27
J18	CP3	Horiz.2 Field	Data Not Available	Data Not Available	Data Not Available	Data Not Available	m119j018	m119ref1	10-4/9:59 10:07
J19	CP12	Heater current	a125j019	a125ref1	b125j019	b125ref1	m125j019	m125ref1	10-4/3:21 3:15

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
J20	CP1	Vert. Field	a106j020	a106ref1	b106j020	b106ref1	m106j020	m106ref1	10-3/1:55 1:41
J21	CP2	Horiz.1 Field	a106j021	a106ref1	b106j021	b106ref1	m106j021	m106ref1	10-3/1:55 1:41
J22	CP3	Horiz.2 Field	a108j022	a108ref1	b108j022	b108ref1	m108j022	m108ref1	10-3/2:34 2:54
J23	EB1	Field	a108j023	a108ref1	b108j023	b108ref1	m108j023	m108ref1	10-3/2:34 2:54
J24	EB2	LRU Voltage	a109j024	a109ref1	b109j024	b109ref1	m109j024	m109ref1	10-3/3:21 3:08
J25	EB3	Cable Current	a111j025	a111ref1	b111j025	b111ref1	m111j025	m111ref1	10-3/3:57 4:28
J26	EB1	Field	a132j026	Data Not Available	b132j026	Data Not Available	m132j026	m132ref2	10-5/9:46 10:03
J27	EB2	LRU Voltage	a131j027	Data Not Available	b131j027	Data Not Available	m131j027	m131ref2	10-5/9:30 9:13
J28	EB3	Cable Current	a130j028	Data Not Available	b130j028	Data Not Available	m130j028	m130ref2	10-5/8:44 9:02
J29	EB1	Field	a127j029	Data Not Available	b127j029	Data Not Available	m127j029	m127ref2	10-4/4:47 4:02
J30	EB2	LRU Voltage	a128j030	Data Not Available	b128j030	Data Not Available	m128j030	m128ref2	10-5/7:03 7:24
J31	EB3	Cable Current	a129j031	Data Not Available	b129j031	Data Not Available	m129j031	m129ref2	10-5/8:06 7:38
J32	C1	Field	a133j032	a133ref1	b133j032	b133ref1	m133j032	m133ref1	10-5/10:56 10:37
J33	C2	Wire Current	a137j033	a137ref1	b137j033	b137ref1	m137j033	m137ref1	10-5/1:21 1:41
J34	C3	Voltage	a133j034	a133ref1	b133j034	b133ref1	m133j034	m133ref1	10-5/10:56 10:37
J35	C4	Field	a137j035	a137ref1	b137j035	b137ref1	m137j035	m137ref1	10-5/1:21 1:41
J36	CP1	Vert. Field	a138j036	a138ref1	b138j036	b138ref1	m138j036	m138ref1	10-6/5:34 8:53
J37	CP2	Horiz.1 Field	a138j037	a138ref1	b138j037	b138ref1	m138j037	m138ref1	10-6/8:34 8:53
J38	CP3	Horiz.2 Field	a139j038	a139ref1	b139j038	b139ref1	m139j038	m139ref1	10-6/9:23 9:17
J39	CP1	Vert. Field	a140j039	a140ref1	b140j039	b140ref1	m140j039	m140ref1	10-6/10:45 11:00

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
J40	CP2	Horiz.1 Field	a140j040	a140ref1	b140j040	b140ref1	m140j040	m140ref1	10-6/10:45 11:00
J41	CP3	Horiz.2 Field	a141j041	a141ref1	b141j041	b141ref1	m141j041	m141ref1	10-6/11:10 11:13
J005	CP5	Wire Voltage	a126j005	a126ref1	b126j005	b126ref1	m126j005	m126ref1	10-4/3:42 3:51
J026	EB1	Field	a164j026	Data Not Available	b164j026	Data Not Available	m164j026	m164ref2	10-11/7:45
J027	EB2	LRU Voltage	a165j027	Data Not Available	b165j027	Data Not Available	m165j027	m165ref2	10-11/8:27
J028	EB3	Cable Current	a167j028	Data Not Available	b167j028	Data Not Available	m167j028	m167ref2	10-11/8:58

Table 6-27. Data ID: Test Series K - Rhombic (Side Incident and Related Tests)

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
K1	CP1	Vert. Field	a142k001	a142ref1	b142k001	b142ref1	m142k001	m142ref1	10-6/2:28 2:46
K2	CP2	Horiz.1 Field	a149k002	a149ref1	b149k002	b149ref1	m149k002	m149ref1	10-7/8:57 5:45
K3	CP3	Horiz.2 Field	a144k003	a144ref1	b144k003	b144ref1	m144k003	m144ref1	10-6/3:21 3:10
K4	CP4	Wire Current	a145k004	a145ref1	b145k004	b145ref1	m145k004	m145ref1	10-6/3:43 4:02
K5	CP5	Wire Voltage	a147k005	a147ref1	b147k005	b147ref1	m147k005	m147ref1	10-7/7:30 7:02
K6	EB1	Field	a144k006	a144ref1	b144k006	b144ref1	m144k006	m144ref1	10-6/3:21 3:10
K7	EB2	LRU Voltage	a145k007	a145ref1	b145k007	b145ref1	m145k007	m145ref1	10-6/3:43 4:02
K8	EB3	Cable Current	a147k008	a147ref1	b147k008	b147ref1	m147k008	m147ref1	10-7/7:30 7:52
K9	C1	Field	a149k009	a149ref1	b149k009	b149ref1	m149k009	m149ref1	10-7/8:57 8:45
K10	C2	Wire Current	a151k010	a151ref1	b151k010	b151ref1	m151k010	m151ref1	10-7/9:37 9:56
K11	C3	Voltage	a142k011	a142ref1	b142k011	b142ref1	m142k011	m142ref1	10-6/2:28 2:46
K12	C4	Field	a151k012	a151ref1	b151k012	b151ref1	m151k012	m151ref1	10-7/9:37 9:56
K13	C3	Voltage	a152k013	a152ref1	b152k013	b152ref1	m152k013	m152ref1	10-7/10:49 10:37
K14	C3	Voltage	a156k014	Data Not Available	b156k014	Data Not Available	m156k014	m156ref2	10-7/2:59 2:41
K15	EB3	Field	a153k015	Data Not Available	b153k015	Data Not Available	m153k015	m153ref2	10-6/12:53 1:21
K23	CP5	Wire Voltage	a154k023	a154ref1	b154k023	b154ref1	m154k023	m154ref1	10-7/1:53 1:47
K24	CP5	Wire Voltage	a155k024	a155ref1	b155k024	b155ref1	m155k024	m155ref1	10-7/2:11 2:18
K25	CP12	Heater current	a152k025	a152ref1	b152k025	b152ref1	m152k025	m152ref1	10-7/10:49 10:37
K26	C3	Voltage	a158k026	Data Not Available	b158k026	Data Not Available	m158k026	m158ref2	10-6/3:31 3:46

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
K27	CP1	Vert. Field	a162k027	a162ref1	b162k027	b162ref1	m162k027	m162ref1	1010/10:02 9:51
K28	CP2	Horiz.1 Field	a162k028	a162ref1	b162k028	b162ref1	m162k028	m162ref1	1010/10:02 9:51
K29	CP3	Horiz.2 Field	a161k029	a161ref1	b161k029	b161ref1	m161k029	m161ref1	10-10/9:15 9:35
K30	CP1	Vert. Field	a159k030	a159ref1	b159k030	b159ref1	m159k030	m159ref1	10-10/7:32 7:52
K31	CP2	Horiz.1 Field	a159k031	a159ref1	b159k031	b159ref1	m159k031	m159ref1	10-10/7:32 7:52
K32	CP3	Horiz.2 Field	a160k032	a160ref1	b160k032	b160ref1	m160k032	m160ref1	1010/8:10 8:05
K007	EB2	LRU Voltage	a146k007	Data Not Available	b146k007	Data Not Available	m146k007	m146ref2	10-6/4:41 4:29
J024 brkr in	EB2	LRU Voltage	a161j024	a161ref1	b161j024	b161ref1	m161j024	m161ref1	10-10/9:15 9:35

Table 6-28. Data ID: Test Series Z - Rhombic (System State Effects - Circuit Breakers)

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz) Data File Name	Low Freq Reference (0.3 - 100 MHz) Data File Name	High Freq Data (100 - 1000 MHz) Data File Name	High Freq Reference (0.3 - 100 MHz) Data File Name	Merged Data (0.3 - 1000 MHz) Data File Name	Merged Reference (0.3 - 100 MHz) Data File Name
Z1	CP1	Vert. Field	a173z001	a173ref1	b173z001	b173ref1	m173z001	m173ref1
Z2	CP2	Horiz.1 Field	a173z002	a173ref1	b173z002	b173ref1	m173z002	m173ref1
Z3	CP3	Horiz.2 Field	a174z003	a174ref1	b174z003	b174ref1	m174z003	m174ref1
Z4	CP4	Wire Current	a177z004	a177ref1	b177z004	b177ref1	m177z004	m177ref1
Z5	CP5	Wire Voltage	a176z005	a176ref1	b176z005	b176ref1	m176z005	m176ref1
Z6	CP12	Heater current	a178z006	a178ref1	b178z006	b178ref1	m178z006	m178ref1
Z7	EB1	Field	a174z007	a174ref1	b174z007	b174ref1	m174z007	m174ref1
Z8	C1	Field	a179z008	a179ref1	b179z008	b179ref1	m179z008	m179ref1
Z9	C2	Wire Current	a180z009	a180ref1	b180z009	b180ref1	m180z009	m180ref1
Z10	C3	Voltage	a178z010	a178ref1	b178z010	b178ref1	m178z010	m178ref1
Z11	CP5	Wire Voltage	a182z011	a182ref1	b182z011	b182ref1	m182z011	m182ref1
Z12	CP5	Wire Voltage	a183z012	a183ref1	b183z012	b183ref1	m183z012	m183ref1
Z13	C3	Voltage	a181z013	Data Not Available	b181z013	Data Not Available	m181z013	m181ref2
Z14	CP2	Horiz.1 Field	a184z014	a184ref1	b184z014	b184ref1	m184z014	m184ref1

Table 6-29. Data ID: Horizontal Polarization

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)
			Data File Name	Data File Name
HP1	CP1	Vert. Field	n010hp01	n010ref1
HP2	CP2	Horiz.1 Field	n010hp02	n010ref1
HP3	CP3	Horiz.2 Field	n018hp03	n018ref1
HP4	CP4	Wire Current	n017hp04	n017ref1
HP5	CP5	Wire Voltage	n019hp05	n019ref1
HP6	EB1	Field	n018hp06	n018ref1
HP7	EB2	LRU Voltage	n017hp07	n017ref1
HP8	EB3	Cable Current	n019hp08	n019ref1
HP9	C1	Field	n020hp09	n020ref1
HP10	C2	Wire Current	n020hp10	n020ref1
HP11	C3	Voltage	n020hp11	n020ref1
HP12	C4	Field	n021hp12	n021ref1
HP13	Weak Signal Line	Wire Current	n022hp13	n022ref1
HP14	Strong Signal Line	Voltage Long Wire	n022hp14	n022ref1

Table 6-30. Data ID: Test Series WF - Window Shielded/Unshielded

Test #	Test Point	Measured Parameter	Low Freq Data (0.3 - 100 MHz)	Low Freq Reference (0.3 - 100 MHz)	High Freq Data (100 - 1000 MHz)	High Freq Reference (0.3 - 100 MHz)	Merged Data (0.3 - 1000 MHz)	Merged Reference (0.3 - 100 MHz)	Acquisition Date/Time
			Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	Data File Name	
WF1	CP1	Vert. Field	a168wf01	a168ref1	b168wf01	b168ref1	m168wf01	m168ref1	1011/12:57 12:33
WF2	CP2	Horiz.1 Field	a168wf02	a168ref1	b168wf02	b168ref1	m168wf02	m168ref1	1011/12:57 12:33
WF3	CP3	Horiz.2 Field	a169wf03	a169ref1	b169wf03	b169ref1	m169wf03	m169ref1	10-11/1:19 1:39
WF4	CP4	Wire Current	a170wf04	a170ref1	b170wf04	b170ref1	m170wf04	m170ref1	10-11/1:59 1:52
WF5	CP5	Wire Voltage	a171wf05	a171ref1	b171wf05	b171ref1	m171wf05	m171ref1	10-11/2:07 2:15
WF6	EB3	Cable Current	a169wf06	a169ref1	b169wf06	b169ref1	m169wf06	m169ref1	10-11/1:19 1:39
WF7	CP12	Heater current	a172wf07	a172ref1	b172wf07	b172ref1	m172wf07	m172ref1	10-11/2:38 2:31

6.2.1 Interpreting a Data File Header

The data files, whose naming and subject have been described, contain the alpha numeric data specific to a given test. Each data file has a header which contains details of the test. Such a sample header is shown in Table 6-31 for test FMJ over the frequency range $0.3 < f < 1000$ MHz. The leading "m" refers to a merged file.

Table 6-31. A Typical Header for a Data File

```
M0997FMJ.COF TS:757T CS:A/B FC:LR AM:AMP6 AP:250 MT:EX NC:12 ED:0 IN:N
D:12SEP94 T:1447 PI:ACD4 PO:000 LI:NF50 LS:18 E1:B644 E2:CO43 E3:E4:L1:L2
:
OR:000 C:RM BW:10 Q:60 AV:1 PW:4.5 W:0 M:.03 CU:YYYYYXX
ELECTRIC FIELD MEASUREMENT @ X=40, Y=5, Z=8.
FREQ
1370
C
(P, R, Error Log and Drive Name not shown in this example)
```

The meaning of the abbreviations defining the fields in this header are provided in Table 6-32.

Table 6-32. Definition of Fields in Data File Header

FIELD NAME	FIELD DESCRIPTION
File_name	File Name
TS	Test ID
CS	Channel Measurement Selection
FC	Facility Code (FR=LESLI Rhombic)
AM	Amplifier ID
AP	Amplifier Power
MT	Measurement Type
NC	Network Analyzer Number/Measurement
ED	Electrical Delay
IN	Integrator On
D	Date
T	Time
PI	Probe ID
PO	Probe Orientation
LI	Link ID
LS	Link Scale Factor
E1	Signal Conditioner 1
E2	Signal Conditioner 2
E3	Signal Conditioner 3
E4	Signal Conditioner 4

FIELD NAME	FIELD DESCRIPTION
L1	Linear Scale Factor 1
L2	Linear Scale Factor 2
OR	Test Article Orientation
C	Test Article Configuration
BW	IF Bandwidth (Hz)
Q	Q
AV	Number of Sweeps Averaged
PW	NA Output Power (dBm)
W	Wait Time (ms)
M	Wait Margin (ms)
P	Peak-to-Peak
R	Rise Time
COMMENT1	The comment line from TOOLKIT file (e.g., CU: ...)
DATA_TYPE	Time or Frequency Sweep
NUM_PTS	Number of Points (e.g., 1370)
NUM_TYPE	Format of the data points (M,C,R) (mag, complex, real)
ERRORLOG	Contains data which caused an error
DriveName	The name of the archive drive

Note that for swept frequency measurements the frequency sample spacing may not be constant. Rather, the spacing is held constant only over the intervals between stopbands (frequency exclusion bands imposed by frequency allocation authorities). The scheme, which has little impact on this measurement program, is described in Randall (1993).

6.3 Pre- and Post-Aircraft Test Activities

Prior to and after the tests involving use of the B-757, a number of additional experimental sequences were necessary. These involved preparation for the tests and calibrations.

6.3.1 Calibration Data for Sensor Systems

The cables and sensors were experimentally characterized, where possible. This was achieved using standard techniques, with some activities carried out at NASA LaRC and others at the Phillips Laboratory.

The AD-60 ground plane electric field probe, also referred to as a d-dot probe, was not experimentally characterized prior to the aircraft tests. Further information on the AD-60 calibration and its effects on the data found in the data files is provided in Section 6.3.1.1.

The data file names for the calibration data are listed in Table 6-33. File nistad60.cal is described in Section 6.3.1.1.

TABLE 6-33. FILE NAMES FOR CALIBRATION DATA

File Name	Subject	File Name	Subject
acd4.cal	Balanced E Field (ACD-4)	nf51.cal	NanoFast F-O Xmtr-Rcvr
ad60.cal	Ground Plane E Field (AD-60)	nf52.cal	NanoFast F-O Xmtr-Rcvr
aprb.cal	Direct Voltage Measurement	nf53.cal	NanoFast F-O Xmtr-Rcvr
b643.cal	Balun	nf60.cal	NanoFast F-O Xmtr-Rcvr
b644.cal	Balun	p132.cal	Prodyn Current Probe
b657.cal	Balun	p133.cal	Prodyn Current Probe
c027.cal	Cable	p134.cal	Prodyn Current Probe
c043.cal	Cable	p135.cal	Prodyn Current Probe
c044.cal	Cable	ps68.cal	Power Splitter
c045.cal	Cable	t1c1.cal	Cable
c046.cal	Cable	t1c2.cal	Cable
c047.cal	Cable	t1c3.cal	Cable
c050.cal	Cable	t1c4.cal	Cable
c071.cal	Cable	t2c1.cal	Cable
mgl6.cal	Balanced H Field (MGL-6)	t2c2.cal	Cable
mgl7.cal	Ground Plane H Field (MGL-7)	t2c3.cal	Cable
nf20.cal	NanoFast F-O Xmtr-Rcvr	t2c4.cal	Cable
nf21.cal	NanoFast F-O Xmtr-Rcvr	t3c1.cal	Cable
nf22.cal	NanoFast F-O Xmtr-Rcvr	t3c2.cal	Cable
nf23.cal	NanoFast F-O Xmtr-Rcvr	t3c3.cal	Cable
nf40.cal	NanoFast F-O Xmtr-Rcvr	t3c4.cal	Cable
nf50.cal	NanoFast F-O Xmtr-Rcvr	nistad60.cal	AD-60 refined

6.3.1.1 Calibration of the AD-60 Electric Field (D-Dot) Probe

During the planning stages for this program, it was intended that the terminal voltages at the AD-60 probes would be recorded and that the modeling activities would be expected to provide the probe terminal voltages. This is a challenge for modellers due to the scale of the probes relative to the rest of the aircraft. Given this difficulty and the value of having field variable information directly available, it was later decided to use probe transfer function (calibration) data to extract the field variable from the acquired data. The original calibration data were constructed by the data acquisition team using information provided by the manufacturer. An analytic function for the probe response, which involves a small number of parameters and is well established in the EMP community, was used to generate the calibration data as a function of frequency. These calibration data, presented in the calibration files as ad60.cal, were used throughout in correcting the data acquired during the tests. Well after the tests were executed and the raw data had been corrected and processed to provide the variables of interest prior to dissemination, a more accurate calibration became available.

NASA LaRC commissioned NIST to prepare calibration data for the AD-60. The intent was to obtain calibration data for the probe in its operating environment especially as the AD-60, a probe for vertical electric field measurement over an infinite ground plane, was operating over a ground plane that was rather limited in extent. The details of this calibration are provided in Johnk and Ondrejka (1996). During these calibration tests the probe, in various vertically oriented configurations over a ground plane, was illuminated by a vertically polarized plane (or very nearly plane) wave of known strength and the output voltage recorded as a function of frequency. The test system was a large conical antenna driven against a very large ground plane on which was mounted the probe being calibrated. Five AD-60 probes were used during the aircraft tests and each probe was identified by its serial number. During the calibration tests a different probe was used for each configuration, and the probe identification and its particular configuration are provided in Table 6-34.

Table 6-34. AD-60 Serial Numbers and Configurations for Calibration	
Serial Number	Configuration
33	D-dot mounted on a metal surface simulating top of EME rack in cabin
34	(34n) D-dot mounted on the E Bay fixture with the narrow dimension facing the incident wave
34	(34w) D-dot mounted on the E Bay fixture with the wide dimension facing the incident wave
35	D-dot (vertical orientation) mounted on ATOPS box with pedestal
36	D-dot measured on ground plane
37	D-dot measured on ground plane

The entire set of probes was calibrated over the frequency range from 50 MHz to 6 GHz. In addition, Probes 33, 34, 36 and 37 were calibrated from 10 MHz to 100 MHz in order to extend the low frequency coverage. The ratio of output voltage at the probe terminals to incident electric field strength was recorded and presented as $20 \log(\text{output voltage/incident field})$ which is, in effect, the transfer function (or an effective height) in dB relative to a meter.

Probes 33, 34, and 35 were calibrated in configurations similar, not identical, to the configurations in the aircraft. Probe number 33 was placed on a metal surface identical in size to the upper surface of the EME rack (see Figure 4-8) but the test configuration had this surface only about 3 inches above the ground plane. The entire rack was not included. Probe number 34 was calibrated in two configurations. The platform on which the AD-60 was mounted is shown in Figure 4-6 and the calibration tests were run with the platform in two different orientations relative to the incident plane wave. The vertical portions of the platform, approximately 4 inches in dimension, were solid in the narrow dimension and open in the wide dimension so that the platform looked like a four-sided box mounted on a ground plane. In 34n, the narrow portion of the platform faced the wave

and in 34w, the wide portion of the platform faced the wave. Probe number 35, the vertically oriented D-dot on the ATOPS box, was tested as configured in the aircraft. Probes 36 and 37, which were used in the aircraft for the horizontally polarized field measurements on the ATOPS box, could not be calibrated in that configuration since horizontally polarized fields were not available. Rather, these probes were tested over the large ground plane of the test fixture used by NIST and are representative calibrations for the AD-60 probe in its intended configuration.

Figure 6-1 is a plot of the magnitude of the transfer function for each of the probes referred to as the response in dB as a function of frequency from 50 MHz to 1 GHz. Also included in the figure is a curve labeled AD-60 which represents the calibration used in correcting the raw data acquired in the tests to provide the corrected data in the files described in this report. The curves for probes 36 and 37 are similar to the AD-60 data that was used for correction (file ad60.cal) below 200 MHz but differ by as much as 3 dB beyond 200 MHz. This suggests that the model and its parameters used for construction of the calibration curve may be suspect for frequencies above 200 MHz. The other differences observed in the figure may also be cause for concern as they indicate discrepancies as large as 5 dB above 200 MHz. Particular attention must be paid to the response of the probe on the ATOPS box below 100 MHz where apparent standing waves are causing a behavior which deviates substantially from the expected behavior which is directly proportional to frequency.

The data for the AD-60 probes in the various configurations represented in Table 6-34 and Figure 6-1 can be found in the set of calibration files and are denoted as nistad60.cal. The data for the various measurements using the AD-60 probe that are presented in this report and are provided in the numerous files can be refined by using the new calibration data. This can be done by taking each data file for the desired variables which had used the original AD-60 data for correction purposes, extracting the original AD-60 calibration and then introducing the new AD-60 calibration information. This requires taking each file which involves measurements using the AD-60s, dividing by the ad60.cal file (the original AD-60 calibration) and multiplying by the portion of the nistad60.cal file that relates to the particular probe involved in the measurement of interest. The operations must be performed for each frequency and should, as done with the original calibration data, be performed using complex arithmetic.

6.3.2 Dipole Test Preparation

Dipole antenna testing, which was introduced to permit modelers to explicitly include the radiating structure that created the electromagnetic environment in their computer models, was executed in the vicinity of three frequencies, namely, 25.85, 172, and 430 MHz. Ultimately, dipole testing in these frequency ranges was carried out both with and without the B-757. A wood support structure was assembled for the dipoles and is shown in Figures 6-2 and 6-3. The former is a drawing of the stand to scale and the latter a picture of the stand with a dipole mounted vertically and emanating from the balun on the square plate. Unfortunately, the dipole is not readily visible in this photograph but can be seen in Figure 6-4. The details of the structure and the mounting of the dipoles is contained in Appendix B.

The 25.85 MHz dipole was "tuned" using a process described in Appendix B where the dipole length was trimmed in an attempt to achieve a reasonably flat response, as indicated by a principal field component magnitude at broadside, across the 23 to 28 MHz range. The other dipoles, for 172 and 430 MHz, had been trimmed prior to shipment to the Phillips Lab.

In each case, the balanced dipole was fed through a broadband, high power balun (Sabre Communications Corp.) driven by 50 ohm coaxial cable. The trimmed lengths of the dipoles and the model numbers of the associated baluns for each frequency band were:

25 MHz	5.817 meters	HDC 02 A
172 MHz	0.872 meters	HDC 12 A
430 MHz	0.349 meters	HDC 13 A

Figure 6-1. Calibration curves (magnitude only) for various AD-60 D-dot probes

Figure 6-2. Wooden stand for dipole testing

Figure 6-3. 172 MHz dipole mounted on stand

The 172 MHz dipole with its associated balun mounted on its support structure is shown in Figure 6-4. Short sections of Plexiglas tubing (visible in the photograph) were used to support the dipole wires near the feedpoint.

Figure 6-4. The 172 MHz dipole with balun and mount

6.3.3 Dipole Field Mapping

Prior to performing the tests with the dipoles in the presence of the aircraft, a number of measurements, or field maps, were made of the dipole radiated fields. The data were collected on a number of days both prior to and after the airplane tests. These provide modelers with additional data for comparison and experimenters with an indication of proper performance. The coordinate system for the field mapping is shown in Figure 6-5. The orientation of this coordinate system is similar to that for the rhombic radiator in that the feedpoint is in the $x=0$ plane and the y axis is vertical. The LESLI pad forms the $x-z$ plane. The height of the dipole feedpoint was 3 meters except for vertical polarization in the 25 MHz range. For that case, the height of the feedpoint was 4 meters. In all cases, the dipole was located approximately 1.5 meters from the platform at its feedpoint. Since it was impossible, given the resources available, to measure either the input or radiated power for the dipoles, the fields were measured in all cases at two points, one of which was fixed for all cases (the reference sensor) at $(-2.5, 3, 0)$. Thus, the reference field was to provide a fixed datum for the mapping exercise and thus reduce the uncertainty due to the lack of accurate radiated power measurements. The reference would serve as a scaling factor for comparisons. The fields were measured at a number of points (listed in Table 6-35).

Table 6-36 summarizes the details of the dipole field mapping. It provides information on the map point, the dipole polarization, mapping point location, acquisition date, file names for the field components measured at that particular point and the references in each case. In the comments column one finds information regarding the probe used for measurement of the desired field (ACD-4 for electric fields and MGL-6 for magnetic fields). In all cases, the reference field was measured with a MGL-6 probe. The file names for the calibration data for the various probes are found in Table 6-33. The file names for magnetic fields are in italics.

Figure 6-5. Dipole field mapping coordinate system

It should be noted that the reference field for the dipole measurements is always the dominant magnetic field of a dipole, i.e., it is the component of the magnetic field which, in the far zone, would be orthogonal to the dipole. In the tables and in the data headers it is referred to as H_z , but in all cases it should be interpreted as the component orthogonal to the dipole at the point at which the reference is measured. This comment holds for the dipole field mapping and the dipole tests that included the aircraft.

Table 6-35. Dipole Field Map Locations					
Freq (MHz)	Pol	x (m)	y (m)	z (m)	Fields
25	V	2	4	0	E&H
25	V	8	4	0	E
25	V	8	2	0	E
25	H	2	3	0	E&H
25	H	8	3	0	E
25	H	8	2	0	E
172	V	2	3	0	E&H
172	V	8	3	0	E
172	V	8	2	0	E
172	H	2	3	0	E&H
172	H	8	3	0	E
172	H	8	2	0	E
430	V	2	3	0	E&H
430	V	8	3	0	E
430	V	8	2	0	E
430	H	2	3	0	E&H
430	H	8	3	0	E
430	H	8	2	0	E
25	H	8	3	6	E
25	H	8	3	-6	E
172	H	8	3	6	E
172	H	8	3	-6	E
430	H	8	3	6	E
430	H	8	3	-6	E

Table 6-36. Data ID: Dipole Field Mapping

MAP POINT	FREQ MHz	POL	X	Y	Z	COMMENTS (Probe ID and Measured Field)	DATE	E _x H _x file name	Ref H _x file name	E _y H _y file name	Ref H _y file name	E _z H _z file name	Ref H _z file name
DFMA	25	V	2	4	0	ACD-4; E FIELD MGL-6; H FIELD	9/21	c038dfma <i>c039dfma</i>	<i>c038dref</i> <i>c039dref</i>	c037dfma <i>c040dfma</i>	<i>c037dref</i> <i>c040dref</i>	c036dfma <i>c041dfma</i>	<i>c036dref</i> <i>c041dref</i>
DFMB	25	V	8	4	0	ACD-4; E FIELD	9/21	c029dfmb	<i>c029dref</i>	c031dfmb	<i>c031dref</i>	c034dfmb	<i>c034dref</i>
DFMC	25	V	8	2	0	ACD-4; E FIELD	9/21	c030dfmc	<i>c030ref</i>				
DFMD	25	H	2	3	0	ACD-4; E FIELD MGL-6; H FIELD	9/20	c007dfmd <i>c008dfmd</i>	<i>c007dref</i> <i>c008dref</i>	c005dfmd <i>c009dfmd</i>	<i>c005dref</i> <i>c009dref</i>	c003dfmd <i>c010dfmd</i>	<i>c003dref</i> <i>c010dref</i>
DFME	25	H	8	3	0	ACD-4; E FIELD	9/20			c014dfme	<i>c014ref</i>		
DFMF	25	H	8	2	0	ACD-4; E FIELD	9/20	c012dfmf	<i>c012dref</i>	c018dfmf	<i>c018dref</i>	c020dfmf	<i>c020dref</i>
DFMG	172	V	2	3	0	ACD-4; E FIELD MGL-6; H FIELD	10/21	e062dfmg <i>e063dfmg</i>	<i>e062dref</i> <i>e063dref</i>	e060dfmg <i>e065dfmg</i>	<i>e060dref</i> <i>e065dref</i>	e058dfmg <i>e066dfmg</i>	<i>e058dref</i> <i>e066dref</i>
DFMH	172	V	8	3	0	ACD-4; E FIELD	10/21	e054dfmh	<i>e054dref</i>	e055dfmh	<i>e055dref</i>	e057dfmh	<i>e057dref</i>
DFMJ	172	H	2	3	0	ACD-4; E FIELD MGL-6; H FIELD	10/20	e038dfmj <i>e032dfmj</i>	<i>e038dref</i> <i>e032dref</i>	e037dfmj <i>e033dfmj</i>	<i>e037dref</i> <i>e033dref</i>	e035dfmj <i>e034dfmj</i>	<i>e035dref</i> <i>e034dref</i>
DFMK	172	H	8	3	0	ACD-4; E FIELD	10/21	e051dfmk	<i>e051dref</i>	e050dfmk	<i>e050dref</i>	e049dfmk	<i>e049dref</i>
DFML	430	V	2	3	0	ACD-4; E FIELD MGL-6; H FIELD	10/20	g029dfml <i>g034dfml</i>	<i>g029dref</i> <i>g034dref</i>	g031dfml <i>g035dfml</i>	<i>g031dref</i> <i>g035dref</i>	g033dfml <i>g036dfml</i>	<i>g033dref</i> <i>g036dref</i>
DFMM	430	V	8	3	0	ACD-4; E FIELD	10/20	g038dfmm	<i>g038dref</i>	g039dfmm	<i>g039dref</i>	g040dfmm	<i>g040dref</i>
DFMN	430	H	2	3	0	ACD-4; E FIELD MGL-6; H FIELD	10/20	g053dfmn <i>g058dfmn</i>	<i>g053dref</i> <i>g058dref</i>	g054dfmn <i>g057dfmn</i>	<i>g054dref</i> <i>g057dref</i>	g055dfmn <i>g056dfmn</i>	<i>g055dref</i> <i>g056dref</i>
DFMP	430	H	8	3	0	ACD-4; E FIELD	10/20	g043dfmp	<i>g043dref</i>	g042dfmp	<i>g042dref</i>	g041dfmp	<i>g041dref</i>
DFMQ	25	H	8	3	6	ACD-4; E FIELD	9/21	c028dfmq	<i>c028dref</i>	c027dfmq	<i>c027dref</i>	c025dfmq	<i>c025dref</i>
DFMR	25	H	8	3	-6	ACD-4; E FIELD	9/21	c021dfmr	<i>c021dref</i>	c023dfmr	<i>c023dref</i>	c024dfmr	<i>c024dref</i>
DFMS	172	H	8	3	6	ACD-4; E FIELD	10/21	e044dfms	<i>e044dref</i>	e046dfms	<i>e046dref</i>	e048dfms	<i>e048dref</i>
DFMT	172	H	8	3	-6	ACD-4; E FIELD	10/20	e039dfmt	<i>e039dref</i>	e041dfmt	<i>e041dref</i>	e043dfmt	<i>e043dref</i>
DFMU	430	H	8	3	6	ACD-4; E FIELD	10/20	g051dfmu	<i>g051dref</i>	g049dfmu	<i>g049dref</i>	g048dfmu	<i>g048dref</i>
DFMW	430	H	8	3	-6	ACD-4; E FIELD	10/20	g045dfmw	<i>g045dref</i>	g046dfmw	<i>g046dref</i>	g047dfmw	<i>g047dref</i>

- The italicized file names are for magnetic fields

6.3.4 Rhombic Field Mapping

The fields within the rhombic were also required in order to define the excitation of articles within the test volume for modeling exercises. Also, knowledge of the driving conditions would permit the understanding or interpretation of coupling phenomenology that takes place within the test articles. Estimates of the fields in the rhombic region had been achieved in the test plan using a simple quadrupole transmission line model of the simulator. But, this was for TEM conditions and, over the broad frequency range encountered here, one could not expect that the TEM approximation was adequate. Nonetheless, this model was used to determine estimates of the field strengths involved for safety and detectability forecasting.

The fields using the rhombic radiator in the LESLI were measured at a number of points. Using the geometry and coordinates system of Figure 6-6, the fields were probed in the region near the anticipated location of the aircraft nose during the aircraft tests. The time available for the mapping was severely restricted and the number of points, as with the dipoles, were limited.

Figure 6-6. Rhombic field map points

Table 6-37. Rhombic Field Map Locations					
Freq (MHz)	Pol	x (m)	y (m)	z (m)	Fields
0.3 to 1000	V	40	1	0	E
0.3 to 1000	V	40	3	0	E
0.3 to 1000	V	40	3	2	E
0.3 to 1000	V	40	3	8	E
0.3 to 1000	V	40	3	15	E
0.3 to 1000	V	40	5	-2	E
0.3 to 1000	V	40	5	0	E&H
0.3 to 1000	V	40	5	2	E
0.3 to 1000	V	40	5	5	E&H
0.3 to 1000	V	40	5	8	E
0.3 to 1000	V	40	5	10	E&H
0.3 to 1000	V	40	5	12	E
0.3 to 1000	V	40	5	15	E
0.3 to 1000	V	50	3	0	E
0.3 to 1000	V	50	3	5	E

Table 6-37 is a tabulation of the sample points for the rhombic mapping. The rhombic radiator was always driven in common mode thus giving rise to a very predominantly vertically polarized electric field. The dependability of the differential mode balun was questioned especially the constancy of its characteristics over the full frequency range from 0.3 to 1000 MHz. As a result, the rhombic was not mapped for the differential mode (predominant horizontal polarization). Furthermore, the differential mode was only used over a small frequency range for the purpose of collecting qualitative data on coupling phenomenology. The file names for the data for the rhombic field mapping have been tabulated in Table 6-38. The field map points have a 7FM prefix before a designator for each point. Again, the ACD-4 probe is a balanced electric field probe and the MGL-6 is a balanced magnetic field probe. The reference fields are always the transverse component of the magnetic field at the groundplane on the centerline at a point 10 meters from the rhombic feedpoint. This field is measured with a ground plane magnetic field sensor, MGL-7. The file names for magnetic fields in Table 6-38 are in italics.

Table 6-38. Rhombic Field Map Points
(Common mode, $0.3 < \text{frequency} < 1000 \text{ MHz}$)

MAP POINT	X	Y	Z	COMMENTS (Probe ID and Measured Field)	DATE	E_x H_x file name	$Ref H_z$ file name	E_y H_y file name	$Ref H_z$ file name	E_z H_z file name	$Ref H_z$ file name
7FMA	40	5	-2	ACD-4; E FIELD	9/12/94	m0947fma	m09410cl	m0957fma	m09510cl	m0967fma	m09610cl
7FMB	40	1	0	ACD-4; E FIELD	9/8/94	m0527fmb	m05210cl	m0537fmb	m05310cl	m0547fmb	m05410cl
7FMC	40	3	0	ACD-4; E FIELD	9/7/94	m0427fmc	m04210cl	m0437fmc	m04310cl	m0417fmc	m04110cl
7FMD	40	5	0	ACD-4; E FIELD MGL-6; H FIELD	9/8/94	m0587fmd m0597fmd	m05810cl m05910cl	m0567fmd m0607fmd	m05610cl m06010cl	m0577fmd m0627fmd	m05710cl m06210cl
7FME	40	3	2	ACD-4; E FIELD	9/7/94	m0457fme	m04510cl	m0447fme	m04410cl	m0467fme	m04610cl
7FMF	40	5	2	ACD-4; E FIELD	9/12/94	m0937fmf	m09310cl	m0927fmf	m09210cl	m0917fmf	m09110cl
7FMG	40	5	5	ACD-4; E FIELD MGL-6; H FIELD	9/9/94	m0657fmg m0687fmg	m06510cl m06810cl	m0667fmg m0707fmg	m06610cl m07010cl	m0677fmg m0717fmg	m06710cl m07110cl
7FMH	40	3	8	ACD-4; E FIELD	9/7/94	m0497fmh	m04910cl	m0487fmh	m04810cl	m0477fmh	m04710cl
7FMJ	40	5	8	ACD-4; E FIELD	9/12/94	m0887fmj	m08810cl	m0897fmj	m08910cl	m0907fmj	m09010cl
7FMK	40	5	10	ACD-4; E FIELD MGL-6; H FIELD	9/9/94	m0767fmk m0747fmk	m07610cl m07410cl	m0777fmk m0737fmk	m07710cl m07310cl	m0787fmk m0727fmk	m07810cl m07210cl
7FML	40	5	12	ACD-4; E FIELD	9/9/94	m0817fml	m08110cl	m0807fml	m08010cl	m0797fml	m07910cl
7FMM	40	3	15	ACD-4; E FIELD	9/6/94	m0507fmm	m05010cl	m0157fmm	m01510cl	m0167fmm	m01610cl
7FMN	40	5	15	ACD-4; E FIELD	9/9/94	m0847fmn	m08410cl	m0857fmn	m08510cl	m0867fmn	m08610cl
7FMP	50	3	0	ACD-4; E FIELD	9/1/94	m0097fmp	m00910cl	m0107fmp	m01010cl	m0117fmp	m01110cl
7FMQ	50	3	5	ACD-4; E FIELD	9/1/94	m0147fmq	m01410cl	m0137fmq	m01310cl	m0127fmq	m01210cl

6.3.5 LESLI Pad Characterization

The LESLI pad required electromagnetic characterization in order to enable the modelers to include it in the definition of the electromagnetic environment. The evaluation of the constitutive parameters was to be performed under a number of constraints, namely,

- In order to limit costs, the measurement process was to be minimized in time extent without severely compromising the quality of the data.
- The measurement process was limited by the availability of the data acquisition system for only a one week period. This included assembly/disassembly, testing/dry runs, equipment down-time, and data acquisition.
- Construction details for the pad built over 40 years ago, were unavailable.
- The measurement techniques were to be completely noninvasive, namely, the pad could not be cored or probes emplaced below the surface.

The method chosen for the determination of the constitutive parameters is based on the theoretical solution for current propagation on a wire above a homogeneous half-space with arbitrary permittivity ϵ , and conductivity σ . A solution for the current distribution on an infinitely long wire over ground, with no limitations on the ground constants, had been developed by Chang et al. [1975], Olsen et al. [1978], and Kuester et al. [1978]. The solution of the inverse problem starting with measured current distributions allowed for the determination of the constitutive parameters as described in Poggio et al. [1995]. The report is included as Appendix C, for convenience.

Figure 6-7 shows the wire conductor on the LESLI pad. The current distributions on the wire were collected from approximately 1 MHz to 1 GHz at 90 points spaced 30 cm apart.

Figure 6-7. Pad characterization wire layout

While the original plan called for another test set with the wire routed at another angle across the pad, time constraints did not permit this test.

Figure 6-8 is a cross section of the conducting wire on the pad showing the feedpoint, the aluminum plane, the wire, its terminating load, and the dielectric used to maintain its height above the pad.

Figure 6-8. Pad characterization wire layout - cross sectional view

The data for the pad characterization are contained in numerous files. During the measurements, the first spatial point was used as a reference for measurements of every other spatial point. Hence, each spatial point (gp02 through gp90) generated two merged files over the range 0.3 to 1000 MHz, one pertaining to the current at the spatial point and one for the reference (gp01). The file designations are defined in Table 6-39.

Table 6-39 File Designation for Pad Characterization		
file name	Freq. Range	Number
p###gp&&	0.3 - 100 MHz	008≤sweep#≤131, 02≤point&≤90
q###gp&&	100 - 1000 MHz	008≤sweep#≤131, 02≤point&≤90
m###gp&&	0.3 - 1000 MHz	008≤sweep#≤131, 02≤point&≤90
p###ref1	0.3 - 100 MHz	008≤sweep#≤131
q###ref1	100 - 1000 MHz	008≤sweep#≤131
m###ref1	0.3 - 1000 MHz	008≤sweep#≤073
w###ref1	0.3 - 1000 MHz	070≤sweep#≤131

It was realized, as pad characterization data were being acquired, that the merged reference files for this experiment would have identical file names as the rhombic file names; e.g., M070REF1. For this reason, merged files for sweeps 070 and above were assigned the prefix “W” and processed accordingly. Note that the “M” and “W” files for sweeps 071 and 073 are identical. The merged data in this form were used in the analysis in Poggio et al. [1995].

Reasonably accurate estimates of attenuation and phase constants were obtained for frequencies between 10 MHz and 126 MHz. Below this range, the spatial extent of sampling did not permit accurate estimates of the attenuation constant while beyond this frequency range, the sampling density and the limited support of the transmission line mode did not permit accurate estimates of the phase and attenuation constants, respectively.

Over the frequency range, the constants led to estimates of ϵ_r and σ which were “reasonable” and within the range of physical realizability. Outside the range, the estimates for the constitutive parameters were decidedly less reliable. The estimates from the reliable range were used in a least

squares fit to the Debye equations to yield expressions for the constitutive parameters as a function of $\omega = 2\pi f$:

$$\begin{aligned}\epsilon_r &= 4.2418 + 6.1943 / (1 + 1.129 \cdot 10^{-17} \cdot \omega^2) \\ \sigma &= 4.416 \cdot 10^{-11} \cdot \omega / (1 + 1.354 \cdot 10^{-17} \cdot \omega^2)\end{aligned}$$

Analysis of the experimental data allowed the identification of areas where the displacement current effects dominated. Certainly, displacement current effects were dominant above 50 MHz and it was evident from the reflection coefficient analysis that it was effectively independent of conductivity above 50 MHz and effectively independent of frequency above 100 MHz. Thus concern regarding the conductivity was secondary as its impact would be felt only below 50 MHz.

6.4 Aircraft Test Series

The aircraft test series included a sequence of tests involving the aircraft that can be classified as noise measurements (ambient and noise floor) in Tests AN and Noise Floor; dipole measurements (three frequencies, vertical and horizontal dipoles) in Tests A through F; on-board instrumentation checkout using the rhombic radiator (beyond the scope of this report) in Tests G, H, and I; rhombic tests (0.3 to 1000 MHz, vertical polarization, nose-on and side incident) in Tests J and K; some repeated tests to study sensitivities in Test Z; windshield covering effects in Test WF; and the effects of horizontal polarization in limited tests using the rhombic in Test Horizontal Polarization. In the following, these tests will be briefly described with references to the tables appearing earlier in this section.

6.4.1 Ambient Noise Measurements

With the airplane in a nose-on configuration in the LESLI, several measurements were made of the signals that can be expected due to the environment. Figure 6-9 contains plots of the ambient noise signals measured at four test points. These ambient signals were taken at distinct instants and cannot be expected to completely characterize the ambient electromagnetic environment but can be used to provide an indication of the type of background that could be usually expected during the measurement runs. For these tests, two field components in the cockpit, the heater cable current in the E-bay and the external VHF antenna were measured over the entire rhombic frequency range with all sources in the facility in a disabled mode. The test conditions for these tests are described in Table 6-4 and the data identification is provided in Table 6-18.

In these tests, both the test probe and the reference probe (MGL-7 in the LESLI rhombic feedzone 10 meters from the feedpoint on its centerline) signals were measured using the VANAs. The VANAs recorded the reference probe signal and the ratio of the aircraft probe to the reference probe signals. The presence of the FM radio signals is apparent in the AN4 measurement using the external antenna AN4. These measurements can be used to provide some indication of the level at which measurements can become unreliable due to interfering sources of signals in the environment.

6.4.2 Instrumentation Noise Measurements

Instrumentation noise measurements were made for stepped CW measurements in the rhombic. In the nose-on configuration, each data channel was, in turn, tested. The probe on each channel was removed and replaced by a matched load (50 ohms). Then under RF illumination in the rhombic, a complete sweep was executed and recorded for that channel. These data represent the signal in each recorded channel without any apparent input signal from a probe with all other channels in their normal configuration. The test conditions for these tests are described in Table 6-11 and the data identification is provided in Table 6-25. Figures 6-9, -10 and -11 present a representative instrumentation noise plot for voltage, current, and E field measurements involving AD-60 probes.

Figure 6-9. Ambient noise measurements for Test Series AN

Figure 6-10 Instrumentation Noise in measuring an electric field using an AD-60 probe

Figure 6-11 Instrumentation noise in measuring voltage at a point

Figure 6-12 Instrumentation noise in measuring current on a wire

This noise could be due to stray coupling of RF into the cables, crosstalk in the F-O devices and VANAs, and typical noise often experienced in electronic measuring equipment. A review of the data had indicated that the instrumentation noise characteristics were very similar for all channels measuring an identical variable. Hence, a single graphical description adequately conveys information on the instrumentation noise involved in measuring a variable. The external antenna measurement is considered a voltage measurement.

Similar tests were also conducted in the dipole series. There, the channels having the weakest signal and the strongest signal in each test series were determined. Then, in turn, the probe corresponding to each of these was replaced by a matched load and the signal in that channel was recorded. These tests were referred to as the weak signal line and strong signal line tests. Some observations in Test Series C led to concern with crosstalk as indicated in Millard [1995], a test report which is included as Appendix B, for convenience. In test C14, the weak signal line test related to the C4 test, coupling from some source onto the weak signal line was identified. That the measured weak signal was contaminated by a signal from a strong signal line was evidenced by two further measurements on the weak signal line, one with the strong signal probe attached and the weak signal input to the F-O link replaced by 50 ohms (Test C104) and the other with the weak signal input to the F-O link replaced by 50 ohms and the others disconnected (Test C204). This is a manifestation of the crosstalk rejection capability of the NanoFast fiber optic links being limited to the 35 to 40 dB range. The test results are shown in Figure 6-13. Based on these observations

Figure 6-13. Crosstalk signals evaluated during Test Series C

and the potential impact of crosstalk on the measurement of weak signals, operating procedures were changed for following tests so that weak signal measurements were made without any other channels being connected. Further study or the repeat of previous weak signal tests were not possible due to time and resource constraints.

6.4.3 Dipole Tests

The dipole tests were included to provide a test series employing a radiator that is not only well understood and characterized but is also readily included in the mathematical model space when using full wave computer models which are capable of self consistent solutions of Maxwell's Equations. The frequency ranges used in the dipole tests are provided in Table 6-40 as are skip bands, mandated by FAA and FCC as not useable. The number of frequencies at which data were acquired is also provided

Table 6-40. Frequency Table for Dipole Tests				
Test Freq (MHz)	Start Freq (MHz)	Stop Freq (MHz)	No. Freq Points	Skip Bands (MHz)
25.85	23	28	1001	24.99 to 25.10, 25.55 to 25.67
172.0	150	200	1001	162.375 to 162.575
430.0	350	400	1001	401.6 to 402.2, 406 to 406.1

The dipole tests are denoted as Tests A through F as shown in Table 6-41. The test conditions are found in Tables 6-5 through 6-10 and the data identification is found in Tables 6-19 through 6-24.

Table 6-41. Dipole Test Series		
Test Series Designator	Freq Range (MHz)	Orientation
A	23-28	Horizontal, Dipole // to a/c axis
B	23-28	Vertical, left of a/c
C	150-200	Vertical, left of a/c
D	150-200	Horizontal, Dipole // to a/c axis
E	350-500	Vertical, left of a/c
F	350-500	Horizontal, Dipole // to a/c axis

The location of the radiators relative to the aircraft is shown in Figure 6-14. The dipoles are mounted on a stand as shown previously in Figures 6-2 and 6-3. The geometrical arrangement is shown in Figure 6-14 with all coordinates in meters and *the origin at a point on the ground plane directly below the nose of the aircraft, as shown*. The center of the dipole source is located at (-4, 3, -5) for all frequencies except for the vertical polarization test near 25.85 MHz when the center is raised to (-4, 4, -5). A reference probe (B dot sensor) is used in the measurements and is located 3.5 meters from the dipole source for all frequencies except for the measurements near 25.85 MHz when the sensor is 5 meters from the dipole source. The coordinates are (-1.525, 3, -7.475) and (-0.465, 3, -8.535), respectively.

In all cases, the reference probe was oriented for response to the dominant magnetic field, that is, an orientation orthogonal to the dipole. In the data for the dipole tests and their field mappings, the reference field is denoted H_z and care should be exercised in its interpretation.

The dipole tests were conducted over frequency ranges distributed about 25.85 MHz (sometimes referred to as 25 MHz range), 172 MHz, and 430 MHz. Figure 6-15 is a photograph of the 25 MHz dipole mounted on the stand with the reference probe (an MGL-6 balanced magnetic field

Figure 6-14. Dipole and reference locations

Figure 6-15. Dipole in position for aircraft test

sensor) to the right in preparation for an aircraft test. The dipoles were fed by baluns to provide balanced currents on the dipole arms.

During the course of the dipole tests, the pilot and copilot seats were maintained in the fore position. Hence, tests A1 and A2 which were carried out with the seats in the aft position were repeated (tests A101 and A102). This provided additional information to assess the effect of seat position on the measured parameters.

6.4.4 Test Series J & K - Rhombic Tests

Test Series J & K represent the bulk of the "scientific" measurements performed within the LESLI with the rhombic illuminator. The goals of these tests were to provide data for the code validation exercise as well as to provide information regarding the sensitivity of select variables such as field, voltage and current at specific points to variations in system configuration, to repeated measurements at different times, and to angular orientation of the aircraft with respect to the incident electromagnetic field. The test conditions for the J series of tests are found in Table 6-12 while those for the K series are found in Table 6-13. The data ids for the J and K series are found in Tables 6-26 and 6-27, respectively.

Figures 6-15 and 6-16 are photographs of the B-757 in position on the LESLI pad. Figure 6-16 shows the B-757 in the nose-on configuration with its nose at a point 40 meters from the rhombic feedpoint. The leftmost pole in the photo is one of the support towers for the rhombic conductors. The other support tower is out of view to the left. All other poles were not used in this series. The aluminum ground plane is visible as are the source shack (at the apex of the aluminum plane) and the DAS trailer (lower right). In the background is the Kirtland Air Force Base and Albuquerque Airport facilities and runway.

Figure 6-16. B-757 on LESLI pad - overhead view

Figure 6-17 is a view of the B-757 from the rhombic feedpoint. Clearly visible is the balun used to convert the unbalanced RF signal from the coaxial line into a balanced common mode drive for the rhombic conductors. Also visible in the photo are the rhombic wires, the nylon steadying line running transverse to the facility, and the poles supporting the conductors. The cables routed along the aluminum ground plane are fiber optic cables used in the data acquisition system. They are routed to the aircraft and enter through a pressure relief flap on the right side of the aircraft (the left in the figure). The stairs in the photo are completely constructed of fiberglass and stayed in position during the tests.

Figure 6-17. B-757 on LESLI pad - viewed from rhombic feedpoint

The data acquired during the rhombic tests were not scaled to a particular driving or incident field strength. Rather, a reference field measured at a reference probe on the rhombic centerline 10 meters from the feedpoint, was recorded for each data run during which a variable was measured. While the reference field did not vary significantly from run to run, it is provided to permit comparisons of the various runs (one need merely scale data to obtain identical reference fields or identical excitation conditions) or to allow an analyst to convert the reference field at the probe to an incident field at the aircraft.

Some general comments and observations regarding the J series follow:

- Test J1, J2, and J3 were dropped after execution due to malfunctions in the network analyzer. Tests J20, J21 and J22 are suitable replacements as they are identical in configuration and differ only in execution time. The intended repeatability text (data acquired in AM and PM) was not possible.
- Test J6 through J11 dealt with the movement of a conducting box (a 3"x3"x4" plastic box covered with copper conducting tape) emplaced on the aft surface of the ATOPS box in the cockpit. The tests were intended to uncover the effects on the cockpit E fields of such movement. One would compare the condition of no box (J20, J21, J22) with (J6, J7, J8) and (J9, J10, J11).

Figure 6-18 is an example of such a comparison showing the vertical electric field on the ATOPS box for no box, the box located on the lower portion of the rear (aft) surface of the ATOPS with its axis parallel to the floor, and the box on the upper portion of the aft surface with axis perpendicular to the floor.

- J12 is a test over $800 < f < 900$ MHz looking at the field behavior over a narrow frequency range and providing information for later statistical EM studies.
- Test J13 through J19 were executed to uncover the effects of personnel presence and placement in the cockpit. In J13, J14 and J15 only a copilot was seated (right hand seat) at the half-way portion. In tests J16, J17, and J18, both pilot and copilot were seated at the half-way position.
- Test J19 is a wire current measurement using the I-320 current probe (usually used to probe climbing wire current) to measure current on the heater wire for the copilot side window.
- Test J24 (voltage in LRU) was repeated later as Test J024. J24 had the circuit breaker for the VHF unit in the pulled state while J024 had the current breaker engaged (in).

Figure 6-18. The effect of movement of a small conducting box on vertical electric field

- Tests J26 through J31 were executed to assess the effects of various states of the E-bay hatch cover. Figure 6-19 shows the vertical electric field for the normally closed state (J23, J24, J25), hatch sealed with conducting tape (J26, J27, J28), and the hatch open (J29, J30, J31).

Figure 6-19. The effect of hatch cover state on vertical electric field in E-bay

- Tests J36, J37, and J38 were cockpit field measurements with the incident wave at 10 degrees from nose-on while Tests J39, J40, and J41 were at 5 degrees. The comparison in Figure 6-20 illustrates the sensitivity to angle of incidence. The pilot and copilot seats were full forward for the tests at 5 degrees. (they were repeated during the K series with the seats at mid position).

Figure 6-20. Cockpit vertical electric field variation with angle of incidence

- Test J005 was a climbing wire voltage measurement similar to Test J5 except that the current probe was removed in order to determine the effect of the presence of the current probe during climbing wire voltage measurements. A comparison is shown on Figure 6-21.

Figure 6-21. Climbing wire voltage with and without current probe

- Tests J026, J027, and J028 were repeats of the J26, J27, and J28 tests but with the pressure door on the right side of the fuselage which served as an exit port for the data acquisition cables sealed with conductive tape and aluminum foil.

Test Series K was primarily directed towards broadside incidence on the aircraft but also included some repeatability tests and repeats. Comments and observations on the K series follow.

- Tests K1 through K12 were to provide data for a direct comparison of variables for nose-on and side incidence. Corresponding tests in the J series and in the K series could be compared. Figures 6-22 and 6-23 are such comparisons for the vertical electric fields in the cockpit and cabin.
- Test K13 is a repeatability check of the results in K11. An example of such a comparison is presented in Figure 6-24 where repeatability is examined for the long wire base voltage in the cabin. In this case, the possible differences in driving field have been extracted. Recall that all comparisons so far have been made without extracting the differences that might be due to variations in the incident electric field. This was adequate for the qualitative comparisons that have been used as examples. A precise comparison would require that the differences in the driving field be extracted from the resulting data. To normalize the effect, i.e., to remove the impact of changes in results (E) due to changes in the excitation (R_{ef}) for two tests, say test 1 and test 2, one need only perform $E_1 = (R_1/R_2)E_2$. So, the results of Figure 6-24 are for identical excitation conditions and are a reasonable indication of the repeatability of the measurements. Figure 6-25 is a plot of the ratio of the incident fields (R_1/R_2) and is representative of the ratios in other cases. It is indicative of the variability from test to test and highlights the need to normalize the data when performing quantitative comparisons.

Figure 6-22. Cockpit vertical electric field for nose-on and side incidence

Figure 6-23. Cabin vertical electric field for nose-on and side incidence

Figure 6-24. Repeatability check using corrected data

Figure 6-25. Ratio of the incident fields in Tests K11 and K13

- Test K14 was performed in order to evaluate the effect of people in the cabin of the aircraft. For this test, which measured the terminal voltage on the long wire, the pilot and copilot were in place

in the cockpit and personnel were seated in cabin seats denoted 3c, 3d, 2b, and 3b. This result is compared to the result of Test K13 in Figure 6-26.

Figure 6-26. Long wire voltage under several conditions

- Test K26 was meant to evaluate the effect of a static ground on the terminal voltage of the cabin long wire. This static ground, which was ordinarily disconnected throughout the test program, was deliberately connected for this test. The grounding was effected by connecting a strap from the landing gear to a permanent ground hook at the LESLI facility. This result is also shown in Figure 6-26.
- Tests K30, K31, and K32 were repeats of J39, J40, and J41 but with the pilot and copilot seats in the mid position. During the J tests, the seats were in full forward position. Figure 6-27 shows a comparison of the cockpit axial field in the two cases in the form of a ratio of the two fields. The axial electric field probe is pointed directly at the back of the copilot seat and is in close proximity when the seat is at mid position. The size of the ratio emphasizes the importance of knowing configuration details.
- Tests K007 and J024 were performed to investigate the effect of the circuit breaker state on measurements. K007 was in a broadside incidence position and J024 was for nose on incidence. In both cases the breaker was engaged (in).

Figure 6-27. Ratio of axial E field with seat at mid and forward positions

6.4.5 Test Series Z - Effects of System State

During the execution of the on-the-ground tests, the configuration of the aircraft was maintained in a constant state except when deliberate modifications were introduced. Such test conditions are indicated throughout the test plan. During execution, circuit breakers were maintained in a known state. But, it was noted during a particular sequence that the state of a circuit breaker in the VHF transceiver power system was in an open condition while it had been expected to be in the closed condition as when the system was in operation. The effect of changes in this configuration state was a concern although future tests would also be executed in the breaker open state. A portion of Test Series Z (Z1 through Z10) was executed to assess the effects of changes in a single circuit breaker to the closed condition in a communication system power line. This circuit breaker was located in the cockpit panel and the transceiver was mounted in a rack in the E-bay thus indicating a power line for the system (and probably others) that was routed, at a minimum, through the cockpit and E-bay. Thus, this portion of Test Series Z provides data that indicate the relative importance of knowing the state of such systems when performing such tests. Another portion of Test Series Z was directed to evaluating the energy collecting capability of parasitic wires in the cockpit (Z11 and Z12), to assessing the effect of a connected static ground on the aircraft (Z13), and checking repeatability (Z14). The test conditions for Test Series Z are found in Table 6-14 while the data identification is provided in Table 6-28.

The effects of the circuit breaker state were reasonably marked in the E-bay as seen in Figure 6-28 for the vertical electric field in the E-bay and Figure 6-29 for the voltage in the LRU (sensor RC7). The latter observation was made during the K Series where a special test referred to as "J024 brkr in" was performed as a repeat of Test J24 with the breaker out (open). The results are not totally surprising since the circuit breaker could open or complete the power line circuit to the LRU in question and could allow this power line to become a major source, in these tests, of conducted signals into the LRU. Note that in both cases the effects are most pronounced at low frequencies and even then are at low levels of the variables in question.

Figure 6-28. E-bay electric field dependency on circuit breaker state

Figure 6-29. LRU voltage dependency on circuit breaker state

6.4.6 Horizontal Polarization

Early planning of the experimental series did not include horizontal polarization due to the difficulties experienced by the Phillips Lab staff in earlier tests using the differential mode drive in the LESLI with the rhombic radiator. To generate the horizontal electric fields, a balun is used to provide the differential drive for the rhombic. The high power, high quality balun ordinarily used at LESLI for differential drive over a broad frequency range was inoperative. Also, the field behavior of the horizontal E field is quite poor in that the field is strongly horizontal (for pure differential mode current on the wires) only on the vertical plane of symmetry and is indeed vertical on the ground plane (if it were perfectly conducting) and at all points directly under the wires. The aircraft, in the nose-on configuration, has its fuselage illuminated by an electric field that has a predominantly horizontal. In response to requests by some analysts for qualitative measurements using horizontal polarization in the frequency range containing the lowest order resonances of the fuselage, a limited, somewhat ad hoc test series was conducted in the differential mode.

A substitute balun was procured albeit a rather narrowband device when compared to the sweep capability of the LESLI. The balun was rated by the manufacturer for operation in the 2.5 to 30 MHz range. This balun was not tested or characterized for the quality of its output in terms of the required relative phase difference in the current at its terminals and the stability of this quality over the frequency range. It was only tested for the spectral behavior of its impedance transformation characteristic. Time and resource constraints in conjunction with the relative value of the measurements given the concerns mentioned above led to a limited balun characterization. Overall then, the test conditions did not permit scientific quality measurements but only a qualitative "quick look" at typical responses in the twelve probes aboard the aircraft and a determination whether the fundamental aircraft mode is seen at the internal test points.

The reference field measurement was performed using a balanced magnetic field sensor (MGL-6) measuring the vertical component (y-directed) of the magnetic field 3 meters above the pad and 15 meters from the feedpoint on the centerline i.e., at (15, 3, 0).

The executed tests and the data identification for the Horizontal Polarization tests are found in Tables 6-15 and 6-29, respectively.

Some sample results for the tests are shown in Figures 6-29, 6-30, and 6-31. Several features of the data in these figures are notable. In Figure 6-30, it is apparent that the three components of the field in the cockpit are bounded on the topside by the transverse electric field. These fields exceed the other fields in the cabin and E-bay that are measured with an AD-60 probe. The voltage measurements in Figure 6-31 are dominated by the voltage at the feedpoint of the cabin long wire which is parallel to the fuselage with a length of 20 feet and suspended 12 inches below the upper inner surface of the fuselage. The LRU voltage measurement shows some sign of body resonances at low frequencies. Finally, it is seen in Figure 6-32 that the current in the E-bay on the windshield heater wire strongly dominates the current at other points. The magnitude of the dominance is remarkable and worthy of note to system designers as this current, which is probably excited in the cockpit, propagates effectively into the E-bay and can be the source of conducted and radiated coupling to systems in that enclosure.

Figure 6-30. E Field in Cockpit under horizontally polarized excitation

Figure 6-31. Voltage at select points under horizontal excitation

Figure 6-32. Current on certain wires under horizontal excitation

6.4.7 Test Series WF - Windshield Shielding Effects

The dominant port-of-entry (POE) for RF energy into the cockpit is often considered to be the aircraft windshield. To test this hypothesis, a test was suggested and executed wherein, in the nose-on configuration, the windshield of the cockpit was covered with aluminum foil and sealed with conducting copper tape. Data from the entire suite of probes were collected to enable comparison of measurements taken with and without the foil covering and estimation of the shielding afforded by the foil. The test conditions for the windshield covered test (Test Series WF - Window Shielded/Unshielded) are found in Table 6-16 while the data identification is found in Table 6-30.

Data comparisons are enabled by the data. For example, the effect of the aluminum foil shield can be assessed by comparing the results of tests in the WF Series and tests with the corresponding test conditions in Test Series J. As an example, one of the most marked differences in coupling in the two cases is illustrated by the vertical electric field in the cockpit. A comparison of the fields in the two cases is shown in Figure 6-33 where the differences are often 20 dB and should be an indicator to hardening engineers that reduction of this coupling path can yield significant benefits. The data have not been corrected for variations in the incident field. But, a comparison of the reference fields shows only small differences so that the resulting incident fields are sufficiently similar to allow qualitative comparisons. Of course, the reference fields are available so that corrections can be introduced to correct for the incident field variations.

Figure 6-33. Comparison of the vertical electric field in the cockpit with the windshield uncovered and covered with aluminum foil

7.0 Data Availability

The complete data for the Low Power On-the-Ground Tests are available in digital format. The data files have been described in this document and the data ids provide a connection between the files and specific tests. A list of the available data files for each test series is found in Table 6-42.

The data in each file consists of a header as previously described and measured data, specifically, frequency and the real and imaginary part of the variable of interest. Arrangements for access to the data can be made through the funding organization NASA/LaRC which will also provide instructions on the steps required to electronically obtain the data. The point of contact is:

Karl J. Moeller
 NASA Langley Research Center
 Mail Code 490, Bldg. 1299
 Hampton, VA 23665-5225
 Voice: (804) 864-7673
 FAX: (804) 864-7975
 email: k.j.moeller@larc.nasa.gov

Table 6-42. Test Series and Available Data Files

an	a	b	c	d	e	f
an00an01	c053a009	c043b001	e004c001	e021d009	g014e008	g002f001
an00an02	c053ref1	c043b008	e004c011	e021d011	g014e010	g002f002
an00ref1	c054a010	c043ref1	e004ref1	e021ref1	g014ref1	g002ref1
an01an03	c054a011	c044b005	e006c005	e022d006	g015e009	g003f010
an01ref1	c054ref1	c044ref1	e006c012	e022d010	g015e011	g003f012
an02an04	c055a006	c045b003	e006ref1	e022ref1	g015ref1	g003ref1
an02ref1	c055ref2	c045b012	e007c003	e024d003	g020e005	g004f003
bn00an01	c056a003	c045ref1	e007c007	e024d007	g020e006	g004f007
bn00an02	c056a007	c046b002	e007ref1	e024ref1	g020ref1	g004ref1
bn00ref1	c056ref1	c046b004	e009c004	e025d004	g022e003	g005f004
bn01an03	c058a004	c046ref1	e009c008	e025d008	g022e007	g005f008
bn01ref1	c058a008	c047b007	e009ref1	e025ref1	g022ref1	g005ref1
bn02an04	c058ref1	c047ref2	e010c002	e027d001	g023e004	g007f005
bn02ref1	c059a001	c049b010	e010ref2	e027d002	g023ref1	g007f011
mn00an01	c059a002	c049b011	e012c006	e027ref1	g024e001	g007ref1
mn00an02	c059ref1	c049ref1	e012c010	e029d005	g024e002	g009f006
mn00ref1	c060a101	c050b006	e012ref1	e029d012	g024ref1	g009f009
mn01an03	c060a102	c050b009	e013c009	e029ref1	g026e004	g009ref1
mn01ref1	c060ref1	c050ref1	e013ref1	e031d013	g026e012	g012f013
mn02an04	c061a005	c051b014	e015c014	e031d014	g026ref1	g012f014
mn02ref1	c061a012	c051ref2	e015c015	e031ref1	h001e013	g012ref1
mn02ref2	c061ref1	c052b015	e015ref1		h001ref1	g013f008
	c062a014	c052ref2	e016c109			g013f010
	c062ref2	d001b013	e016c111			g013ref1
	c063a013	d001ref1	e016ref1			
	c063ref2		e017c104			
			e017ref1			
			e018c204			
			e018ref1			
			e019c304			
			e019ref1			
			e020c404			
			e020ref1			
			f002c013			
			f002ref1			

Table 6-42. Continued

ni		j				
a100ni01	m102ref1	a106j020	a140j040	b133j034	m120j006	m164j026
a100ni02	m103ni04	a106j021	a140ref1	b133ref1	m120j007	m164ref2
a100ref1	m103ni08	a106ref1	a141j041	b137j033	m120ref1	m165j027
a101ni05	m103ref1	a108j022	a141ref1	b137j035	m121j008	m165ref2
a101ni12	m104ni09	a108j023	a161j024	b137ref1	m121ref1	m167j028
a101ref1	m104ni11	a108ref1	a161ref1	b138j036	m122j009	m167ref2
a102ni03	m104ref1	a109j004	a164j026	b138j037	m122j010	
a102ni07	m105ni06	a109j024	a165j027	b138ref1	m122ref1	
a102ref1	m105ni10	a109ref1	a167j028	b139j038	m123j011	
a103ni04	m105ref1	a111j005	b106j020	b139ref1	m123ref1	
a103ni08		a111j025	b106j021	b140j039	m125j019	
a103ref1		a111ref1	b106ref1	b140j040	m125ref1	
a104ni09		a120j006	b108j022	b140ref1	m126j005	
a104ni11		a120j007	b108j023	b141j041	m126ref1	
a104ref1		a120ref1	b108ref1	b141ref1	m127j029	
a105ni06		a121j008	b109j004	b161j024	m127ref2	
a105ni10		a121ref1	b109j024	b161ref1	m128j030	
a105ref1		a122j009	b109ref1	b164j026	m128ref2	
b100ni01		a122j010	b111j005	b165j027	m129j031	
b100ni02		a122ref1	b111j025	b167j028	m129ref2	
b100ref1		a123j011	b111ref1	m106j020	m130j028	
b101ni05		a123ref1	b112j012	m106j021	m130ref2	
b101ni12		a125j019	b112ref1	m106ref1	m131j027	
b101ref1		a125ref1	b120j006	m108j022	m131ref2	
b102ni03		a126j005	b120j007	m108j023	m132j026	
b102ni07		a126ref1	b120ref1	m108ref1	m132ref2	
b102ref1		a127j029	b121j008	m109j004	m133j032	
b103ni04		a128j030	b121ref1	m109j024	m133j034	
b103ni08		a129j031	b122j009	m109ref1	m133ref1	
b103ref1		a130j028	b122j010	m111j005	m137j033	
b104ni09		a131j027	b122ref1	m111j025	m137j035	
b104ni11		a132j026	b123j011	m111ref1	m137ref1	
b104ref1		a133j032	b123ref1	m116j013	m138j036	
b105ni06		a133j034	b125j019	m116j014	m138j037	
b105ni10		a133ref1	b125ref1	m116ref1	m138ref1	
b105ref1		a137j033	b126j005	m116ref2	m139j038	
m100ni01		a137j035	b126ref1	m117j015	m139ref1	
m100ni02		a137ref1	b127j029	m117ref1	m140j039	
m100ref1		a138j036	b128j030	m118j016	m140j040	
m101ni05		a138j037	b129j031	m118j017	m140ref1	
m101ni12		a138ref1	b130j028	m118ref1	m141j041	
m101ref1		a139j038	b131j027	m118ref2	m141ref1	
m102ni03		a139ref1	b132j026	m119j018	m161j024	
m102ni07		a140j039	b133j032	m119ref1	m161ref1	

Table 6-42. Continued

k			z		hp	wf
a142k001	b144ref1	m146ref2	a173ref1	b183ref1	n010hp01	a168ref1
a142k011	b145k004	m147k005	a173z001	b183z012	n010hp02	a168wf01
a142ref1	b145k007	m147k008	a173z002	b184ref1	n010ref1	a168wf02
a144k003	b145ref1	m147ref1	a174ref1	b184z014	n017hp04	a169ref1
a144k006	b146k007	m149k002	a174z003	m173ref1	n017hp07	a169wf03
a144ref1	b147k005	m149k009	a174z007	m173z001	n017ref1	a169wf06
a145k004	b147k008	m149ref1	a176ref1	m173z002	n018hp03	a170ref1
a145k007	b147ref1	m151k010	a176z005	m174ref1	n018hp06	a170wf04
a145ref1	b149k002	m151k012	a177ref1	m174z003	n018ref1	a171ref1
a146k007	b149k009	m151ref1	a177z004	m174z007	n019hp05	a171wf05
a147k005	b149ref1	m152k013	a178ref1	m176ref1	n019hp08	a172ref1
a147k008	b151k010	m152k025	a178z006	m176z005	n019ref1	a172wf07
a147ref1	b151k012	m152ref1	a178z010	m177ref1	n020hp09	b168ref1
a149k002	b151ref1	m153k015	a179ref1	m177z004	n020hp11	b168wf01
a149k009	b152k013	m153ref2	a179z008	m178ref1	n020ref1	b168wf02
a149ref1	b152k025	m154k023	a180ref1	m178z006	n021hp10	b169ref1
a151k010	b152ref1	m154ref1	a180z009	m178z010	n021hp12	b169wf03
a151k012	b153k015	m155k024	a181z013	m179ref1	n021ref1	b169wf06
a151ref1	b154k023	m155ref1	a182ref1	m179z008	n022hp13	b170ref1
a152k013	b154ref1	m156k014	a182z011	m180ref1	n022hp14	b170wf04
a152k025	b155k024	m156ref2	a183ref1	m180z009	n022ref1	b171ref1
a152ref1	b155ref1	m158k026	a183z012	m181ref2	b171wf05	
a153k015	b156k014	m158ref2	a184ref1	m181z013	b172ref1	
a154k023	b158k026	m159k030	a184z014	m182ref1	b172wf07	
a154ref1	b159k030	m159k031	b173ref1	m182z011	m168ref1	
a155k024	b159k031	m159ref1	b173z001	m183ref1	m168wf01	
a155ref1	b159ref1	m160k032	b173z002	m183z012	m168wf02	
a156k014	b160k032	m160ref1	b174ref1	m184ref1	m169ref1	
a158k026	b160ref1	m161k029	b174z003	m184z014	m169wf03	
a159k030	b161k029	m161ref1	b174z007		m169wf06	
a159k031	b161ref1	m162k027	b176ref1		m170ref1	
a159ref1	b162k027	m162k028	b176z005		m170wf04	
a160k032	b162k028	m162ref1	b177ref1		m171ref1	
a160ref1	b162ref1		b177z004		m171wf05	
a161k029	m142k001		b178ref1		m172ref1	
a161ref1	m142k011		b178z006		m172wf07	
a162k027	m142ref1		b178z010			
a162k028	m144k003		b179ref1			
a162ref1	m144k006		b179z008			
b142k001	m144ref1		b180ref1			
b142k011	m145k004		b180z009			
b142ref1	m145k007		b181z013			
b144k003	m145ref1		b182ref1			
b144k006	m146k007		b182z011			

Table 6-42. Continued

25 MHz Dipole Map		172 MHz Dipole Map		430 MHz Dipole Map	
c003dfmd	c038dfma	e032dfmj	e065dfmg	g029dfml	g057dfmn
c003dref	c038dref	e032dref	e065dref	g029dref	g057dref
c005dfmd	c039dfma	e033dfmj	e066dfmg	g031dfml	g058dfmn
c005dref	c039dref	e033dref	e066dref	g031dref	g058dref
c007dfmd	c040dfma	e034dfmj		g033dfml	
c007dref	c040dref	e034dref		g033dref	
c008dfmd	c041dfma	e035dfmj		g034dfml	
c008dref	c041dref	e035dref		g034dref	
c009dfmd		e037dfmj		g035dfml	
c009dref		e037dref		g035dref	
c010dfmd		e038dfmj		g036dfml	
c010dref		e038dref		g036dref	
c012dfmf		e039dfmt		g038dfmm	
c012dref		e039dref		g038dref	
c014dfme		e041dfmt		g039dfmm	
c014dref		e041dref		g039dref	
c018dfmf		e043dfmt		g040dfmm	
c018dref		e043dref		g040dref	
c020dfmf		e044dfms		g041dfmp	
c020dref		e044dref		g041dref	
c021dfmr		e046dfms		g042dfmp	
c021dref		e046dref		g042dref	
c023dfmr		e048dfms		g043dfmp	
c023dref		e048dref		g043dref	
c024dfmr		e049dfmk		g045dfmw	
c024dref		e049dref		g045dref	
c025dfmq		e050dfmk		g046dfmw	
c025dref		e050dref		g046dref	
c027dfmq		e051dfmk		g047dfmw	
c027dref		e051dref		g047dref	
c028dfmq		e054dfmh		g048dfmu	
c028dref		e054dref		g048dref	
c029dfmb		e055dfmh		g049dfmu	
c029dref		e055dref		g049dref	
e030dfmc		e057dfmh		g051dfmu	
c030dref		e057dref		g051dref	
c031dfmb		e058dfmg		g053dfmn	
c031dref		e058dref		g053dref	
c034dfmb		e060dfmg		g054dfmn	
c034dref		e060dref		g054dref	
c036dfma		e062dfmg		g055dfmn	
c036dref		e062dref		g055dref	
c037dfma		e063dfmg		g056dfmn	
c037dref		e063dref		g056dref	

Table 6-42. Continued

Rhombic Field Map			Calibration	
m00910cl	m05710cl	m0857fmn	acd4.cal	
m0097fmp	m0577fmd	m08610cl	ad60.cal	
m01010cl	m05810cl	m0867fmn	aprb.cal	
m01110cl	m0587fmd	m08810cl	b643.cal	
m0117fmp	m05910cl	m0887fmj	b644.cal	
m01210cl	m0597fmd	m08910cl	b657.cal	
m0127fmq	m06010cl	m0897fmj	c027.cal	
m01310cl	m0607fmd	m09010cl	c043.cal	
m0137fmq	m06210cl	m0907fmj	c044.cal	
m01410cl	m0627fmd	m09110cl	c045.cal	
m0147fmq	m06310cl	m0917fmf	c046.cal	
m01510cl	m06510cl	m09210cl	c047.cal	
m0157fmm	m0657fmg	m0927fmf	c050.cal	
m01610cl	m06610cl	m09310cl	c071.cal	
m0167fmm	m0667fmg	m0937fmf	mgl6.cal	
m04110cl	m06710cl	m09410cl	mgl7.cal	
m0417fmc	m0677fmg	m0947fma	nf20.cal	
m04210cl	m06810cl	m09510cl	nf21.cal	
m0427fmc	m0687fmg	m0957fma	nf22.cal	
m04310cl	m07010cl	m09610cl	nf23.cal	
m0437fmc	m0707fmg	m0967fma	nf40.cal	
m04410cl	m07110cl	m09810cl	nf50.cal	
m0447fme	m0717fmg	m0987fmd	nf51.cal	
m04510cl	m07210cl	m09910cl	nf52.cal	
m0457fme	m0727fmk	m0997fmj	nf53.cal	
m04610cl	m07310cl		nf60.cal	
m0467fme	m0737fmk		p132.cal	
m04710cl	m07410cl		p133.cal	
m0477fmh	m0747fmk		p134.cal	
m04810cl	m07610cl		p135.cal	
m0487fmh	m0767fmk		ps68.cal	
m04910cl	m07710cl		t1c1.cal	
m0497fmh	m0777fmk		t1c2.cal	
m05010cl	m07810cl		t1c3.cal	
m0507fmm	m0787fmk		t1c4.cal	
m05210cl	m07910cl		t2c1.cal	
m0527fmb	m0797fml		t2c2.cal	
m05310cl	m08010cl		t2c3.cal	
m0537fmb	m0807fml		t2c4.cal	
m05410cl	m08110cl		t3c1.cal	
m0547fmb	m0817fml		t3c2.cal	
m05510cl	m08410cl		t3c3.cal	
m05610cl	m0847fmn		t3c4.cal	
m0567fmd	m08510cl		nistad60.cal	

Table 6-42. Continued

Ground Plane Characterization Data						
m008gp02	m031gp24	m053gp15	m078gp39	m116gp76	p022ref1	p045ref1
m008ref1	m031ref1	m053ref1	m079gp40	m117gp77	p023gp17	p046gp08
m009gp03	m032gp25	m054gp16	m080gp41	m119gp78	p023ref1	p046ref1
m009ref1	m032ref1	m054ref1	m081gp42	m120gp79	p025gp18	p047gp09
m010gp04	m033gp26	m055gp17	m082gp43	m121gp80	p025ref1	p047ref1
m010ref1	m033ref1	m055ref1	m083gp44	m122gp81	p026gp19	p048gp10
m011gp05	m034gp27	m056gp18	m084gp45	m123gp82	p026ref1	p048ref1
m011ref1	m034ref1	m056ref1	m085gp46	m124gp83	p027gp20	p049gp11
m012gp06	m035gp28	m057gp19	m086gp47	m125gp84	p027ref1	p049ref1
m012ref1	m035ref1	m057ref1	m087gp48	m126gp85	p028gp21	p050gp12
m013gp07	m036gp29	m058gp20	m087ref1	m127gp86	p028ref1	p050ref1
m013ref1	m036ref1	m058ref1	m088gp49	m128gp87	p029gp22	p051gp13
m014gp08	m037gp30	m059gp21	m088ref1	m129gp88	p029ref1	p051ref1
m014ref1	m037ref1	m059ref1	m089gp50	m130gp89	p030gp23	p052gp14
m015gp09	m038gp05	m060gp22	m089ref1	m131gp90	p030ref1	p052ref1
m015ref1	m038ref1	m060ref1	m090gp51	p008gp02	p031gp24	p053gp15
m016gp10	m039gp06	m061gp23	m090ref1	p008ref1	p031ref1	p053ref1
m016ref1	m039ref1	m061ref1	m091gp52	p009gp03	p032gp25	p054gp16
m017gp11	m040gp02	m062gp24	m091ref1	p009ref1	p032ref1	p054ref1
m017ref1	m040ref1	m062ref1	m092gp53	p010gp04	p033gp26	p055gp17
m018gp12	m041gp03	m064gp25	m092ref1	p010ref1	p033ref1	p055ref1
m018ref1	m041ref1	m064ref1	m093gp54	p011gp05	p034gp27	p056gp18
m019gp13	m042gp04	m065gp26	m093ref1	p011ref1	p034ref1	p056ref1
m019ref1	m042ref1	m065ref1	m094gp55	p012gp06	p035gp28	p057gp19
m020gp14	m043gp05	m066gp27	m095gp56	p012ref1	p035ref1	p057ref1
m020ref1	m043ref1	m066ref1	m096gp57	p013gp07	p036gp29	p058gp20
m021gp15	m044gp06	m067gp28	m097gp58	p013ref1	p036ref1	p058ref1
m021ref1	m044ref1	m067ref1	m098gp59	p014gp08	p037gp30	p059gp21
m022gp16	m045gp07	m068gp29	m099gp60	p014ref1	p037ref1	p059ref1
m022ref1	m045ref1	m068ref1	m101gp61	p015gp09	p038gp05	p060gp22
m023gp17	m046gp08	m069gp30	m102gp62	p015ref1	p038ref1	p060ref1
m023ref1	m046ref1	m069ref1	m103gp63	p016gp10	p039gp06	p061gp23
m025gp18	m047gp09	m070gp31	m104gp64	p016ref1	p039ref1	p061ref1
m025ref1	m047ref1	m070ref1	m105gp65	p017gp11	p040gp02	p062gp24
m026gp19	m048gp10	m071gp32	m106gp66	p017ref1	p040ref1	p062ref1
m026ref1	m048ref1	m071ref1	m107gp67	p018gp12	p041gp03	p063gp25
m027gp20	m049gp11	m072gp33	m108gp68	p018ref1	p041ref1	p063ref1
m027ref1	m049ref1	m072ref1	m109gp69	p019gp13	p042gp04	p064gp25
m028gp21	m050gp12	m073gp34	m110gp70	p019ref1	p042ref1	p064ref1
m028ref1	m050ref1	m073ref1	m111gp71	p020gp14	p043gp05	p065gp26
m029gp22	m051gp13	m074gp35	m112gp72	p020ref1	p043ref1	p065ref1
m029ref1	m051ref1	m075gp36	m113gp73	p021gp15	p044gp06	p066gp27
m030gp23	m052gp14	m076gp37	m114gp74	p021ref1	p044ref1	p066ref1
m030ref1	m052ref1	m077gp38	m115gp75	p022gp16	p045gp07	p067gp28

Table 6-42. Continued

Ground Plane Characterization Data (continued)						
p067ref1	p089ref1	p111ref1	q010ref1	q033ref1	q055ref1	q078ref1
p068gp29	p090gp51	p112gp72	q011gp05	q034gp27	q056gp18	q079gp40
p068ref1	p090ref1	p112ref1	q011ref1	q034ref1	q056ref1	q079ref1
p069gp30	p091gp52	p113gp73	q012gp06	q035gp28	q057gp19	q080gp41
p069ref1	p091ref1	p113ref1	q012ref1	q035ref1	q057ref1	q080ref1
p070gp31	p092gp53	p114gp74	q013gp07	q036gp29	q058gp20	q081gp42
p070ref1	p092ref1	p114ref1	q013ref1	q036ref1	q058ref1	q081ref1
p071gp32	p093gp54	p115gp75	q014gp08	q037gp30	q059gp21	q082gp43
p071ref1	p093ref1	p115ref1	q014ref1	q037ref1	q059ref1	q082ref1
p072gp33	p094gp55	p116gp76	q015gp09	q038gp05	q060gp22	q083gp44
p072ref1	p094ref1	p116ref1	q015ref1	q038ref1	q060ref1	q083ref1
p073gp34	p095gp56	p117gp77	q016gp10	q039gp06	q061gp23	q084gp45
p073ref1	p095ref1	p117ref1	q016ref1	q039ref1	q061ref1	q084ref1
p074gp35	p096gp57	p119gp78	q017gp11	q040gp02	q062gp24	q085gp46
p074ref1	p096ref1	p119ref1	q017ref1	q040ref1	q062ref1	q085ref1
p075gp36	p097gp58	p120gp79	q018gp12	q041gp03	q064gp25	q086gp47
p075ref1	p097ref1	p120ref1	q018ref1	q041ref1	q064ref1	q086ref1
p076gp37	p098gp59	p121gp80	q019gp13	q042gp04	q065gp26	q087gp48
p076ref1	p098ref1	p121ref1	q019ref1	q042ref1	q065ref1	q087ref1
p077gp38	p099gp60	p122gp81	q020gp14	q043gp05	q066gp27	q088gp49
p077ref1	p099ref1	p122ref1	q020ref1	q043ref1	q066ref1	q088ref1
p078gp39	p100gp61	p123gp82	q021gp15	q044gp06	q067gp28	q089gp50
p078ref1	p100ref1	p123ref1	q021ref1	q044ref1	q067ref1	q089ref1
p079gp40	p101gp61	p124gp83	q022gp16	q045gp07	q068gp29	q090gp51
p079ref1	p101ref1	p124ref1	q022ref1	q045ref1	q068ref1	q090ref1
p080gp41	p102gp62	p125gp84	q023gp17	q046gp08	q069gp30	q091gp52
p080ref1	p102ref1	p125ref1	q023ref1	q046ref1	q069ref1	q091ref1
p081gp42	p103gp63	p126gp85	q025gp18	q047gp09	q070gp31	q092gp53
p081ref1	p103ref1	p126ref1	q025ref1	q047ref1	q070ref1	q092ref1
p082gp43	p104gp64	p127gp86	q026gp19	q048gp10	q071gp32	q093gp54
p082ref1	p104ref1	p127ref1	q026ref1	q048ref1	q071ref1	q093ref1
p083gp44	p105gp65	p128gp87	q027gp20	q049gp11	q072gp33	q094gp55
p083ref1	p105ref1	p128ref1	q027ref1	q049ref1	q072ref1	q094ref1
p084gp45	p106gp66	p129gp88	q028gp21	q050gp12	q073gp34	q095gp56
p084ref1	p106ref1	p129ref1	q028ref1	q050ref1	q073ref1	q095ref1
p085gp46	p107gp67	p130gp89	q029gp22	q051gp13	q074gp35	q096gp57
p085ref1	p107ref1	p130ref1	q029ref1	q051ref1	q074ref1	q096ref1
p086gp47	p108gp68	p131gp90	q030gp23	q052gp14	q075gp36	q097gp58
p086ref1	p108ref1	p131ref1	q030ref1	q052ref1	q075ref1	q097ref1
p087gp48	p109gp69	q008gp02	q031gp24	q053gp15	q076gp37	q098gp59
p087ref1	p109ref1	q008ref1	q031ref1	q053ref1	q076ref1	q098ref1
p088gp49	p110gp70	q009gp03	q032gp25	q054gp16	q077gp38	q099gp60
p088ref1	p110ref1	q009ref1	q032ref1	q054ref1	q077ref1	q099ref1
p089gp50	p111gp71	q010gp04	q033gp26	q055gp17	q078gp39	q101gp61

Table 6-42. Continued

Ground Plane Characterization Data (continued)	
q101ref1	q124ref1
q102gp62	q125gp84
q102ref1	q125ref1
q103gp63	q126gp85
q103ref1	q126ref1
q104gp64	q127gp86
q104ref1	q127ref1
q105gp65	q128gp87
q105ref1	q128ref1
q106gp66	q129gp88
q106ref1	q129ref1
q107gp67	q130gp89
q107ref1	q130ref1
q108gp68	q131gp90
q108ref1	q131ref1
q109gp69	w070ref1
q109ref1	w071ref1
q110gp70	w072ref1
q110ref1	w073ref1
q111gp71	w074ref1
q111ref1	w075ref1
q112gp72	w076ref1
q112ref1	w077ref1
q113gp73	w078ref1
q113ref1	w079ref1
q114gp74	w080ref1
q114ref1	w081ref1
q115gp75	w082ref1
q115ref1	w083ref1
q116gp76	w084ref1
q116ref1	w085ref1
q117gp77	w086ref1
q117ref1	w087ref1
q119gp78	w088ref1
q119ref1	w089ref1
q120gp79	w090ref1
q120ref1	w091ref1
q121gp80	w092ref1
q121ref1	w093ref1
q122gp81	w094ref1
q122ref1	w095ref1
q123gp82	w096ref1
q123ref1	w097ref1
q124gp83	w098ref1

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Appendix A

NASA FBL / PBW Program NASA Boeing 757 HIRF TEST PLAN Low Power On-the-Ground Tests

10/7/94

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1.0 Acknowledgments

This test plan was developed by the Lawrence Livermore National Laboratory (LLNL) in support of NASA's Fly-by-Light / Power-by-Wire program. The NASA Langley Research Center (LaRC) has responsibility for the HIRF effects and assessment methodology portions of the program. LLNL is tasked with developing modeling and analysis tools as well as with directing the aircraft tests to validate these tools. This test plan was written with input from Felix Pitts, K. Peter Zaepfel, Peter Padilla, and Charles Meissner of LaRC. Buddy Walton and Ly Dao of the USAF Phillips Laboratory and John Millard of United International Engineering, Inc. also provided valuable input. This plan also borrows heavily from a test plan written by Howard LaValley of UIE.

2.0 Introduction

The NASA Fly-by-Light / Power-by-Wire (FBL/PBW) program was initiated to develop technology for a future generation of commercial transport aircraft. Studies have shown that an all-electric aircraft (PBW) could have substantial benefits in terms of weight and maintenance costs over today's aircraft that rely on hydraulic and pneumatic controls. However, one major concern regarding the all-electric aircraft is the potential for conducted and radiated electromagnetic susceptibility of its electronic controls. A way to potentially alleviate this problem (and save weight at the same time) is to route all control and signal information over optical fiber control links (FBL) that are inherently easier to harden against the electromagnetic environment (EME).

Since electro-optic devices and electronic digital computers will still be required, a major objective of the FBL/PBW program is to develop tools and techniques for assessing the survivability of the modern aircraft using such equipment in the electromagnetic environment. The EME includes both externally generated high intensity radiated fields (HIRF) and internally-generated radiated or conducted emissions. The ability to withstand internally-generated emissions is often referred to as electromagnetic compatibility (EMC).

The EME effects assessment tools and techniques developed under the program must ultimately be accepted by industry and the FAA regulatory body to be useful. Therefore, an important aspect of the program is that these tools and techniques must be validated to the satisfaction of this community. A series of aircraft tests are being planned for this purpose. Specifically, low power on-the-ground tests and fly-by tests will be conducted. This test plan describes, in detail, the on-the-ground tests which include those used for generating data for code validation as well as those which support the study of the stirred frequency technique. The test plan for the fly-by tests will be provided in a subsequent document.

3.0 Background

Full-threat tests of each make, model, and modification of each aircraft type would be far too expensive for the commercial aircraft community. Less expensive assessment methods usually rely on an EM stress-vs.-strength approach. In these methods, the EM stress that is applied to a component or subsystem is compared against the EM strength of the component or subsystem. The stress is measured as the current, voltage, power, or field that is received by or impressed upon an installed component or subsystem when the aircraft is exposed to the EME. The strength is the level of signal, expressed in the same units, the component or subsystem can withstand without upset or damage. There are several advantages to separating stress and strength. First, separating the stress estimate from the strength estimate allows the use of computer models, low power measurements, and/or similarity to estimate stress. These methods are much less expensive since they do not require the entire aircraft to be tested at full power. The strength can be measured

with direct injection or radiation tests that involve only individual components or subsystems. Such tests inherently require less power and space to test than would full aircraft tests. This separation would allow the avionics manufacturers to test their boxes (strength tests) and the airframe manufacturers to test or analyze their airframes (stress tests) separately at reduced cost.

4.0 Test Program Objectives

The primary thrust of this aircraft test program is to develop a library or database of experimental results to be used in the evaluation of modeling codes. A second objective is to support the development of other assessment techniques such as mode-stirred chamber measurements. To support these objectives, it is also necessary to quantify measurement errors and to perform sensitivity studies to allow an estimation of the degree of agreement between measurement and model results that can reasonably be expected.

The data library will necessarily be limited in size and scope by cost and time constraints but will nonetheless provide a reasonable database for validation exercises involving computer codes that can be used for EME modeling activities. Here, the term validation is used to denote the determination whether a particular code is capable of producing accurate results for specific modeling tests in which it has been applied. Clearly, this will "validate" the physics kernel of the code, its numerical algorithms, and its overall ability to provide the "right" answer. Of possibly equal importance, the data might help to establish the limits of applicability of a code, the validity of approximations and extensions which can enlarge its applicability, and the resources such as computer time and memory required to attain various levels of accuracy.

A primary focus in this test plan is the validation of FDTD modeling of coupling into the airframe using a code such as TSAR. It will be tested extensively in its "intended" range where approximations other than discretization are not required (up to a few hundred MHz) as well as in the range where approximations and special algorithms will be required to estimate stress. While a description of the approximations used to extend the domain of applicability of the code is beyond the scope of this plan, adequate attention has been paid to collecting appropriate data to allow for its use in future validation activities.

In many cases deterministic models are insufficient to predict the stress within an airframe. Statistical approaches to this problem are being considered at several institutions, and theoretical and experimental foundations are being developed. LLNL has been studying statistical electromagnetics and experimental techniques based on mode stirred chambers. At frequencies where the airframe is many wavelengths, the aircraft interior can be modeled as a complex highly-overmoded cavity having random internal fields. It is hypothesized that the power at a randomly selected point has a statistical distribution that is independent of the details of the shape of the cavity. If this assertion is validated, it may be possible to use a similarity concept to characterize the stress applied to the line replaceable units (LRUs) within the aircraft. That is, once the parameters of the distribution are known, the LRUs environment is statistically determined. Airframe testing or analysis would be required only to determine the parameters of the distribution of coupling into the airframe. The statistical distribution and its parameters would not be expected to change with modifications of the avionics or other changes inside the complex airframe cavity. LRUs could be tested in a mode-stirred chamber that develops an internal EME having the same statistical distribution. Validating these concepts is another test objective.

It can be expected that a comparison of the results generated by measurements and computer analysis will not result in perfect agreement. The experimental and analytical or computational modeling approaches each have their own uncertainties and sources of error so that neither can be assumed to be the "standard" against which all other results must be evaluated. There are numerous sources of systematic and random measurement error and modeling error. The measurement sample size will be insufficient to eliminate the random errors, and some amount of

systematic errors will always exist in the measurements. Also, there will always be some amount of modeling error in the model. The intent here is to maintain an appreciation of these errors and to perform a comparison in the light of the fact that measurement and analysis may provide equally valid results given the errors associated with each process. So, in order to quantify some of the larger of these errors, a series of tests will be made. These tests will allow us to establish reasonable error bounds about the measurement and computer model predictions for use during our comparisons.

5.0 Test Aircraft

The primary test object is the NASA/Eastern (Boeing) 757-200. The onboard certificate identifies the aircraft as a Boeing 757-225, Serial Number 22191 with the 225 denoting the specific configuration requested by the original sole owner (Eastern Airlines). In the following, this aircraft is referred to as the B-757, NASA B-757, NASA 757, etc., for convenience.

6.0 Program Test Sequence

Aircraft flight tests are required to convince the community of the validity of effects assessment techniques for in-flight aircraft. However, such tests are difficult and expensive. Orientation and position parameters and incident field values are difficult to control or measure accurately in such a test. A series of on-the-ground tests to validate both modeling and mode-stirred measurement techniques under well-controlled conditions will precede the flight tests to provide data under better controlled conditions and to reduce the risks associated with the flight tests.

This test sequence is not being planned to certify the safety of an aircraft. Rather, it is being planned to validate tools and techniques for assessment. Hence, the test plan will have a somewhat different emphasis than a certification test would have. Here, it will not be necessary to measure or predict EM effects on each critical subsystem nor is it necessary to measure coupling into every section of the aircraft that contains critical equipment. A few representative subsystems in a few aircraft sections will suffice.

In the next section of this test plan, we concentrate on the first validation step, the low level on-the-ground measurements. The fly-by tests will be the subject of another test plan. Suffice it to say, the fly-by tests will include measurements associated with radiation from a UHF radar at Wallops Island, an antenna driven by a VHF source, and a VOA station in Greenville, NC. The on-the-ground tests have elements which are in preparation for the fly-by tests.

7.0 Low-Power On-the-Ground Tests

The low-power on-the-ground tests encompass a series of tests which are meant to achieve a set of objectives defined in Sect 7.1. The tests have been arranged to enable execution of the tests in priority order and the rationale will become clear during the course of this plan. An attempt was made to construct a plan paying due attention to the limited aircraft availability time, the need for maximizing data acquisition time, the requirements for system dry-runs, and the existence of priority in the test series. In light of such considerations, the following represents a test plan satisfying significant constraints yet striving for maximum value. It has been constructed using reasonably conservative time estimates, some slack time, and a prioritization that permits inclusion and exclusion of tests as time permits.

7.1 On-the-Ground Test Objectives

There are four objectives and four test series for the on-the-ground tests. The first test series will meet the first objective which is to generate data to be used directly for coupling code validation. For this objective, discrepancies and uncertainties between measurement and model must be minimized. These tests will use dipole antennas, so the antenna can be included in the model. This eliminates the uncertainty in the exact form of the wave entering the model problem space. The second test series will meet the second test objective for the on-the-ground tests which is to exercise the equipment that will be used for the fly-by tests. For these tests, the test signals should match those planned for the fly-by tests. Thus, rather than stepped CW measurements, these tests will be conducted with fixed-frequency CW or pulsed waveforms. The exact polarizations and orientations are not required. Only test points planned for the fly-by tests need be examined. The third test series will meet the third objective for the on-the-ground tests which is to prepare for the fly-by tests, as well as to provide more data for validation of the codes (objective one). We wish to know the coupling into the airframe so that any high-Q coupling resonances near the fly-by frequencies can be taken into account as well as the sensitivity of coupling to uncertainties in aspect angle or the position of interior objects. The fourth test series will involve a continuing study of stirred frequency techniques.

7.2 On-the-Ground Test Facility

These tests will be conducted at the US Air Force Phillips Laboratory (PL) Large Electromagnetic System-Level Illuminator (LESLI) test facility. The LESLI facility is operated and maintained by the PL/WSM. This facility consists of a concrete pad, a two-wire rhombic antenna, and an instrumentation trailer. Time has been allocated for assembly and checkout of the data acquisition system and for a dry-run of the complete experimental system.

In the preparation of this test plan, an attempt has been made to minimize time-consuming aircraft operations such as repositioning of the aircraft on the pad. For example, as presently configured, this plan requires initial placement of the NASA B-757 at nose-on incidence in the LESLI, i.e., an orientation of the aircraft with its axis parallel to the LESLI axis. Following the tests in this orientation, tests will be executed at 10° and at angles less than 10° , if called for, and finally at broadside (90° from nose-on).

The standard LESLI facility instrumentation will be used. This instrumentation is referred to as the CWDAS. The second test series will employ the LESLI rhombic antenna. PL will supply CW RF amplifiers which are part of the normal LESLI instrumentation while LLNL will supply a source capable of low power pulsed operation such as the HP 8360. The third test series will employ the LESLI rhombic antenna and its standard transmitters and instrumentation.

7.3 On-the-Ground Test Organizations and Responsibilities

7.3.1 Test Organization

The test support comes from many organizations. The NASA Langley Research Center (LaRC) is the funding organization for these tests. LaRC developed the on-board instrumentation. The Lawrence Livermore National Laboratory has responsibility for test planning and managing test execution. The Air Force Phillips Laboratory (PL) is located at Kirtland Air Force Base (KAFB). Emergency services, e.g., hospital, ambulance, and fire protection, are provided by the 377th Air Base Wing (377 ABW), KAFB. The Advanced Weapons and Survivability Directorate (PL/WS) within the PL is responsible for the LESLI facility. United International Engineering, Inc. (UIE) is a PL support contractor. The roles of each of these organizations is detailed below.

7.3.1.1 Air Force - 377th Air Base Wing - Emergency and Security Services

Air Force - 377th Air Base Wing will provide as required:

- (a) hospital
- (b) ambulance
- (c) security
- (d) fire protection (a 150 lb power bottle aviation-type fire extinguisher on the pad satisfies NASA safety requirements in this regard)

7.3.1.2 Lawrence Livermore National Laboratory : Experimenter

LLNL is responsible for the following tasks:

- (a) Defining test points, test sequence, test priorities
- (b) Defining sensor types
- (c) Defining test orientations, configurations and test frequencies
- (d) Final data analysis
- (e) Analytical predictions to compare to test results
- (f) Final data preparation before introduction into a test data library
- (g) Provide calibration factors for field (D dot) and voltage sensors used in the tests
- (h) Provide pulsed RF source

7.3.1.3 NASA Langley Research Center: Program Manager

NASA has the following responsibilities:

- (a) Provide the aircraft
- (b) Provide required aircraft safety / quality control personnel to assure that the aircraft flight worthiness has not been compromised by the tests
- (c) Provide a qualified ground crew who can power up aircraft systems, tow the aircraft to the required positions (or who can direct the PL/UIE aircraft ground crew to do this), etc. A 1/2 day notice will be provided to PL/UIE when towing is required.
- (d) Provide on-board instrumentation responsive to experiment needs
- (e) Provide personnel, as required, for set-up/operation of on-board instrumentation
- (f) Provide calibration data for the installed coaxial cables and VHF antenna

7.3.1.4 Air Force Phillips Laboratory/WSM: Test Facility

PL/WSM, in conjunction with UIE, will provide the following:

- (a) Provide and configure the LESLI test facility with rhombic antenna and calibrated instrumentation
- (b) Provide an aircraft tug and driver to install the aircraft into the LESLI facility
- (c) Provide instrumentation personnel
- (d) Provide safety assurance personnel, as required
- (e) Provide data processing support for quick-look processed data during testing
- (f) Calibrate current probes (current probes will be provided by NASA)
- (g) Provide data Quality Control (QC) personnel to review the test data.

7.3.2 Functional Responsibilities

The functional organization is shown in Figure 7.3-1.

Figure 7.3-1. Functional organization.

7.3.2.1 Experiment Test Director (LLNL)

The Experiment Test Director will be Dr. Andrew Poggio. During testing, the LLNL Experiment Test Director, assisted by the PL Facility Test Director, will perform the test control function and will determine the experiment test sequence.

7.3.2.2 Facility Test Director (PL/WSM)

The PL Facility Test Director, Mr. Ly Dao, is responsible for the implementation of the approved test plan and test safety plan. The responsibility of Facility Director will encompass coordination of all activities required to acquire data, including aircraft/instrumentation readiness, data acquisition system readiness, and coordination of CW sweep initiation.

7.3.2.3 LESLI Facility Operations, Test Operations, and Support (PL/WSM supported by UIE)

Facility Operations is responsible for simulator facility support, including facility operations, data acquisition system integration and check-out, instrumentation characterization, data acquisition system operation, and data translation. Test Support is responsible for fiber optic instrumentation installation and quick-look data analysis.

7.3.2.4 Data Processing Support (PL/WSM supported by UIE)

CW data will be uploaded to the LESLI processing PC where it will be corrected for instrumentation effects. Accepted data will be written to standard tapes for delivery to LLNL and the data will be archived in the PCSLEET database.

7.3.2.5 Aircraft Operations (NASA LaRC)

NASA LaRC is responsible for movement, operations, and maintenance of the NASA aircraft. PL/UIE will support these activities during the tests. PL/UIE will also move the aircraft under NASA direction and provide other test support, as required.

7.3.2.6 Test Operations Working Group (All)

The Test Operations Working Group (TOWG), comprised of representatives from each organization, will meet daily during the test to insure test activity integration. Potential problems will be identified and an action item assigned for timely resolution.

7.4 Ground Plane

The concrete surface forming the pad in the LESLI facility will be used in an unaltered state as the ground surface. The aircraft will be positioned on this surface for the experiments. The LESLI is shown with and without the airplane in the scale drawings in Figures 7.4-1 through 7.4-4. The coordinate system for the ground plane is shown in Figure 7.4-1. The origin (0,0,0) is located at the rhombic feedpoint. This right-handed coordinate system, denoted $\underline{x}$, $\underline{y}$, $\underline{z}$, is distinct from the coordinate system used for the interior of the aircraft that is fixed to the aircraft.

Figure 7.4-1. LESLI Facility with rhombic antenna and ground plane coordinate system

Figure 7.4-2. LESLI with B 757 nose-on incidence

Figure 7.4-3 LESLI with B 757 broadside incidence

Figure 7.4-4 Side view of LESLI with B 757

7.5 Sensors

The sensors for the on-the-ground tests will be fitted into the aircraft prior to its arrival at Kirtland. Some of the sensors will be removed for the flight to Kirtland, and installed for the tests. The suite of 12 sensors will sample fields and cable currents and voltages in three aircraft bays: the cockpit, the electronics bay, and the cabin. Figures 7.5-1, 7.5-2, and 7.5-3 show sensor locations.

There will be five sensors in the cockpit. All of these sensors will be mounted onto the same sensor box that will be fabricated by NASA LaRC. This box is also referred to as the ATOPS box. The box contains three orthogonal Prodyne AD-60 D-dot sensors and a wire that extends through the box on which a voltage measurement is made within the box. Thus there are four connectors on the box. In addition, a Prodyne I-320 current probe will be used on the bare wire just outside of the box.

The electronics bay will contain three sensors. A Prodyne AD-60 will be used to measure fields within the bay. A Prodyne I-320 current probe will be placed onto an existing aircraft line for the windshield heater within the bay. The third measurement in the electronics bay will be made on a Collins VHF-700 transceiver box. In the remainder of this plan, this unit will often be referred to as the RC-7 box or unit. The unit will have been previously modified to provide a probe to measure the voltage on an internal power line pin. The unit will be installed into an existing slot in the electronics rack in the electronics bay after the aircraft arrives at Kirtland. The box will thus be connected to the avionics bus for low RF power stepped frequency tests. The box will be installed after the aircraft is positioned for tests. The box will be removed for the on-board instrumentation tests where aircraft power would be applied and then reinstalled for later power-off tests. (See 7.8.1).

There will be four sensors in the cabin area. One of these will be an AD-60 D-dot mounted on top of the EME instrumentation rack. The second sensor will be a long-wire mounted along the ceiling of the cabin. This long wire will allow the measurement of small-signal low-frequency coupling. The long wire will terminate into a 50 ohm cable across which voltage will be measured. A current sensor will also be installed onto the semi-rigid coaxial cable feeding the long wire to sense external shield current. The fourth cabin sensor will be the VHF-L (left) antenna which is part of the normal complement of external antennas for the NASA aircraft. This antenna will provide a measurement of the external field (perturbed by the aircraft) and will provide a strong signal to be used as a trigger for the fly-by tests.

LaRC will provide cables from each sensor that will mate to either the on-board instrumentation or will mate to fiber optic transmitters for the swept frequency measurements.

Ch.#	Probe	Parameter	Location	Fly-by channel?
T1C1	AD-60	Ex Field	ATOPS box	N
T1C2	AD-60	Ey Field	ATOPS box	N
T1C3	AD-60	Ez Field	ATOPS box	Y
T1C4	I-320	Current	ATOPS box	N
T2C1	Wire	Voltage	ATOPS box	N

Figure 7.5-1. Cockpit sensors.

Ch. #	Probe	Parameter	Location	Fly-by channel?
T2C2	AD-60	E Field	Elect. bay	Y
T2C3	I-320	Current	Existing wire	Y
T2C4	50 ohm	Voltage	RC-7 Tcwr	N

Figure 7.5-2. Electronics bay sensors

Ch. #	Probe	Parameter	Location	Fly-by channel?
T3C1	Ext. Ant.	Ext. Field	Fuselage	Y
T3C2	AD-60	Field	Equip rack	Y
T3C3	Long Wire	Voltage	Ceiling	Y
T3C4	I-320	Current	Long wire	Y

Figure 7.5-3. Cabin sensors.

7.6 Pretest Procedures

7.6.1 Characterization and Checkout

7.6.1.1 Probe Characterization. Characterizations of the field mapping probes and current probes will be performed by the PL LESLI Facility Operation and Support Group prior to the start of the test. Probe characterizations shall be performed following the Continuous Wave Data Acquisition System (CWDAS) User's Guide. Figures 7.6-1 and 7.6-2 show the configurations used for the cable/attenuator/splitter, and current probe characterization. Current probes and cables will be characterized over the allowable CW logarithmic sweep frequencies in the 300KHz to 1 GHz band as listed in the CWDAS User's Guide using Q's developed for the LESLI Field Map Testing. These data points will match those used for the rhombic antenna sweeps described in Section 7.9. For the narrowband sweeps using the dipole (described in Section 7.7) or narrowband rhombic sweeps, calibration data will be acquired in the same manner. Sensor characteristics will be provided by NASA/LLNL while calibration data for the cables installed aboard the aircraft will be provided by NASA.

7.6.1.2 Coaxial Instrumentation Cable Check-out. All external cables will be characterized using CWDAS by the Facility Support Group. Four sets of data characterizations will be done for each of the experiments described above. The data will be recorded in Toolkit format on PC-readable floppy disks and uploaded to the LESLI processing PC running MatLab. Cables will be visually inspected during the test. When acquired data are questionable, a cable characterization may be repeated as requested by the Test Director.

7.6.1.3 Link Characterization. Fiber optic data links will be characterized using CWDAS by Facility Support Group. The data will be uploaded to the LESLI processing PC running MatLab. The test setup used to characterize the fiber optic data links is shown in Figure 7.6-3. The links shall be characterized over a frequency range of 300 KHz through 1 GHz.

7.6.1.4 Dry Runs. A series of dry runs will be executed to provide assurance that all elements of the experiment system are functioning properly. The dry runs will involve use of all available RF sources and amps, all antenna (illuminator) systems, selected sensors, and the data acquisition system that includes the instrumentation, computer control, acquisition and display functions. In effect, these runs will be "full-up" except for the presence of the NASA aircraft. It will test both the systems and the operational procedures in effect during the tests.

7.6.1.5 FAA Compatibility Tests Prior to the arrival of the aircraft, compatibility tests will be conducted to assure that the tests involving new frequency and antenna configurations cause no interference with operation of the FAA control tower. These tests will include all stepped frequency dipole test configurations (see Section 7.7) and all fixed CW and pulsed CW configurations (see Section 7.8). Power levels expected during the test sequences will be used.

Figure 7.6-1. Cable / attenuator / splitter characterization test setup.

Figure 7.6-2. Probe characterization test setup.

Figure 7.6-3. Fiber link characterization test setup.

7.6.2 Field Mapping

7.6.2. Rhombic Antenna

Prior to making swept CW measurements with the Rhombic antenna, field mapping measurements will be made to provide a baseline of the incident field wavefront. It is prohibitively expensive to make sufficient measurements to completely determine field components throughout the entire volume or over the closed surface of any computational volume for the numerical models which might be employed. (This is the primary reason for the dipole experiments described in Section 7.7.)

A model for the rhombic antenna exists that will relate the voltage incident to the antenna to the field at any point in space under the antenna. If this model were completely accurate and validated, no field mapping would be necessary. Since this is not the case, we must make measurements to validate it. However, we can use the model to greatly reduce the number of field map measurements required. Our plan is to make a few measurements to recalibrate the model, and then use the model to define the incident fields in the computer coupling models.

The field map locations are described in Table 7.6-1. Field measurements will be made in each of three orthogonal directions at each test point. B-field measurements will be made at each point and E- (or D-) field measurements will be made at select points. These are denoted E&H in the table. Measurements will be made over the entire 300 KHz to 1 GHz band. The frequency sample spacing will be adjusted to match that of the stepped CW measurements described in Section 7.9.

In Table 7.6-1, the coordinates are defined with the x axis along the center line of the rhombic illuminator, the y axis orthogonal to the ground plane in the vertical direction, and the z axis orthogonal to the y - z plane and parallel to the ground plane. The origin is at the feed point and the system is right-handed. This coordinate system is shown in Figure 7.4-1.

Table 7.6-1. Rhombic Field Map Locations.

x (meters)	y (meters)	z (meters)
40	1	0
40	3	0
40	3	2
40	3	8
40	3	15
40	5	-2
40 E&H	5	0
40	5	2
40 E&H	5	5
40	5	8
40 E&H	5	10
40	5	12
40	5	15
50	3	0
50	3	5

7.6.2.2 Dipole Antennas

Dipole antennas will also be used in certain tests. While these are to be included in the modeling volume and should, in principle, not require field mapping, it has been considered advisable to perform a limited mapping exercise. To this end, the dipole fields will be mapped as described in Table 7.6-2 with the field at each point measured for the three orthogonal directions. In some cases denoted by E&H, both the E- and H- field will be measured. The coordinate system for these maps is indicated in Figure 7.6-4. The frequencies in the table define the approximate center frequency of a range of frequencies that is defined in the test matrices for the dipole tests. These frequency ranges will be extended above and below the center frequencies by an amount that will allow the structure of the spectrum in that vicinity to be investigated. The range may be limited by self-protection devices in the amplifiers which protect against high VSWRs at the transmitter output.

H Pol and V Pol refer to horizontal and vertical polarization, respectively, for the dipoles. For convenience, both orientations are shown in Figure 7.6-4. The height of the dipole feed point in the mapping exercises is 3 meters except for vertical polarization near 25 MHz when it is 4 meters.

The coordinates in the table are relative to a point on the pad directly below the feed point of the dipoles. This point will be identical to that used during the dipole test sequence.

Original plans included use of a highly conducting plane composed of interlocked aircraft landing mats. Unavailability has required use of the concrete pad in an unaltered state. Hence, it will be necessary to characterize the pad from an electromagnetic standpoint. This will be performed after the NASA 757 test series is complete and will be the subject of another test plan.

Figure 7.6-4 Dipole Field Mapping Coordinate System

Table 7.6-2. Dipole Field Map Locations.

freq(MHz)	pol	x (meters)	y (meters)	z (meters)	
25	V	2	4	0	E&H
25	V	8	4	0	
25	V	8	2	0	
25	H	2	3	0	E&H
25	H	8	3	0	
25	H	8	2	0	
172	V	2	3	0	E&H
172	V	8	3	0	
172	V	8	2	0	
172	H	2	3	0	E&H
172	H	8	3	0	
172	H	8	2	0	
430	V	2	3	0	E&H
430	V	8	3	0	
430	V	8	2	0	
430	H	2	3	0	E&H
430	H	8	3	0	
430	H	8	2	0	
25	H	8	3	6	
25	H	8	3	-6	
172	H	8	3	6	
172	H	8	3	-6	
430	H	8	3	6	
430	H	8	3	-6	

7.6.3 Aircraft Pretest Activities

Before the aircraft arrives at KAFB, NASA LaRC will have installed some test probes and will have marked them with identification tags. Once the aircraft is positioned for the first test series, additional probes (including the RC-7 unit) will be installed by LaRC personnel. Not all probes are used for all test series. The sensors will remain installed in the same position for all test series, with a few exceptions which are noted in the test matrix.

The NASA aircraft will arrive at Kirtland AFB on September 18, 1994. The following paragraphs detail the expected pre-test activities.

7.6.3.1 Initial Aircraft Positioning. The aircraft will be towed from the runway to the LESLI facility and positioned under the antenna. The aircraft will be positioned appropriate for a test using the LESLI antenna with the aircraft cockpit facing the incident wave. However, at this time the LESLI two wire antenna will have been removed. NASA LaRC will be responsible for moving and repositioning the aircraft with support from PL/UIE Aircraft Operations. LLNL will provide additional support for aircraft alignment. Facility Support will provide the required aircraft grounding equipment which will be installed during down times and after-hours only, not during the tests. The aircraft will remain in place through the dipole tests, unless otherwise directed by NASA LaRC.

7.7 Stepped CW Measurements: CWDAS with Dipole Antennas

7.7.1 Probe Installation

Two 300 KHz to 1 GHz Nanofast fiber optic data links will be employed for acquiring data from probes mounted in the aircraft.. Each link can support four inputs. Upon placement of fiber cables, the aircraft may be inspected by NASA and Aircraft Operations to ensure that all installations are done according to previously approved test modification packages and that the aircraft integrity has not been compromised.

7.7.2 Dipole Antennas

Dipole antennas will be used for these test series. The antennas will be simple thin-cylinder or thin-wire antennas mounted parallel to both the aircraft fuselage axis and ground for horizontal polarization or mounted perpendicular to the ground for vertical polarization. The geometrical arrangement is shown in Figure 7.7-1 with all coordinates in meters and the origin on the ground directly below the nose of the aircraft, as shown. The dipole source (its center) is located at (-4, 3, -5) for all frequencies except for the vertical polarization test near 25.85 MHz when the center is raised to (-4, 4, -5). A reference probe (B dot sensor) is used in the measurements and is located 3.5 meters from the dipole source for all frequencies except for the measurements near 25.85 MHz when the sensor is 5 meters from the dipole source. The coordinates are (-1.525, 3, -7.475) and (-0.465, 3, -8.535), respectively. Details for the emplacement are found in Figure 7.7-1.

These thin-wire dipole antennas are not expected to have ultra-wide bandwidths. Thus, separate antennas will be required for each of the three fly-by frequencies. These frequencies are set at 25.850 MHz, 172.0 MHz, and 430 MHz. The aircraft will be illuminated with both vertical and horizontal polarization using dipoles for both polarizations. The dipoles will be cut to half-wavelength resonance near each fly-by frequency. Stepped frequency measurements will be made over a band extending from 80% to 120% of each center frequency or as permitted by equipment VSWR restrictions. The starting frequency, frequency step size, and number of data points to be taken for each test series is shown in Table 7.7-1.

Figure 7.7-1. Dipole and reference probe locations for dipole tests

7.7.3 Dipole Test Operations

This section outlines the specific operations which will be employed for the dipole tests. A block diagram of the instrumentation used for the dipole tests is shown in Figure 7.7-2.

Figure 7.7-2. Dipole test instrumentation.

7.7.3.1 CW Procedures. The aircraft will be unpowered for these tests. The aircraft will be unmanned for this test series, although there is no RF hazard. The CW test points will be instrumented with the appropriate sensors as indicated on the detailed setup sheets. The probes will be connected to fiber optic transmitters; the outputs of the receivers will be connected to the network analyzer located in the source shack. On-board cables required to connect probes to the fiber transmitters will be supplied by LaRC. The network analyzers will be controlled by a control computer running the CWDAS software. CW sweeping will be accomplished using the FCC approved frequencies. Data acquisition (sweep) logs will be maintained by the Facility Operations Group.

Details of the data acquisition and processing to be accomplished are described in detail in the next subsection which also includes a detailed discussion of the acceptance criteria for data. Operationally, the Facility Test Director will follow the Test Point Matrix contained in this test plan and instrumentation setup sheets prepared by LLNL and Test Operations and Support. Facility Support will set up the appropriate DAS to acquire the requested test-points on any given sweep. When all are ready, the Facility Test Director will request that the sweep be initiated. The raw data

Figure 7.7-3. Example of CW data acquisition and processing flow.

will be displayed on the in-DAS monitors for immediate QC. After data acceptance based on the "immediate-QC", the data will be uploaded for further processing. Data that has gone through final processing as well as the raw data may be plotted and provided to the Test Directors. Data, including characterization/calibration files, will be provided to LLNL on floppy disks. Data will be downloaded and archived in PCSLEET.

The Test Operation and Support Group will inspect the installation of the probes, cables, and links each evening after the last test. These will be inspected to insure that they have been properly placed, that they match the required test points, and that the instrumentation log sheets are correct.

7.7.4 CWDAS Data Acquisition, Processing, and Analysis

7.7.4.1 CWDATA

The following sections describe the data acquisition, quality control and data processing procedures to be used for CW test data.

7.7.4.2 Acquisition

CW data acquisition will be accomplished using the CWDAS hardware and software configured in a two-network analyzer setup. The data flow is identical in all cases. Figure 7.7-3 shows the acquisition setup and data processing flow. Each test point will be connected to a recording channel on an HP 8753C Network Analyzer via a NanoFast fiber optic link. Test frequencies will be linearly spaced between skipbands but will have a logarithmic distribution over the broad frequency range and will use the start, stop, and frequency steps shown in Table 7.7-1. These may be modified by transmitter VSWR or FCC restrictions. Due to FCC restrictions, data will be acquired using the allowable transmit bands as listed in the CWDAS manual. Note that there are two skip bands in the 26 MHz dipole band, one skip band in the 172 MHz dipole band, and two skip bands in the 430 MHz dipole band. Once a sweep has been completed, the data will be reviewed on the screen of the controlling personal computer. Instrumentation changes will be made and the data retaken as necessary. The acceptance criteria for the in-DAS QC of the CW data are listed in Table 7.7-2. Once accepted, the data, which include the measured variable at each test point and each frequency point, will be saved to the hard drive in the personal computer. The data will be periodically, at the direction of the Test Director, translated into TSA format and uploaded to the processing PC.

Table 7.7-1. Frequency tables for Dipole Tests (MHz)

f(test)	f(start)	f(stop)	f(step)	# freq	frequency skip bands
25.085	23.00	28.00	.005	1001	24.99 to 25.10, 25.55 to 25.67
172.00	155.00	189.00	.034	1001	162.375 to 162.575
430.00	387.00	473.00	.086	1001	401.60 to 402.20, 406.00 to 406.10

Table 7.7-2. In-DAS QC criteria for CW data.

1. Sufficient attenuation/gain has been used to prevent an overload or noise floor corruption of the network analyzer.
2. The peak of the recorded waveform is greater than -10 dBm for full scale screen deflection.
3. All header data is the same as that recorded on the data setup sheets.

7.7.4.3 Processing in TSA

As part of the uploading process into TSA, the data will be processed as described in Table 7.7-3.

Table 7.7-3. TSA processing steps for CW data.

1. Correct the data for probe/link, etc., frequency dependent and linear scale factors and save it as a .COF file.
2. Plot the following for use by QC:
Raw frequency (.RAW)
Corrected frequency (.COF)

The plots indicated in Table 7.7-3 will be used as they are available by Test Support/QC to ensure the quality of the processed data. Data sets returned for reprocessing will be documented on a User Change Request (UCR). Each UCR will identify the test point, the shot number, and what specific reprocessing is requested. Upon completion of the correction, UCRs will be filed in the original data folders. The QC criteria for TSA processing are listed in Table 7.7-4.

Table 7.7-4. TSA QC criteria for CW data.

1. Probes/links/etc. have been properly unfolded from the data.
2. Final frequency dependent magnitude data look reasonable.

7.7.4.4 Processing in PCSLEET

Prior to the start of the test, all of the characterization files will be loaded onto the LESLI processing PC as well as loaded into PCSLEET. Field mapping and test data will be uploaded to the LESLI processing PC running MatLab for processing. Raw and processed data will be loaded into PCSLEET. During this process the header data and archive will be checked using the criteria listed in Table 7.7-5.

Table 7.7-5. PCSLEET Processing QC Criteria for CW Data

1. Header information is complete.
2. Only one data set is archived for each test point/test shot. (NOTE: Multiple sweeps may be taken at many test points. However, only one measurement will be archived for each test sweep.)

Note: Final data files will be immediately backed up by copying to an auxiliary storage medium such as copying to disk, the Boeing 720B database or PC disk.

7.7.5 Noise Measurements

The noise environment will be characterized in order to quantify measurement quality, dynamic range, and error bounds. During these experiments, noise sources will be defined as arising from two sources, namely, the ambient environment and instrumentation.

The ambient noise will be established soon after the NASA 757 is in position on the pad and will be used as the standard for the entire test program. For the purposes of characterizing the ambient

environment, four distinct measurements will be made. Using measurements made with two probes in the cockpit (vertical and transverse electric field probes), a cable current probe in the electronics bay, and an external VHF blade antenna on the airplane, a spectral map will be constructed of the noise environment.

Instrumentation noise for the dipole tests will be carried out for each specific frequency range and dipole polarization. The instrumentation noise measurements will be executed after each test sequence is performed. The strongest and weakest set of data in each sequence will be identified. Then, the corresponding probe will be removed, replaced by a matched load, and a data measurement sweep performed. The resulting data will provide an indication of the instrumentation noise at the lowest and highest gain settings for the data acquisition system.

7.7.6 Test Matrix for Dipole Tests

A detailed test matrix is presented in Appendix C. The dipole tests are series A through F. Tests are shown in prioritized order so that if insufficient time is allotted, the lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.8 Fixed CW and Pulsed Measurements with On-Board Instrumentation

This on-the-ground test series is intended to validate the instrumentation required for the fly-by tests. These tests would also allow a comparison between the power coupled to the aircraft interior both on and off the ground and would validate the modeling code's ability to predict this difference. In addition to determining whether the system can measure and record the RF signals, an equally important aspect of these tests is to determine whether the measurement system can measure the RF signals in the presence of noise generated by on board electronic systems.

These tests will be made with aircraft power supplied by the on-board auxiliary power unit (APU). If aircraft electronic systems can be powered (though not operating) when the aircraft is illuminated with RF, then all aircraft and experimental electronics systems will be powered to simulate the noise environment expected for the fly-by. If powering of the aircraft electronic systems (other than those associated with the power system) is not permissible, then the test series will necessarily proceed in two stages. Namely, with all electronic systems powered and no RF, the signals will be measured to provide an indication of the noise environment. Then, with all electronic systems off and RF on, the test series will be repeated. Clearly, this requires twice as many measurements as when allowed to have RF and all electronic systems powered simultaneously and somewhat compromises the test of the measurement system. The tests referred to in the preceding are denoted G, H, and I. Should a double set of runs be required, the noise background measurements will be referred to as G1, H1, and I1.

The aircraft will be manned by LaRC ground crew and experimental systems operator personnel and by LLNL personnel. No upsets are expected for any installed aircraft hardware. Section 7.12.3 and Appendix B deal with the RF levels expected to be encountered.

Since this is not a certification test, there will be no need to test a large number of frequencies. Three frequencies have been chosen to match those selected for the fly-by tests. The illumination will be provided by the two-wire rhombic antenna configured in its common-mode configuration for vertical polarization. A fixed-frequency CW RF source will drive the appropriate LESLI RF amplifier. The UHF source will also be operated in a pulsed mode to simulate the pulsed radar planned for the fly-by (Wallops Island ASRF Radar).

7.8.1 Sensors

The sensors for the on-the-ground on-board instrumentation check-out tests will be the same as those used for the fly-by tests. These are a subset of the sensors used for the on-the-ground tests described in Section 7.5. The suite of 7 sensors will consist of one in the cockpit, two in the electronics bay, and four in the cabin. The cockpit sensor will be the vertically polarized D-dot on the sensor box. The electronics bay sensors will consist of the D-dot and cable current probe. All four of the cabin probes described in Section 7.5 will be included in the fly-by sensor suite.

The modified Collins VHF-700 transceiver box (RC-7) within the electronics bay will be removed for these tests so that the unqualified box will not be on the aircraft bus when aircraft power is applied.

7.8.2 Test Instrumentation

The instrumentation for these tests will be quite different from the stepped frequency experiments. It consists of spectrum analyzers and oscilloscopes rather than a network analyzer. The instrumentation will be provided by NASA LaRC and will already be installed into the aircraft and checked out prior to the aircraft's arrival at PL. A block diagram of the instrumentation is shown in Figure 7.8-1.

7.8.2.1 RF Instrumentation

RF signals from antennas and sensors will be multiplexed to the RF instrumentation by switches. These switches will be computer controlled in order to select the proper antenna and sensor for each test. Amplitude or power measurements will be made in real time on each of two external or internal RF probe channels simultaneously. A 2-channel digitizing scope will be employed for absolute voltage measurements. A pair of spectrum analyzers will be used for power measurements.

Data acquisition and instrument control will be computer based. An automated system will be used to maximize data returned during the fly-by tests. There will be minimal operator intervention during simulated in-flight data collection; all sensors will be recorded within a few seconds.

7.8.3 Set Up

The aircraft will remain in the same location as for the previous set of dipole tests. The LESLI rhombic antenna will be installed for common mode, vertical polarization operation by Test Operations and Support. The source will be connected as shown in Figure 7.8-2.

Sensor cables will be disconnected from the fiber optic links by PL/UIE personnel and reconnected to the on-board instrumentation by LaRC or LLNL personnel once disconnected from the on-board FO transmitters.

7.8.4 On-Board Equipment Test Procedure

Aircraft power will be applied by the LaRC ground crew. The on-board instrumentation will be powered up by the LaRC experimental systems personnel. The aircraft will be manned during this test series. A block diagram of the on-board instrumentation set up is shown in Figure 7.8-1.

On-board personnel and transmitter source operators will be in communication via walkie talkies. Once the instrumentation has been determined to be operational, the on-board experiment director will request that RF power to the rhombic antenna be turned on. RF power will be applied for a period of 30 seconds, unless either the Experiment Test Director or Facility Test Director requests power to be shut off earlier. This time period is estimated as the dwell time at a particular frequency that is likely to be acceptable by the FAA. Earlier tests in the LESLI have always been

stepped and dwells at a frequency in the millisecond range have been acceptable. During this 30 second period, the automated on-board instrumentation will collect data. This procedure will be repeated until the instrumentation is operating satisfactorily

LaRC personnel will be responsible for archiving any data collected during the on-board experiments. LLNL, PL, and UIE personnel will assist as needed.

7.8.5 Test Matrix for On-Board Instrumentation Checkout

A detailed test matrix is presented in Appendix C. The on-board check-out test are series G through I. Tests are shown in prioritized order so that if insufficient time is allotted, the lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.9 Stepped CW Measurements: CWDAS with Rhombic Antenna

The instrumentation for this test series will be the same as described in Section 7.7, except that the rhombic antenna will be used instead of dipoles with a frequency range from 300 KHz to 1 GHz.

7.9.1 Set Up and Probe Installation

A block diagram of the stepped CW measurements made with CWDAS and the Rhombic antenna is shown in Figure 7.9-1.

Probes will be disconnected from the on-board instrumentation and reconnected to the fiber optic transmitters by Test Support and Operations.

7.9.2 Test Operations

The NASA aircraft will be pre-positioned for the start of these tests. During the test sequence, the aircraft will be moved up to four times. Repositioning of the aircraft will be accomplished by LaRC and Aircraft Operations personnel.

The PL/WSM LESLI Data Acquisition System (DAS)/CWDAS will be used to acquire CW data. Acquired data will be uploaded to the LESLI processing PC running MatLab for processing and distribution. Data will also be downloaded and archived into the PCSLEET data base.

The aircraft will be manned during portions of this test. There is no RF hazard to on-board personnel associated with these tests (see Sect. 7-11 and Appendix B). The antenna is the two-wire rhombic antenna described above.

The majority of the instrumentation resides in the Source Shack. The instrumentation will be controlled by a PC-based controller that resides in the LESLI DAS trailer. The LESLI DAS trailer is located off the side of the antenna. The Source Shack is located at the drive point of the antenna. With the exception of the NASA/LLNL provided probes, sensors, and cables, all of the required instrumentation will be provided by the Phillips Laboratory.

Figure 7.8-1. NASA B757 On-board instrumentation

SOURCE SHACK

Figure 7.8-2. Source set up for on-board instrumentation check-out.

Figure 7.9-1. CWDAS instrumentation for stepped CW measurements with the rhombic antenna.

7.9.3 CWDAS Data Acquisition, Processing, and Analysis

Data acquisition, processing, and analysis will follow the same procedures described in Section 7.7.

7.9.4 Instrumentation Noise Measurements for Stepped CW

Instrumentation noise measurements for stepped CW measurements in the rhombic will be performed at the beginning of the rhombic test sequence. In the nose-on configuration, each data channel will, in turn, be tested. The probe on each channel will be removed and replaced by a matched load. Then under RF illumination in the rhombic, a complete sweep will be executed and recorded for that channel. The complete set of data will include a complete sweep for each channel and will represent the characterization of the noise floor for the measurements to be executed.

7.9.5 Test Matrix for Stepped CW Measurements with Rhombic Antenna

A detailed test matrix is presented in Appendix C. The stepped frequency tests with the rhombic antenna are series J and K. Tests are shown in prioritized order so that if insufficient time is allotted, the lower priority tests can be dropped. Estimates of the duration of each test are also shown in Appendix C.

7.10 Stirred Frequency Tests

7.10.1 Background

As discussed in Section 4.0 it is hypothesized that the power density at a point in an aircraft cavity can have a statistical distribution that is dependent on the variation in excitation conditions (e.g., aspect angle) and the cavity losses. This hypothesis is based on the assumption the aircraft cavity is complex and large enough to be multimoded at the lowest frequency of interest. There is theoretical evidence that there exists statistical distribution function which describes the aircraft cavity electromagnetic environment (EME) for all possible excitation conditions and cavity configurations¹. The theoretical distribution function is independent of the details of the shape or size of the aircraft cavity, the location of cable bundles, and the location of metal boxes such as avionics systems. Except for a normalization factor to account for specific external to internal coupling efficiencies and aircraft cavity losses, normally characterized by the quality factor (Q), the statistical power density distribution is predicted to be independent of the particular cavity within the aircraft as well as the specific type of aircraft. These are very significant predictions which bear directly on how an aircraft's internal EME should be determined and how avionics systems should be tested.

The limited experimental data base currently available^{2,3,4} supports this hypothesis and agrees with the postulated theoretical distribution function.

¹ Lehman, T. H., Paper presented at the Anechoic Chamber and Reverberation Chamber Operators Group Meeting, NSWCDD, Dahlgren, VA, Nov. 1992.

² Hatfield, M.O., Freyer, G.J., Johnson, D.M., and Farthing, C.E., Electromagnetic Reverberation Characteristics of a Large Transport Aircraft, NSWCDD/TR-93/339, July 1994.

³ Hill, D.A., Crawford, M. L., Johnk, R. T., Ondrejka, A.R., and Camell, D.G., Measurements of Shielding Effectiveness and Cavity Characteristics of Airplanes, NISTIR 5023, July 1994.

⁴ Loughry, T. A., Hatfield, M.O., Freyer, G. J., Johnson, D. M., Ondrejka, A. R., and Johnk, R. T., Phase II Demonstration Test of the Electromagnetic Reverberation Characteristics of a Large Transport Aircraft, NSWCDD/TR, In Process.

This test will provide additional data from a current operational passenger-configured aircraft.

7.10.2 Specific Test Objectives

1. Determine the statistical characteristics of the B-757 cavity EME.
2. Determine the cavity Q by direct measurement of pulse decay time.
3. Determine cavity insertion loss.
4. Determine cavity-to-cavity coupling efficiency.

7.10.3 Approach

The characterization of cavity EME as described in this section will be performed with no power applied to any aircraft system. The test objectives will involve direct insertion of low power (< 1 watt) signals into the aircraft cavities. The signals will be inserted into an aircraft cavity using a wide band horn transmit (TX) antenna. The power density in the cavity will be monitored by a similar wide band receive (RX) antenna. To achieve the desired statistical distribution data, an effective technique for cavity mode-mixing is required. The most common approach to date has been to use a mode-mixing technique, band limited white Gaussian noise (BLWGN), has been developed at the USAF Phillips Laboratory. This technique has been compared with mechanical mode-mixing in standard reverberation chamber (or mode stirred chamber) test facilities⁵. A primary objective of the Phase II demonstration test on a B-707, performed in March 1994, was to compare the BLWGN technique with mechanical mode-mixing for characterization of aircraft cavity EME. The analysis of the test data is still in process, but to date no unexpected results have been found.

A specific advantage of using BLWGN over mechanical mode-mixing is a significant reduction in test time. The demonstrated reduction in data acquisition time in the B-707 Phase II test was approximately a factor of 4.0.

Figures 7.10-1 and 7.10-2 show the test instrumentation for characterizing the aircraft cavity EME using the BLWGN excitation technique. The control, stimulus, and measurement module, shown in Figure 7.10-1, contains the computer controller and plotter used to control the test equipment, acquire data and display data.

⁵ Crawford, M.L., Loughry, T.A., Hatfield, M.O., and Freyer, G.J., Validation of Band Limited, White Gaussian Noise Excitation of Reverberation Chambers and Verification of Applications to Radiated Susceptibility and Shielding Effectiveness Testing, NIST TR, In Process.

Figure 7.10-1. Control, stimulus and measurement module

Figure 7.10-2. Modulator, amplifier, and switching module

The sweeper generates the local oscillator signal which will cover the range 0.5 to 6 GHz for this test. The WGN source generates noise at the proper bandwidth (50 MHz for this test) as commanded by the computer.

For test objectives 1, 3, and 4 the function generator produces either a discrete frequency or a swept frequency continuous wave (CW) signal. The scalar analyzer is used to measure the signals from the RX antenna.

For test objective 2, the function generator produces a discrete frequency, repetitively pulsed signal. A wide range of pulse repetition rates are available within the capabilities of the instrumentation system. Based on previous aircraft test experience, a 1 KHz rep rate has been found to provide adequate accuracy and reasonable data acquisition times. A 1 KHz rep rate will be used in this test for direct measurements of all aircraft cavity Q values. The digitizing signal analyzer (DSA) is used to measure the pulse decay time of the signals from the RX antenna.

The modulator, amplifier and switching module, shown in Figure 7.10-2, performs the up-conversion and amplification of the noise to produce the BLWGN signal. Part of the BLWGN signal is sampled and diode detected to provide an external level reference signal for the sweeper in Figure 7.10-1. The external level reference ensures that the BLWGN signal at the TX antenna remains constant despite varying amplifier gain and cable losses. The power radiated into an aircraft cavity will be controlled to be 1 watt or less. The switch controller selects the appropriate modulator and amplifier combination for the frequency being generated.

The transmit antenna locations and orientations are selected such that they are directed toward appropriate metal reflecting surfaces (e.g., the pressure hull, compartment walls, etc.) in each aircraft cavity. In no case will the TX antenna be directed toward aircraft electronic systems. Two TX antenna locations are defined for the cockpit and passenger cabin. Due to space limitations only one TX antenna location is defined for the electronics bay. These locations are identified in Figure 7.10-3 and described in Table 7.10-1.

Table 7.10-1. Transmit Antenna Location, Orientation and Polarization

Num	Cavity	Location	Orientation	Polarization
#1	cockpit	3' forward of cabin door 3' above floor on aircraft center line	225° from nose 45° above horizontal	vertical
#2	cockpit	3' forward of cabin door	vertical	parallel to aircraft center line
#3	electronics bay	centered between electronics racks (approx. 52" from rear electronics rack), 12" above platform, 24" left of center line	270° from nose	horizontal
#4	cabin	on aisle seat approx. 12' forward of main cabin door	vertical	transverse to aircraft center line
#5	cabin	on aisle seat approx. 3' rear of main cabin door	45° off vertical	parallel to aircraft center line

Several RX antenna locations will be used in each aircraft cavity. The RX antenna is passive and does not present any hazard to on board electronics systems. The RX antenna will be placed to

obtain the desired aircraft cavity EM characteristics. The RX antenna will be located to avoid direct illumination by the TX antenna. A minimum of four RX antenna locations/orientations/polarizations will be sampled in each aircraft cavity. If test time permits, additional RX antenna locations/orientations/polarizations will be sampled in the cockpit and passenger cabin.

Coaxial cables will be attached to the TX and RX antenna feed points. These will be routed through the electronics bay or passenger cabin to the pressurization equalization port in the same manner as the sensor fiber optic cable for the primary test points. The coaxial cables installed for the cockpit ATOPS sensors will be used for the BLWGN TX and RX antennas.

Note that installation of all cables and placement of antennas will be coordinated with NASA aircraft operations personnel.

Sucoflex cable will be used from a point just inside the aircraft to the instrumentation cart located some distance from the aircraft. The Sucoflex cables have a highly attenuating cover which will minimize energy leakage into the aircraft. This approach will compensate for not using the standard isolating feed-throughs at the aircraft pressure hull.

The test matrix for the BLWGN excitation is given in Table C-22 in Appendix C.

7.10.4 Test Organization

The principal investigator on the BLWGN excitation test will be Capt. T. Loughry, PL/WSM. He will be assisted by SSgts. D. Little and C. VanZandt, also of PL/WSM. One or more of the following may also participate in this test: M. Hatfield, Naval Surface Warfare Center, Dahlgren Division; G. Freyer, Universal Systems, Inc.; and/or M. Johnson, Computer Science Corp. All of the above personnel have participated in at least one aircraft test using the BLWGN excitation technique.

All test instrumentation and data processing will be provided by Capt. Loughry. PL/WSM will designate a safety officer for the BLWGN test. All remaining organizational support function will be the same as on the primary test.

7.10.5 Pretest Procedures

Other than the aircraft survey which led to selection of the TX antenna locations, no special pretest activities are required.

The instrumentation, setup, and data acquisition and processing to be used for this test is the same as that employed on the recent B-707 test conducted by PL/WSM. All instrumentation and data acquisition software are available.

Calibration runs are performed on the "as installed" instrumentation, cables, and connectors.

7.10.6 Safety

During the BLWGN excitation test, all RF emissions will be within the aircraft and the aircraft will not be manned, therefore no test unique personnel safety hazards exist.

The aircraft can remain grounded throughout the BLWGN test.

Figure 7.10-3 Planned Antenna Locations

Figure 7.10-3 Planned Antenna Locations

Note all test personnel access to the aircraft will be coordinated with the NASA aircraft operations personnel.

The safety issues and procedures for this test are the same as for the pertinent Sections of 7.12.

7.10.7 Risk Analysis for Aircraft Electronic Systems

If a directional TX antenna were pointed directly at an on board electronic system one meter from the antenna, the worst case field strength could be as high as 10 v/m. Standard mode-mixing test procedures avoid direct illumination of test objects since this test configuration will bias the test results. In this test special care was taken in selecting TX antenna configurations to preclude direct illumination of any aircraft systems.

The mode-mixing accomplished through the BLWGN technique, in the ideal case, provides a uniform, isotropic, randomly polarized EME throughout the cavity. The power density in the cavity will depend on the Q and volume of the cavity and the input power. Using the following equation derived from material in reference⁶

$$E(v / m) = 0.02 * \left(Q * \lambda * P_{in}(w) / Vol(m^3) \right)^{1/2}$$

the estimated worst case power density is less than 14 v/m. This value is based on the maximum input power of 1 w, on an estimate of the smallest test cavity volume in the B-757, and the maximum of all Q*λ values available from the B-707 tests. This last value was an isolated data point which was at least a factor of two higher than any other test data.

Since no power will be applied to any aircraft electronics system, these worst case estimates for the BLWGN test should present no risk to the on board electronics systems of the B-757.

7.11 On-the-Ground Test Schedule

The overall test schedule is presented in Figure 7.11-1. This schedule may be modified by the Test Director.

7.11.1 Daily Test Schedule

A typical test day for the stepped frequencies tests includes 8 hours of actual measurement time and additional time for preparation and stand-down of the site. A typical day will consist of the following:

- a. Open site/site prep at 0630
- b. Stand-up meeting at 0645
- c. First measurement at 0715 hours
- d. Lunch break 1100-1200
- e. Last measurement at 1615
- f. Meeting (TOWG) approximately 10 minutes after the last sweep
- g. Data transfer complete/site secured by 1700

⁶ Crawford, M. L., and Koepke, G.H., Evaluation and Use of a Reverberation Chamber for Performing Electromagnetic Susceptibility/Vulnerability Measurements, NBS TN 1092, 1986.

Figure 7.11-1. On-the-ground test schedule.

7.12 Safety

Performance of test operations in a hazardous manner can result in personnel injury, loss of life, or equipment damage. Serious mishaps can also affect meeting planned test objectives. This section summarizes data presented in more detailed hazards analysis and system safety program documentation and provides details for this specific test.

7.12.1 Documents List

The documents which define the applicable safety requirements and provide safety information are listed below:

- (a) System Safety Program Plan, UIE-TR-88-0009, 22 Apr 1988
- (b) Preliminary Hazards Analysis, UIE-TR-88-0010, 15 Apr 1988
- (c) MIL-STD-882A, System Safety Program Requirements, 28 Jun 77
- (d) Code of Federal Regulations, Title 29, Parts 1910 (Feb 83) and 1926 (Mar 83), (Occupational Safety and Health Act (OSHA))
- (e) AFR 127 Series (-2, -4, -7, -8, -12, and -100)
- (f) AFOSH 127 Series (as applicable)
- (g) AFOSH 161 Series (-1 through -9 as applicable)
- (h) AFPLR 127-3, Air Force Phillips Laboratory Regulation, Systems Safety Requirements

7.12.2 Documentation Overview

Document (a) is the System Safety Program Plan for the Boeing 720B. It establishes the basic system safety program for the maintenance and use of the Boeing 720B.

Document (b) is the Hazards Analysis for the Boeing 720B. It covers all of the potential hazards associated with the use of the Boeing 720B and discusses the efforts to reduce all known hazards to acceptable safety levels.

Document (c) is the source of the major safety requirements. It is required in the UIE contract.

Document (d), Code of Federal Regulations (Title 29, OSHA), is a broad and detailed delineation of general safety standards for industry. It covers a wide variety of occupations and working conditions to be considered in developing safe operating procedures.

Document (e), AFR 127 Series, provides information and guidelines on safety responsibility, safety program components, safety hazard abatement, and Department of Labor Inspections and Evaluations within the Air Force.

Document (f), AFOSH 127 Series, provides guidance for Air Force-wide and industrial safety accident prevention programs. It explains the hazards in and prescribes safety precautions for operating industrial equipment. It is designed to augment other Air Force publications and covers such subjects as the fundamentals of accident prevention, safety practices in construction and maintenance, health hazards and protection, fire protection, and safety in materials handling.

Document (g), AFOSH 161 Series, relates to health and environmental conditions such as radio frequency radiation, permissible exposure limits, carcinogenic substances, and other health subjects.

Document (h), AFPLR 127-3, establishes a Technical Safety Committee within the Phillips Laboratory and describes safety review procedures. The document specifies that all experiments include an Emergency Action Plan which provides: (1) the general requirements and methods for alerting personnel of an emergency, and (2) the appropriate actions to be taken to respond to the emergency.

7.12.3 Hazards Analysis

The aircraft test environment during the tests, both under illumination during the dipole tests and the tests within the LESLI facility using the rhombic antenna, has been determined to be below the levels that might present a hazard to on-board electronic systems and to humans. Further discussion of this issue is found in Appendix B. In addition, an on board electric field sensor, such as a Narda 8616, will be used to provide a real time indication of field strengths when the sources are operational and personnel are present in the airplane.

Many hazards associated with the NASA aircraft are similar to those associated with the PL Boeing 720B aircraft noted in the document Preliminary Hazards Analysis, UIE-TR-88-0010, 15 Apr 1988, which was prepared for the operation, maintenance, and use of a Boeing aircraft in EM testing experiments. The reader is directed to these documents for detailed discussions of the hazards and their mitigation to acceptable levels.

7.12.3.1 Facility SAFETY PROGRAM

Fundamental to a responsive and responsible safety program is implementation of the concept that anyone who detects an unsafe condition has the responsibility to alert the rest of the test team and immediately stop the hazardous operation(s). This section presents the safety program to be enforced for the facility.

7.12.3.2 Safety Organization

Ultimate responsibility for ensuring safety throughout the program resides in the Facility Test Director. Responsibility for implementation of all safety measures on-site will be delegated by the Facility Test Director to the designated Safety Officers as listed in Table 7.12-1. Each Test Safety Officer will ensure that the safety rules and procedures established by the PL are followed. The Facility Test Director will determine when conditions are safe for testing, including restart of test operations after an unsafe condition has been detected. The Facility Test Director will make this decision after consulting with each Safety Officer, who has direct access to the Facility Test Director. The responsibilities of each safety position are described in the following paragraphs.

Table 7.12-1. Test safety assignments.

Title	Name	Office	Test Site
Facility Test Director:	Mr. L. Dao	505-846-0995	846-5998
NASA Aircraft Safety	Mr. M. Basnett	804-864-3900	
Site Aircraft Safety:	Mr. R. Christianson	505-846-1177	822-4702*
Site / Operation Safety:	Mr. Don Lin	505-846-0995	846-5998

* Pager Number

7.12.3.3 Facility Test Director. The designated Facility Test Director has the overall authority to execute and implement those efforts required to achieve safe operation. He will be supported by

specifically designated personnel in each of three areas: (1) Test Operations , (2) Aircraft Operations, and (3) Facilities.

7.12.3.4 Test Operations Safety. This individual is responsible for safe operations during test setup, preparation, and aircraft instrumentation.

7.12.3.5 Aircraft Operations Safety.(NASA and Site) These individuals are responsible for safe operations in and around the NASA aircraft while at the Phillips Lab.

7.12.3.6 Facility Safety. This individual is responsible for the safety of facility operations including data acquisition equipment, DAS operations, weather impacts, and general facility O&M.

7.12.4 Safety Procedures

The procedures that are needed to ensure safe operations for the facility fall into three categories: (1) normal site safety operations, (2) NASA B-757 operations, and (3) procedures unique to test operations.

7.12.4.1 Normal Safety Operations

7.12.4.1.1 Site Safety

The Facility Support will set up safety barricades and signs for the test pads. A site safety briefing will be conducted prior to the start of work. Important considerations include:

- (a) The use of physical barriers such as safety ropes and fences to limit personnel access into hazardous areas,
- (b) Limits on the number of personnel allowed into the hazardous area,
- (c) Establishment of functions, procedures and locations for personnel required in the hazardous area,
- (d) Control of general personnel access to the facility from a safety standpoint,
- (e) Control of personnel access to the site and in the site working volume during the direct drive and CW test operations,
- (f) Provision of safety equipment and instructions for its use, and
- (g) Regular inspection and checkout of safety equipment.

7.12.4.1.2 Area Signs. All hazardous areas require proper marking and identification so personnel not familiar with hazards in the area are made aware of the dangers. General guidelines for this type of activity are contained in both AFR 127-101 and OSHA Safety and Health Standards 29CFR 1910; 2206, revised Nov 7, 1978. A detailed discussion, therefore, of area posting requirements is not repeated in this supplement.

7.12.4.1.3 Access to Area. As one consequence of the security requirements of the test sites, access is limited to those personnel who have a definite need to be in the area. This supports safety considerations by limiting the number of people in the working areas. During times of hazardous operations, the Facility Test Director and Test Safety Officers will have complete control over the operations on the site and of access to the working areas. They will be able to suspend or terminate any test activity at their sole discretion, if in their judgment, safety is being compromised. Any visitors wishing to go within the controlled test area must get the permission of the Facility

Test Director (or his delegate) prior to entering. PL will provide Contractors and Government organizations with any special site safety equipment that may be required such as hard hats, radiation detectors, etc.

7.12.4.1.4 Safety Equipment. The on-site safety equipment is divided into three classes:

- (a) First aid equipment,
- (b) Personal safety equipment, and
- (c) Special safety equipment.

Adequate first aid equipment is currently located at the sites, and site personnel are trained in first aid techniques. Individuals performing hazardous operations, such as working on and around the test stands, will be required to use proper safety equipment to minimize hazards. Contractors and Government organizations which have personnel operating on the site will provide safety equipment for their personnel.

7.12.4.1.5 Personnel Safety Briefing. Safety procedures are only effective when adhered to. Each Test Safety Officer will ensure all test personnel receive a safety briefing prior to the start of testing at each test site. All personnel will be briefed in the following areas:

- (a) Performance of daily tasks in a safe manner,
- (b) Adherence to safety procedures for hazardous operations,
- (c) Observance of all warning signs in the area,
- (d) Continual examination of the site and test operations for potentially dangerous activities and conditions,
- (e) Adherence to emergency procedures and regulations,
- (f) Notification of proper personnel regarding safety matters,
- (g) Adherence to safety requirements on the NASA aircraft, and
- (h) Adherence to site safety requirements (e.g. hard hats, high voltage equipment, environmental hazards, etc.).

"Safety consciousness" is each individual's responsibility at all times, not just the responsibility of the Safety Officers.

Selected site and contractor personnel have been trained in areas of first aid, CPR, safety inspections and the proper use of special safety equipment. At least one person who is qualified to administer first aid will be physically present at the test site at all times.

7.12.4.2 NASA B-757 Safety

The NASA aircraft is a fully operational Boeing 757-200 aircraft. After the aircraft is towed, parked and properly oriented on the LESLI pad, it will be inspected by the Ground Crew Chief to ensure that it is properly and safely positioned. Personnel working on the NASA aircraft will adhere to NASA aircraft safety procedures. All personnel will be briefed on aircraft specific safety issues by the NASA aircraft Ground Crew Chief prior to work on or around the aircraft. The aircraft will be grounded at all times except when testing is being performed. The aircraft will be grounded prior to the entry or egress of personnel prior to or after RF illumination. A 150 lb power bottle aviation-type fire extinguisher on the pad satisfies NASA safety requirements for fire hazards.

7.12.4.3 Test Unique Operations

Operating procedures have been established at the EM test sites in the following areas: operations and maintenance, protective equipment, housekeeping, lighting and general safety practices. Under general safety practices there are restrictions concerning clothing, jewelry, intoxicants, tampering with equipment, personal conduct, electrical repairs, railings and toe boards, and the use and storage of hazardous material and equipment. Aircraft maintenance and test support personnel will comply with all safety requirements. It is the responsibility of the Facility Test Director to inform or to designate others to inform NASA, LLNL, or other visitors regarding these practices.

7.12.5 Emergency Procedures

If an emergency situation exists, all test activities will cease and the proper emergency personnel shall be contacted. All personnel will be briefed on access to emergency services.

7.12.5.1 Medical Services

The USAF Hospital at Kirtland AFB will provide emergency assistance and ambulance services for all on-site personnel.

7.12.5.2 Fire Protection

The 377 ABW will provide fire protection services on an on-call basis. It is not expected that any on-site support will be required. Portable fire extinguishers will be required at the aircraft at all times. A 150 lb power bottle aviation-type fire extinguisher on the pad will be required. Small portable fire-extinguishers will be located in trailers and office buildings for office/equipment fires.

7.12.5.3 Accident Reporting

Property and equipment damage, and personnel injury accident reporting procedures required by the Federal and State Governments, by the Government and its participating contractors and subcontractors/vendors will be complied with. Table 7.12-1 lists the personnel to be notified in case of any emergency or safety hazard.

7.12.6 Safety Summary

The Facility Safety Program consists of five major elements:

- (a) The designation of a safety team with complete safety authority on the test site,
- (b) The establishment and implementation of safety procedures for normal site operations, test preparation and testing operations,
- (c) The acquisition and training for the proper utilization of required safety equipment. These include First Aid equipment, personal safety equipment, and any special safety equipment as may be required to minimize potential accidents,
- (d) Personnel briefings stressing day-to-day safety practices, and specialized training for designated personnel in the areas of first aid and other safety matters, and
- (e) The establishment and implementation of emergency procedures.

7.13 Security

No classified documentation, equipment, or data will be handled during this test. Therefore accounting and control procedures for classified information are not required. There will, however, be base, facility, and test aircraft access and physical security requirements.

7.13.1 Classified Information and Equipment

No classified documentation, equipment, or data will be handled during this test.

7.13.2 Base and Test Site Access

7.13.2.1 Base Access

Kirtland AFB is a controlled access Air Force facility. In general, personnel entering base premises are required to show a vehicle entry pass. Contractors who routinely require access should follow the procedures in their On-Base Security Agreement for the issuance of entry passes.

7.13.2.2 Test Site Access

During test operations, the test site will be unrestricted to personnel who have base access. Appropriate signs will be displayed to require visitors to report to a central location at each test site. A roster of authorized personnel will be provided to all test participants at the start of the test. All test personnel will be charged with challenging individuals who are unfamiliar and are not on the roster. During off-testing hours, the test site will be locked and site security will be ensured by base security police within their normal patrolling routes.

7.13.3 NASA Aircraft Access

During test operations, access to the aircraft may be controlled by Aircraft Operations. Access will be permitted only to personnel who have been approved by Aircraft Operations or who are escorted by a person with escort authorization. During off-testing hours, the aircraft doors will be closed and the stairs and test stands may be pulled away from the aircraft. At the discretion of Aircraft Operations, the stairs and stands may be chained together to prevent unauthorized movement.

7.14 Add-on Tests

As time permits and necessity dictates, additional tests may be added to the program. At present, two major test have been indicated as needed for completeness.

7.14.1 Pad Characterization

As has already been mentioned, an electromagnetic characterization of the pad will be required. Specifically, the constitutive parameters of the pad must be measured to permit modelers to include the ground in simulations. Since the parameters are unknown, and the concrete/aggregate/rebar/soil is not precisely describable, a measurement of the parameters is needed. Since it is expected that the ground is inhomogeneous, a measurement scheme returning parameters averaged over a spatial extent will be made. These measurements will be made without the NASA 757.

To execute the tests, a long wire (the rhombic wire) will be supported a fixed height above the concrete pad on a styrofoam support strip and will be extended across the pad to the full extent of

the wire. The height will be chosen to be as small as possible but consistent with the thicknesses of commercially available styrofoam panels. At this time the height is expected to be between 1/4 and 3/4 inches. The wire will be driven against the aluminum source-region ground screen at the rhombic feed point. The wire will be extended in two separate directions (Cases 1 and 2) since the ground plane may be inhomogeneous with constitutive parameter variation as a function of angle with respect to the original rhombic axis. Overhead and cross sectional views of the wire placement are shown in Figures 7.14-1 and 7.14-2.

The wire will be driven against the aluminum plane and the current distribution will be measured by probing with an Prodyn I-320 current probe. The current will be probed at specified points along the wire so that estimates can be made of the attenuation and phase constants of the wave propagating along the wire. From this information, it is expected that the conductivity and permittivity of the pad can be extracted using the theory presented by Chang, Olsen and Kuester^{7,8,9}. The test matrix for the pad characterization is presented in Table C-23.

7.14.2 Horizontal Polarization Near Lowest Order Resonances

A set of measurements at frequencies in the vicinity of the first body resonance of the B-757 has been suggested. Since the resonant wavelength for the fuselage is in the vicinity of 94 meters, the resonant frequency is approximately 3.2 MHz. The lowest order resonance associated with the wings falls above 4 MHz while resonances associated with combinations of the wings and fuselage fall above 3.7 MHz. To make such measurements under horizontal polarization, it is expected that the LESLI rhombic will be used in its differential mode rather than attempting to use a $\lambda/2$ dipole since a 47 meter dipole might be mechanically difficult to handle. A balun will be used at the rhombic feed point to ensure push-pull operation so that a horizontally polarized field can be generated. Due to the lack of a reliable broadband balun covering 0.3 to 1000 MHz and questionable quality of the horizontal field, this was not included in the extensive set of rhombic measurements. Nonetheless, given the advisability of having horizontal drive and the inability to efficiently deal with a dipole at the 94 meter wavelength, it was decided to use a balun able to deal with a band possibly covering the lowest order resonances of the aircraft. A balun available to radio amateurs and advertised for 3.5 to 30 MHz will be used and an attempt will be made to reach 3.2 MHz. The airplane will driven in its broadside configuration and measurements will be made at select test points. The decision as to which test points will be recorded will have to include factors such as priority and time available. The test matrix for this horizontal polarization test is provided in Table C-24.

⁷ Chang, D. C. and Olsen, R. G., "Excitation of an Infinite Antenna Above a Dissipative Earth," Radio Science, Volume 10, No8,9, pp. 823-831, August-September, 1975.

⁸ Kuester, E. F. , Chang, D. C. and Olsen, R. G. , " Modal Theory of Long Horizontal Wire Structures Above the Earth, 2, Properties of Discrete Modes", Radio Science, Vol 13, No. 4, pp 615-623, July-August 1978.

⁹ Olsen, R. G. , Kuester, E. F. and Chang, D. C. , Modal Theory of Long Horizontal Wire Structures Above the Earth, 1, Excitation", Radio Science, Vol. 13, No. 4, pp. 605-613, July-August 1978.

Figure 7.14-1 Pad Characterization Wire Layout for Two Cases

Figure 7.14-2 Pad Characterization Wire Layout - Cross Sectional View

Appendix A Plane Wave On-the-Ground Test Technical Objectives

In this section we discuss some specific technical objectives of the on-the-ground low-level tests.

A primary objective of the tests is the collection of data for use in the validation of codes that are employed in the modeling of electromagnetic environment in aircraft and its effects on aircraft-borne electronic systems. Of particular interest at this time is the validation of FDTD modeling of coupling into the airframe using a code such as TSAR. The data are also intended for inclusion in a library for use in validation exercises involving modeling tools based on the broad range of techniques and algorithms that are either presently available, in development or otherwise.

The term validation is used to denote the determination whether a particular code is capable of producing accurate results for specific modeling assessments in which it has been applied. Clearly, this will "validate" the physics kernel of the code, its numerical algorithms, and its overall ability to provide the "right" answer. In this particular program, the codes will be tested extensively in their "intended" range where approximations other than discretization are not required (perhaps up to hundreds of MHz) as well as in the range where approximations and special algorithms will be required to estimate stress. While a description of the approximations used to extend the domain of applicability of the code is beyond the scope of this plan, adequate attention has been paid to collecting appropriate data to allow for its use in future validation activities.

During the course of collecting data for the validation exercise, we will also collect data to help us deal with some issues related to modeling, the impact of resolution or "graininess" in the model, random effects, repeatability, and robustness of the measured results. The following, while not totally inclusive, are some of these issues. Note that scheduling constraints may preclude some of the tests.

A.1 Body Resonance. A concern is whether the computer models can accurately account for coupling into the airframe at low frequencies, especially when the external airframe is in body resonance. At these low frequencies, the wavelength is very long with respect to windows and other apertures so that the major coupling path to the interior would likely be through wires or structures that electrically penetrate the airframe or through evanescent wave pickup onto wires or structures near apertures. The degree of coupling may depend heavily on small or seemingly-innocuous features that could easily be missed in converting the physical structure into a computer model. Since we are emphasizing the FDTD model technique for low frequency coupling prediction, it is important that this capability be validated. This can be done by comparing predicted and measured field coupling at interior points in the airframe.

A.2 Thin Wires. Once the EM energy penetrates the airframe, it couples onto the wires and cables that connect the LRUs. (Even fiber-optically interfaced LRUs will have power cables that will pick up energy.) The basic FDTD technique would have difficulty modeling these cables because they are very thin with respect to the resolution element of the computer model. To overcome this problem, special algorithms have been developed that allow thin wires to be modeled. The performance of these algorithms has been validated in simpler geometries and will now be validated in an aircraft environment. This can be done by comparing predicted and measured bulk cable current coupling. Since the only interconnect cables in the FBL/PBW aircraft will be power cables (that are isolated from the airframe), the measurement and simulation will choose a cable that simulates the expected configuration - even if it has to be a dummy cable. This cable should have the correct type of bulkhead feedthrough and the correct type of airframe bonding, if any.

A.3 Thin Slots. Another feature that the basic FDTD model must often treat in a special way is a thin slot. Thin slots are analogous to thin wires - they require special algorithms. In the Boeing 757-200 test object, we feel that the coupling through windows will dominate and that coupling

through thin slots such as door frame and hatch frame cracks will be negligible by comparison. However, this assertion, while very likely to be true for the test points of interest during these tests, should be validated. This can be checked by comparing coupling measurement with a suspected door frame or other thin slot initially open and then sealed with metallized tape. If the internal coupling doesn't change, the slot aperture coupling was negligible. The measurement should also be repeated with the door open, because if the door does not make good electrical contact around its perimeter, the coupling would be similar at resonant frequencies to that of an open door.

A.4 FDTD Resolution and the Effect of Randomly Located Features. When the airframe is modeled for the FDTD analysis, a resolution element is selected based on a combination of issues including the wavelength at the highest frequency of interest, the detail desired in the model, and/or the computer resources available. Metallic and dielectric structures that are small with respect to the size of the resolution element may be ignored. Some internal objects such as the crew, passengers, carry-on luggage, and other moveable cargo may be large, but their instantaneous positions cannot be described deterministically. The positions of "fixed" objects may vary from aircraft to aircraft over the fleet ensemble, so their positions must also be considered as randomly placed. In the computer model, these variations are either ignored or are described with representative structures in the model. The aggregate effect that these omitted or approximated structures have on coupling may be significant. It is important that the magnitude of the effect that these omitted or approximated features have on coupling be understood. In order to get an approximate estimate of the effect of these features a few measurements will be made where realistic representations of such objects of various sizes are moved around in random positions, or with someone in the cockpit to represent the pilot. The variations we see in these measured data will provide insight as to how accurately we can ever expect the predictions to approach reality.

A.5 Cockpit Window. The cockpit window is expected to be a significant coupling aperture. However, this window is usually coated with an electrically conducting film that is connected by cable to a power supply to allow it to be heated for deicing. Therefore, the coupling through this aperture will depend strongly upon how this film is electrically bonded to the surrounding metal surface, if it is at all. If there is no bonding to the airframe, this window might act like a large patch antenna, admitting frequencies above and below the aperture resonance that would be expected for an open window of the same size. If the film is bonded to the airframe in one location, the window would still accept frequencies only above its aperture resonance. If the film is electrically opaque to the wave, then a thin slot algorithm may be required to describe it. We must validate that the model we use to represent this window is accurate. We can isolate the coupling through the window by making a measurement with the window open and then repeating it with the window sealed with metallic foil and tape. These measurements would allow us to investigate the computer model of the window. Similar data has been taken by the Phillips Laboratory that will provide a qualitative insight to cockpit coupling. This reduces the priority for this measurement. This low priority test will be placed at the end of the test schedule. Due to the compressed test schedule, this test will not likely occur.

A.6 Angular Sensitivity. When flight tests are ultimately made, the exact orientation of the aircraft at the time that the EME signal measurement is made will be estimated using on-board systems. There will be some error in these estimates. It is important to know how sensitive the measurements of coupling are to small changes in pitch, roll, and yaw. In the on-the-ground coupling tests, varying pitch and roll may be difficult. However, it is simple to vary yaw. Therefore, a series of measurements will be made with small changes in yaw in order to quantify the error such variations will have in coupling.

A.7 Measurement Repeatability. Measurement repeatability is an issue similar to angular variation. We can never expect to validate to an accuracy better than the random measurement error. To test this error, measurements of coupling into the airframe for a few select configurations and orientations will be repeated several times over the testing period.

A.8 Effects of the Earth. One potential source of modeling error associated with on-the-ground tests that is not found in airborne tests is the effect of conductivity and dispersion in the soil or concrete upon which the aircraft sits. These values will change with the moisture content of the soil or pad.

Appendix B Power Densities and Field Strengths for Aircraft Tests

LESLI Rhombic Tests

The aircraft will be manned during several tests, namely, during the fly-by instrumentation tests and during some tests which call for evaluation of sensitivity of the results to personnel deployment. The field strengths or power density in such tests must be below the levels which represent a hazard to humans. The IEEE C95.1-1991 / DoDI 6055.11 (Draft) standard for maximum permissible field exposure for personnel in a controlled environment is 1 mW/cm² over the frequency range from 300 KHz to 1 GHz. This corresponds to an electric field strength of 61.4 V/m for a plane wave field in free space. Neither LLNL, NASA, PL, or the older ANSI standard C95.1-1982 have exposure limits below 1 mW/cm² over any frequency band. Hence field levels below this level can be considered innocuous to humans.

Concern is also expressed for the safety of on-board equipment. While the vulnerability levels of this gear is not known at this time, field levels estimated below will allow the safety assessment to be performed.

The field within the LESLI rhombic, while not precisely describable by a transmission line model, has been approximately modeled in such a manner.^{10,11} The results have been found to be adequate in trials against experimental results. The following are some results from this analysis.

In a coordinate system with x along the axis of the rhombic, z transverse and along the ground plane, and y oriented perpendicular to the ground (see Fig 7.4-1 for help in this visualization)

$$E_y = \text{Sqrt}[1.87 W/(\pi Z_c/Z_o)] (1/b) [\exp(-j\omega r/c)] f_{cm}(z,y)$$

$$E_z = \text{Sqrt}[1.87 W/(\pi Z_c/Z_o)] (1/b) [\exp(-j\omega r/c)] g_{cm}(z,y)$$

where

$$f_{cm} = b(y-b) / [(z-a)^2 + (y-b)^2] + b(y-b) / [(z+a)^2 + (y-b)^2] \\ - b(y+b) / [(z-a)^2 + (y+b)^2] - b(y+b) / [(z+a)^2 + (y+b)^2]$$

$$g_{cm} = b(z-a) / [(z-a)^2 + (y-b)^2] + b(z+a) / [(z+a)^2 + (y-b)^2] \\ - b(z-a) / [(z-a)^2 + (y+b)^2] - b(z+a) / [(z+a)^2 + (y+b)^2]$$

$$Z_c = \ln[1 + (1 + (R/b)^2)^{1/2} - R/b] / [1 - (1 + (R/b)^2)^{1/2} + R/b] / (4\pi) + \ln[1 + (b/a)^2] / (8\pi)$$

$$Z_o = 377 \text{ Ohms}$$

$$W = \text{Input Power}$$

$$l = \text{distance from source to max height of rhombic}$$

$$a = \text{distance of wire from centerline at any } x$$

$$b = \text{height of wire from ground at any } x$$

$$R = \text{wire radius}$$

$$r = \text{distance from source}$$

Using these expressions, fields were calculated for points within the test volume. The specific quantities used were:

¹⁰ Kehere, W. S., Atchley, L., Engheta, N., Marin, L., Martinez, J. P., "Results of the Initial Field Mapping of the AFWL Hardness Surveillance Illuminator", Kaman Sciences Corp Report DC-TR-4088.430-2, January 1987.

¹¹ Darras, D., Zuffada, C., Marin, L., Atchley, L., "Theory of Operation of Achilles III and Performance Evaluation", Achilles Memos: Memo 11, AFWL.

$W = 100$ watts (radiated power)
 $l = 100$ m
 $a(\text{maximum}) = 16$ m
 $b(\text{maximum}) = 26$ m
 $R = 0.002$ m

The ranges of the parameters in the figures were chosen to approximately cover the spatial extent of the airplane and the intended test volume. The airplane will be located at least 40 meters from the source. Its fuselage radius is approximately 4.5 meters and its wingspan approximately 38 meters. Its fuselage height is less than 6.5 meters.

Figure B-1 shows the principal electric field (the y component) for x between 35 and 70 meters and z from 0 to 20 meters at the ground plane. The field never exceeds 3 V/m.

Fig B-1. Principal Electric Field at $y=0$

The corresponding electric field in the transverse plane (y-z plane) at $x = 40$ meters is shown in Figure B-2. The peaking taking place near $y = 4$ meters is due to proximity to the rhombic wire. Figure B-3 shows the same field component over a greater range of height and transverse position.

The cross polarized components of the field (the z-directed component) is also of concern. Physics requires this component to be zero along the ground plane (for a perfect conductor) and symmetry requires it to be zero along the $z = 0$ plane. Figures B-4 and B-5 show this transverse field in the transverse plane at $x = 40$ meters. At heights less than 5 meters the field is less than 1 V/m.

Figure B-2. Principal Electric Field at $x = 40$ meters, y less than 7 meters

Figure B-3. Principal Electric Field at $x = 40$ meters, y less than 10 meters

Figure B-4. Transverse electric field at $x = 40$ meters

Figure B-5. Transverse electric field at $x = 40$ m, $z < 4$ m, $y < 7$ m

The field levels at the location of the airplane without its presence is thus below 5 volts per meter over the extent of the fuselage. This statement is true for either nose on or broadside incidence with the airplane in the positions shown in Figures 7.4-2 and 7.4-3. The equivalent power density is less than 0.007 mW/cm^2 . Even allowing for inaccuracy in the model, this is well below the personnel safety standard by almost an order of magnitude in field¹². Shielding provided by the aircraft will, of course, reduce the field levels.

Dipole Tests

The dipole tests will be performed with the dipole located at a point forward of the wing and outboard of the fuselage. Closest approach to the airplane is 10 meters. The dipoles will be very close to their half-wave resonances in the tests.

For horizontal polarization, the dipoles will be at a distance above the ground plane.

The incident power density in the direction of maximum gain is given by

$$S = \text{Gain} \times \text{Power Input} / (4 \pi R^2)$$

For a dipole in free space with gain of 1.64 (2.15 dBi), a range of 5 meters, and a power input of 1 watt, the incident power density at the axis airplane is 0.0052 W/m^2 with the attendant electric field of 1.4 V/m. For a dipole over a ground plane, the peak gain can be twice as high as free space with peak incident power density of 0.021 W/m^2 and attendant electric field of 2.8 V/m. Hence, for a dipole over ground radiating 100 watts, the peak power density at 5 meters would be 2.1 W/m^2 and the peak electric field would be 28 V/m. These estimates are below safety thresholds.

¹² Further confidence in personnel safety is provided by measurements made within the facility. During the F-16 Pre Test Field Measurements in the LESLI facility, UIE reported on the field levels at various points on the test pad. For full-level, output power from the RF amps driving the rhombic with 100 watts, peak power density did not exceed 0.16 mW/cm^2 at a point 10m from the feed on the centerline of the rhombic. ("Report of High Frequency Research Facility F-16 Pre-Test Field Measurements" United International Engineering, Inc., UIE-TR-92-0010, 22 June 1992.

Appendix C On-the-Ground Test Matrix

This section contains an estimate of the time required to for the on-the-ground tests and a test matrix for low-power tests. These estimates are found in Tables C-1 through C-8.

The test matrix is presented in Tables C-9 though C-24. Test Series A through F correspond to the dipole tests described in Section 7.7. Test Series G through I correspond to the on-board instrumentation tests described in Section 7.8. Tests Series J and K correspond to the stepped frequency rhombic tests described in Section 7.9. Test Series PL, Pad Characterization, and Horizontal Polarization - Rhombic are described in Sections 7.10, 7.14.1, and 7.14.2, respectively. Each table contains the configurations, orientations, and test points for a test series with a given polarization and frequency band. Antenna configurations and/or instrumentation systems will be changed for each test series. This matrix also indicates a preferred order for the tests. The test will proceed such that the most time-consuming changes (such as moving the aircraft) occur less frequently, at the expense of making the less time-consuming changes (such as swapping probe locations) more often.

In all cases, the frequency ranges shown are the likely minimum. The ranges will be extended to include as much of the frequency range around the center frequency as possible

Table C-1. Pre-aircraft field time at PL

Set up data acquisition format, run-number code, etc.	1 day
Set up data acquisition instrumentation, antennas in required locations and check out equipment. Dry run tests.	5. days
Tests to assure FAA compatibility	2. days
Field map survey for Test Series J, K	10. days
Total pre-aircraft field time at PL	18 days @ 8 hrs/day

Table C-2. Test Series A - F (three frequencies, vertical and horizontal dipoles, aircraft nose-incident orientation on ground plane)

Fly In to ABQ, Aircraft Operations activities	1 day
Install non-flightworthy items, switch cable connections, cal cables	1 day
Position aircraft	2.5 hrs
Hook up instrumentation, fibers	1.5 hrs
RC-7 replaces installed NASA aircraft transceiver.	1 hr
Initial tests - dynamic range, noise floor 12 tests	1 day
26 MHz, vertical whip stepped measurements, setup, 12 tests:	1 day
26 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
172 MHz, vertical dipole stepped measurements, setup, 12 tests	1 day
172 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
430 MHz, vertical dipole stepped measurements, setup, 12 tests	1 day
430 MHz, horizontal dipole stepped measurements, setup, 12 tests	1 day
Slack 4 hrs	
Total	10 days @ 10 hr/day

Table C-3 Test Series G, H, I
(On-board instrumentation check-out, rhombic, vertical, aircraft nose-incident)

Hook up sensors to on-board instrumentation,	1 hr
Remove RC-7 box and install NASA aircraft transceiver	1 hr
Power up aircraft and instrumentation	2 hrs
Tests at 25.85 MHz, Debug, exercise equipment	4 hrs
Tests at 172.0 MHz, Debug, exercise equipment	4 hrs
Tests at 430.0 MHz, Debug, exercise equipment	4 hrs
Slack (large slack time to accommodate potential problems)	5 hrs
Reconnect sensors to fibers for stepped frequency tests,	
install RC-7 box	10 hrs
Install Rhombic Antenna	4 hrs
Total	3.5 days @ 10 hr/day

Table C-4 Test Series J (0.3 - 1000 MHz, vertical, nose incident)

Reposition aircraft, 5°	1.5 hrs
Reposition aircraft, 2° or 10°	1.5 hrs
Stepped measurements, 41 Tests	37 hrs
Total	4.0 days @ 10 hr/day

Table C-5 Test Series K (0.3 - 1000 MHz, vertical, side incident)

Reposition aircraft to 90°	1.5 hrs
Stepped measurements, 30 tests	37 hrs
Remove fibers, RC-7 box, etc.	1.5 hrs
Total	4.0 days @ 10 hr/day

Table C-6 Post-Test Aircraft Time

Return aircraft to flightworthy state, QA inspection	2 day
Roll out aircraft, return to airport, fly out to LaRC	1 day
Total post-test aircraft time	3 days @ 10 hrs/day

Total aircraft test time 21.5 days @ 10 hr/ day

Table C-7 Post Aircraft Decommission

Clean up	2 days
Total post-aircraft field time	<u>2 days @ 8 hrs/day</u>

Table C-8 Total Time Allocations

Total Pre-Aircraft Field Time at PL	18 days @ 8 hrs/day
Test Series A-F	10 days @ 10 hr/day
Test Series G, H, I	3.0 days (up to 10 hr/day)
Test Series J	4.0 days @ 10 hr/days
Test Series K	4.0 days @ 10 hr/day
Post-Test Aircraft Time	3.0 days @ 8 hrs/day
Post Aircraft Decommission	2 days @ 8 hrs/day

Table C-9. Ambient Noise Measurements

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes
AN1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000				U
AN2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000				U
AN3	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000				U
AN4	C4	Cabin	Field	Ext. antenna	0.3 - 1000				U

- Notes: This measurement set will investigate or validate:
- U) Ambient noise measurement

Table C-10. Test Series A

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes
A1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A4	CP4	Cockpit	Wire Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A5	CP5	Cockpit	Wire Voltage	climbing wire	23 - 28	Dipole	H	Dipole // to a/c axis	B
A6	EB1	E-bay	Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A7	EB2	E-bay	LRU Voltage	Voltage Probe	23 - 28	Dipole	H	Dipole // to a/c axis	D
A8	EB3	E-bay	Cable Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A9	C1	Cabin	Field	AD-60 D-Dot	23 - 28	Dipole	H	Dipole // to a/c axis	A
A10	C2	Cabin	Wire Current	I-320 Probe	23 - 28	Dipole	H	Dipole // to a/c axis	B
A11	C3	Cabin	Voltage	Long Wire	23 - 28	Dipole	H	Dipole // to a/c axis	B
A12	C4	Cabin	Field	Ext. antenna	23 - 28	Dipole	H	Dipole // to a/c axis	* C
A13	Weak Signal Line			23 - 28	Dipole	H	Dipole // to a/c axis		V
A14	Strong Signal Line				23 - 28	Dipole	H	Dipole // to a/c axis	V

- Notes: This measurement set will investigate or validate:
- A) FDTD predictions of field coupling; transmit antenna in computational volume
- B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
- C) Calibration of aircraft external field measurement
- D) Typical coupling into a representative critical LRU in the E-bay
- V) Dipole Instrumentation Noise Measurements: Strongest and Weakest channels observed over the test series are chosen. Probe is replaced by matched load and noise signals recorded.
- * Lower priority, skip if short of time

Table C-11. Test Series B

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
B1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B4	CP4	Cockpit	Wire Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B5	CP5	Cockpit	Wire Holtage	climbing wire	23 - 28	Dipole	V	front, left of a/c	B
B6	EB1	E-bay	Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B7	EB2	E-bay	LRU Voltage	Voltage Probe	23 - 28	Dipole	V	front, left of a/c	D
B8	EB3	E-bay	Cable Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B9	C1	Cabin	Field	AD-60 D-Dot	23 - 28	Dipole	V	front, left of a/c	A
B10	C2	Cabin	Wire Current	I-320 Probe	23 - 28	Dipole	V	front, left of a/c	B
B11	C3	Cabin	Voltage	Long Wire	23 - 28	Dipole	V	front, left of a/c	B
B12	C4	Cabin	Field	Ext. antenna	23 - 28	Dipole	V	front, left of a/c *	C
B13	C1	Cabin	Field	AD-60 D-Dot	25.7 - 26	Dipole	V	1% BW, 1000 pts	E
B14	Weak Signal Line				23 - 28	Dipole	V	front, left of a/c	V
B15	Strong Signal Line				23 - 28	Dipole	V	front, left of a/c	V

- Notes: This measurement set will investigate or validate:
 - A) FDTD predictions of field coupling; transmit antenna in computational volume
 - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
 - C) Calibration of aircraft external field measurement
 - D) Typical coupling into a representative critical LRU in the E-bay
 - E) Variations in coupling with frequency (frequency stirring)
 - V) Dipole Instrumentation Noise Measurements
- * Lower priority, skip if short of time

Table C-12. Test Series C

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
C1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C4	CP4	Cockpit	Wire Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C5	CP5	Cockpit	Wire Voltage	climbing wire	150 - 200	Dipole	V	front, left of a/c	B
C6	EB1	E-bay	Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C7	EB2	E-bay	LRU Voltage	Voltage Probe	150 - 200	Dipole	V	front, left of a/c	D
C8	EB3	E-bay	Cable Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C9	C1	Cabin	Field	AD-60 D-Dot	150 - 200	Dipole	V	front, left of a/c	A
C10	C2	Cabin	Wire Current	I-320 Probe	150 - 200	Dipole	V	front, left of a/c	B
C11	C3	Cabin	Voltage	Long Wire	150 - 200	Dipole	V	front, left of a/c	B
C12	C4	Cabin	Field	Ext. antenna	150 - 200	Dipole	V	front, left of a/c *	C
C13	C1	Cabin	Field	AD-60 D-Dot	171 - 173	Dipole	V	1% BW, 1000 pts	E
C14	Weak Signal Line				150 - 200	Dipole	V	front, left of a/c	V
C15	Strong Signal Line				150 - 200	Dipole	V	front, left of a/c	V

- Notes: This measurement set will investigate or validate:
 - A) FDTD predictions of field coupling; transmit antenna in computational volume
 - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
 - C) Calibration of aircraft external field measurement
 - D) Typical coupling into a representative critical LRU in the E-bay
 - E) Variations in coupling with frequency (frequency stirring)
 - V) Dipole Instrumentation Noise Measurements
- * Lower priority, skip if short of time

Table C-13. Test Series D

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
D1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D4	CP4	Cockpit	Wire Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D5	CP5	Cockpit	Wire Voltage	climbing wire	150 - 200	Dipole	H	Dipole // to a/c axis	B
D6	EB1	E-bay	Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D7	EB2	E-bay	LRU Voltage	Voltage Probe	150 - 200	Dipole	H	Dipole // to a/c axis	D
D8	EB3	E-bay	Cable Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D9	C1	Cabin	Field	AD-60 D-Dot	150 - 200	Dipole	H	Dipole // to a/c axis	A
D10	C2	Cabin	Wire Current	I-320 Probe	150 - 200	Dipole	H	Dipole // to a/c axis	B
D11	C3	Cabin	Voltage	Long Wire	150 - 200	Dipole	H	Dipole // to a/c axis	B
D12	C4	Cabin	Field	Ext. antenna	150 - 200	Dipole	H	Dipole // to a/c axis*	C
D13	Weak Signal Line				150 - 200	Dipole	H	Dipole // to a/c axis	V
D14	Strong Signal Line				150 - 200	Dipole	H	Dipole // to a/c axis	V

- Notes: This measurement set will investigate or validate:
 - A) FDTD predictions of field coupling; transmit antenna in computational volume
 - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
 - C) Calibration of aircraft external field measurement
 - D) Typical coupling into a representative critical LRU in the E-bay
 - V) Dipole Instrumentation Noise Measurements
- * Lower priority, skip if short of time

Table C-14. Test Series E

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
E1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E4	CP4	Cockpit	Wire Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E5	CP5	Cockpit	Wire Voltage	climbing wire	350 - 500	Dipole	V	front, left of a/c	B
E6	EB1	E-bay	Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E7	EB2	E-bay	LRU Voltage	Voltage Probe	350 - 500	Dipole	V	front, left of a/c	D
E8	EB3	E-bay	Cable Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E9	C1	Cabin	Field	AD-60 D-Dot	350 - 500	Dipole	V	front, left of a/c	A
E10	C2	Cabin	Wire Current	I-320 Probe	350 - 500	Dipole	V	front, left of a/c	B
E11	C3	Cabin	Voltage	Long Wire	350 - 500	Dipole	V	front, left of a/c	B
E12	C4	Cabin	Field	Ext. antenna	350 - 500	Dipole	V	front, left of a/c *	C
E13	C1	Cabin	Field	AD-60 D-Dot	427 - 432	Dipole	V	1% BW, 1000 pts	E
E14	Weak Signal Line				350 - 500	Dipole	V	front, left of a/c	V
E15	Strong Signal Line				350 - 500	Dipole	V	front, left of a/c	V

- Notes: This measurement set will investigate or validate:
 - A) FDTD predictions of field coupling; transmit antenna in computational volume
 - B) FDTD predictions of thin wire coupling; transmit antenna in computational volume
 - C) Calibration of aircraft external field measurement
 - D) Typical coupling into a representative critical LRU in the E-bay
 - E) Variations in coupling with frequency (frequency stirring)
 - V) Dipole Instrumentation Noise Measurements* Lower priority, skip if short of time

Table C-15. Test Series F

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
F1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F4	CP4	Cockpit	Wire Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F5	CP5	Cockpit	Wire Voltage	climbing wire	350 - 500	Dipole	H	Dipole // to a/c axis	B
F6	EB1	E-bay	Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F7	EB2	E-bay	LRU Voltage	Voltage Probe	350 - 500	Dipole	H	Dipole // to a/c axis	D
F8	EB3	E-bay	Cable Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F9	C1	Cabin	Field	AD-60 D-Dot	350 - 500	Dipole	H	Dipole // to a/c axis	A
F10	C2	Cabin	Wire Current	I-320 Probe	350 - 500	Dipole	H	Dipole // to a/c axis	B
F11	C3	Cabin	Voltage	Long Wire	350 - 500	Dipole	H	Dipole // to a/c axis	B
F12	C4	Cabin	Field	Ext. antenna	350 - 500	Dipole	H	Dipole // to a/c axis	* C
F13	Weak Signal Line				350 - 500	Dipole	H	Dipole // to a/c axis	V
F14	Strong Signal Line				350 - 500	Dipole	H	Dipole // to a/c axis	V

• Notes: This measurement set will investigate or validate:

A) FDTD predictions of field coupling; transmit antenna in computational volume

B) FDTD predictions of thin wire coupling; transmit antenna in computational volume

C) Calibration of aircraft external field measurement

D) Typical coupling into a representative critical LRU in the E-bay

V) Dipole Instrumentation Noise Measurements: Strongest and Weakest channels observed over the test series are chosen. Probe is replaced by matched load and noise signals recorded.

The frequency range shown is the likely minimum. The range will be extended to include as much of the 350 to 510 MHz range as possible

* Lower priority, skip if short of time

Table C-16. Noise Floor Measurements

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Configuration	Notes
NO1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	Nose Incident	T
NO6	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO7	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO8	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	Nose Incident	T
NO9	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	Nose Incident	T
NO10	C2	Cabin	Wire Current	I-320 Probg	0.3 - 1000	Rhombic	V	Nose Incident	T
NO11	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	Nose Incident	T
NO12	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	Nose Incident	T

• Notes: This measurement set will investigate or validate:

T) Measurement noise floors

Table C-17. Test Series G

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
G1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G2	EB1	E-bay	Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G3	EB3	E-bay	Cable Current	I-320 Probe	25.85	Rhombic	V	a/c nose incident	F
G4	C1	Cabin	Field	AD-60 D-Dot	25.85	Rhombic	V	a/c nose incident	F
G5	C2	Cabin	Wire Current	I-320 Probe	25.85	Rhombic	V	a/c nose incident	F
G6	C3	Cabin	Voltage	Long Wire	25.85	Rhombic	V	a/c nose incident	F
G7	C4	Cabin	Field	Ext. antenna	25.85	Rhombic	V	a/c nose incident	C, F

• Notes: This measurement set will investigate or validate:

C) Calibration of aircraft external field measurement

F) On-board instrumentation check-out

Table C-18. Test Series H

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
H1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H2	EB1	E-bay	Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H3	EB3	E-bay	Cable Current	I-320 Probe	172.0	Rhombic	V	a/c nose incident	F
H4	C1	Cabin	Field	AD-60 D-Dot	172.0	Rhombic	V	a/c nose incident	F
H5	C2	Cabin	Wire Current	I-320 Probe	172.0	Rhombic	V	a/c nose incident	F
H6	C3	Cabin	Voltage	Long Wire	172.0	Rhombic	V	a/c nose incident	F
H7	C4	Cabin	Field	Ext. antenna	172.0	Rhombic	V	a/c nose incident	C, F

• Notes: This measurement set will investigate or validate:

C) Calibration of aircraft external field measurement

F) On-board instrumentation check-out

Table C-19. Test Series I

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
I1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I2	EB1	E-bay	Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I3	EB3	E-bay	Cable Current	I-320 Probe	430 pulsed	Rhombic	V	a/c nose incident	F
I4	C1	Cabin	Field	AD-60 D-Dot	430 pulsed	Rhombic	V	a/c nose incident	F
I5	C2	Cabin	Wire Current	I-320 Probe	430 pulsed	Rhombic	V	a/c nose incident	F
I6	C3	Cabin	Voltage	Long Wire	430 pulsed	Rhombic	V	a/c nose incident	F
I7	C4	Cabin	Field	Ext. antenna	430 pulsed	Rhombic	V	a/c nose incident	C, F

• Notes: This measurement set will investigate or validate:

C) Calibration of aircraft external field measurement

F) On-board instrumentation check-out

F) Measure aircraft Q

Table C-20. Test Series J

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
J1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident, AM	G
J4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	nose incident	H
J6	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J7	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J8	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	small box	L
J9	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J10	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J11	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move sensor box	L
J12	CP1	Cockpit	Vert. Field	AD-60 D-Dot	800 - 900	Rhombic	V	1% BW, 1000 pts	E
J13	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J14	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J15	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat	M
J16	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J17	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J18	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats	M
J19	CP12	Cockpit	Heater Current	I-320 Probe	0.3 - 1000	Rhombic	V	new probe position	N
J20	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J21	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J22	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability, PM	K
J23	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G
J24	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	J
J25	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J26	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G2
J27	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	G2
J28	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	G2
J29	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G3
J30	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	nose incident	G3
J31	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	G3
J32	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	nose incident	G
J33	C2	Cabin	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	nose incident	H
J34	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	nose incident	H
J35	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	nose incident	I
J36	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J37	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J38	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 10° off axis	P
J39	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P
J40	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P
J41	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	move a/c 5° off	P

• Notes: This measurement set will investigate or validate: -

- E) Variations in coupling with frequency (frequency stirring)
- G) FDTD predictions of field coupling; plane wave incident
- G2) E Bay hatch cover electrically sealed with conducting tape to assess leakage at seam
- G3) E Bay hatch cover open to assess energy leakage
- H) FDTD predictions of thin wire coupling; plane wave incident
- I) Calibration of aircraft external field measurement, plane wave incident
- J) Typical coupling into a representative critical LRU in the E-bay, plane wave incident
- K) Repeatability
- L) FDTD resolution element effects. "Small box" refers to emplacement of a small metallic box (dimensions order of resolution element size) near the sensor box. Movement of sensor box may be impossible if rigidly bonded to airframe
- M) Stirring effects caused by people. Remove small box
- N) Cockpit Window model
- P) Angular sensitivity. Movement to 5° will be performed if measurements at 10° indicate strong sensitivity

Table C-21. Test Series K

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
K1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K4	CP4	Cockpit	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K5	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	side incident	H
K6	EB1	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K7	EB2	E-bay	LRU Voltage	Voltage Probe	0.3 - 1000	Rhombic	V	side incident	J
K8	EB3	E-bay	Cable Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K9	C1	Cabin	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	side incident	G
K10	C2	Cabin	Wire Current	I-320 Probe	0.3 - 1000	Rhombic	V	side incident	H
K11	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	side incident	H
K12	C4	Cabin	Field	Ext. antenna	0.3 - 1000	Rhombic	V	side incident	I
K13	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	repeatability	K
K14	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	move bodies in cabin	M
K15	EB3	E-bay	Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	repeatability	K
K16	CP1	Cockpit	Vert. Field	AD-60 D-Dot	800 - 900	Rhombic	V	1% BW, 1000 pts ⚡	E
K17	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat ⚡	M
K18	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat ⚡	M
K19	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	person in left seat ⚡	M
K20	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats ⚡	M
K21	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats ⚡	M
K22	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	persons in both seats ⚡	M
K23	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	add parasitic wire	O
K24	CP5	Cockpit	Wire Voltage	climbing wire	0.3 - 1000	Rhombic	V	add parasitic wire	O
K25	CP12	Cockpit	Heater current	I-320 Probe	0.3 - 1000	Rhombic	V	new probe position	N
K26	C3	Cabin	Voltage	Long Wire	0.3 - 1000	Rhombic	V	add static ground	Q
K27	CP1	Cockpit	Vert. Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R
K28	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R
K29	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	0.3 - 1000	Rhombic	V	return to nose incident	R

• Notes: This measurement set will investigate or validate:

- E) Variations in coupling with frequency (frequency stirring)
- G) FDTD predictions of field coupling; plane wave incident
- H) FDTD predictions of thin wire coupling; plane wave incident
- I) Calibration of aircraft external field measurement, plane wave incident
- J) Typical coupling into a representative critical LRU in the E-bay, plane wave incident
- K) Repeatability (instrumentation)
- M) Stirring effects caused by people. Remove small box
- O) Effect of cable loads on cavity absorption
- P) Angular sensitivity
- Q) Effect of ground wire
- R) Repeatability (angular)

⚡ Skip if included in previous test series

Table C-22. Test Series PL

TX Ant location	Rx Ant location	Comments
<u>A) STATISTICAL CHARACTERIZATION/INSERTION LOSS</u>		
#1	four locations in cockpit	
#2	four locations in cockpit	
#3	four locations in electronics bay	
#4	four locations in cabin	
#5	four locations in cabin	
<u>B) CAVITY Q</u>		
#1	one location in cockpit	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
#3	one location in electronics bay	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
#4	one location in cabin	use DSA 602, 100 MHz steps to 1 GHz, 200 MHz steps from 1 GHz to 6 GHz
<u>C) CAVITY TO CAVITY COUPLING</u>		
#1	four locations in cabin	
#1	four locations in electronics bay	
#3	four locations in cockpit	
#3	four locations in cabin	
#4	four locations in cockpit	
#4	four locations in electronics bay	

Table C-23. Test Series Pad Characterization

Measurement	Probe	Frequencies		Positions
		Range	Increment	
<u>Case 1 and Case 2</u>				
Current	Prodyn I-320	1 to 15 MHz	2 MHz	Pairs: Starting 22.5 m from feed $P_n = \{ 22.5 + \Delta r (2n-2) , 22.5 + \Delta r (2n-1) \}$ for $n=1$ to 45 with $\Delta r = 30$ cm
		20 to 100 MHz	5 MHz	
		110 to 1000 MHz	10 MHz	

Table C-24. Horizontal Polarization - Rhombic

Test #	Test Point	Coupling Point	Measured Parameter	Probe or Antenna	Freq. (MHz)	Xmit Ant.	Pol	Orientation / Config.	Notes
HP1	CP1	Cockpit	Vert. Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP2	CP2	Cockpit	Horz.1 Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP3	CP3	Cockpit	Horz.2 Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP4	CP4	Cockpit	Wire Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP5	CP5	Cockpit	Wire Voltage	climbing wire	3 - 30	Rhombic	H	Side incident	B
HP6	EB1	E-bay	Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP7	EB2	E-bay	LRU Voltage	Voltage Probe	3 - 30	Rhombic	H	Side incident	D
HP8	EB3	E-bay	Cable Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP9	C1	Cabin	Field	AD-60 D-Dot	3 - 30	Rhombic	H	Side incident	A
HP10	C2	Cabin	Wire Current	I-320 Probe	3 - 30	Rhombic	H	Side incident	B
HP11	C3	Cabin	Voltage	Long Wire	3 - 30	Rhombic	H	Side incident	B
HP12	C4	Cabin	Field	Ext. antenna	3 - 30	Rhombic	H	Side incident *	C
HP13	Weak Signal Line				3 - 30	Rhombic	H	Side incident	V
HP14	Strong Signal Line				3 - 30	Rhombic	H	Side incident	V

• **Notes: This measurement set will investigate or validate:**

- A) FDTD predictions of field coupling
- B) FDTD predictions of thin wire coupling
- C) Calibration of aircraft external field measurement
- D) Typical coupling into a representative critical LRU in the E-bay
- V) Dipole Instrumentation Noise Measurements

* Lower priority, skip if short of time

Appendix B

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NASA B-757 Aircraft Test Report

EMP Development, Analysis, and Testing (EMPDAT)
Program

Contract F29601-88-C-0001

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FOREWORD

This NASA B-757 Aircraft Test Report, UIE-TR-94-0025, has been prepared in accordance with Subtask 03-18, Contract Data Requirements List A016. This report is submitted by UIE, Inc., 2201 Buena Vista Drive S.E., Suite 207, Albuquerque, New Mexico 87106 to the Phillips Laboratory/WSM, 3550 Aberdeen S.E., Kirtland Air Force Base, New Mexico 87117-5776.

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1.0 INTRODUCTION

1.1 BACKGROUND

The Phillips Laboratory (PL), by agreement with the NASA Langley Research Center (LaRC), provided support to test a NASA Boeing 757 (B-757) aircraft in its Large Electromagnetic System-Level Illuminator (LESLI) facility. The purpose of the test series was to acquire low level CW data to validate computer modeling codes and to provide an estimation of the aircraft response to electromagnetic threats expected in a future fly-by test program.

As stated in the General Test Plan provided by Lawrence Livermore National Laboratory (LLNL), "NASA FBL/PBW Program, NASA Boeing 757 HIRF Test Plan, Low Power on-the-Ground Tests" (Ref. 1),

The NASA Fly-by-Light/Power-by-Wire program was initiated to develop technology for a future generation of commercial transport aircraft. Studies have shown that an all-electric aircraft (PBW) could have substantial benefits in terms of weight and maintenance costs over today's aircraft that rely on hydraulic and pneumatic controls. However, one major concern regarding the all-electric aircraft is the potential for conducted and radiated electromagnetic susceptibility of its electronic controls. A way to potentially alleviate this problem (and save weight at the same time) is to route all control and signal information over optical fiber control links (FBL) that are inherently easier to harden against the electromagnetic environment (EME).

Since electro-optic devices and electronic digital computers will still be required, a major objective of the FBL/PBW program is to develop tools and techniques for assessing the survivability of the modern aircraft using such equipment in the electromagnetic environment. The EME includes both externally generated high intensity radiated fields (HIRF) and internally-generated radiated or conducted emissions. The ability to withstand internally-generated emissions is often referred to as electromagnetic compatibility (EMC).

The EME effects assessment tools and techniques developed under the program must ultimately be accepted by industry and the FAA regulatory body to be useful. Therefore, an important aspect of the program is that these tools and techniques must be validated to the satisfaction of this community. A series of aircraft tests are (sic) being planned for this purpose. Specifically, low power on-the-ground tests and fly-by tests will be conducted....

The primary thrust of this aircraft test program is to develop a library or data base of experimental results to be used in the evaluation of modeling codes. A second objective is to support the development of other assessment techniques such as mode-stirred chamber measurements. To support these objectives, it is also necessary to quantify measurement errors and to perform sensitivity studies to allow an estimation of the degree of agreement between measurement and model results that can be reasonably expected.

This report describes the on-the-ground tests performed at the LESLI facility to generate the data which will be used for computer modeling code validation and measurement/model result comparison. Most of the data to support mode-stirred chamber techniques were acquired in a parallel effort by the PL and a report of this aspect of the test program will be provided separately.

1.2 ORGANIZATION

Support for the NASA B-757 CW test came from several organizations. The NASA Langley Research Center is the funding organization which also developed and installed the on-board instrumentation. The Lawrence Livermore National Laboratory was responsible for test planning and test execution management. The Phillips Laboratory (PL/WSM), supported by United International Engineering (UIE), provided the test environment which included the LESLI facility, instrumentation, data acquisition, data reduction, aircraft support, and detailed test planning. Figure 1-1 depicts the key participants in the test.

Figure 1-1. B-757 Test Organization.

1.3 EXPERIMENTS

Reference 1 discussed in detail the experiments which were performed during the B-757 on-the-ground test. They are summarized as follows:

1. Experiments in which the aircraft was excited by dipole antennas driven by stepped CW around three center frequencies (25.85 MHz, 172 MHz, and 430 MHz) and in two polarizations (vertical and horizontal). The three center frequencies represent the frequencies of the threats against which the aircraft is to fly.

2. Experiments to check out the on-board instrumentation in which the aircraft was excited by the common mode rhombic antenna dwelling at 25.85 MHz and 172 MHz and pulsed with a burst of modulated 430 MHz CW.
3. Experiments to assess the broadband response of the aircraft when it was excited by the common mode rhombic antenna driven by stepped CW from 300 kHz to 1 GHz. The excitation was provided with the aircraft nose on, side on, and with orientation variations.
4. Experiments to assess the aircraft's resonant response at 3 MHz when excited by the differential mode (horizontal polarization) rhombic antenna driven by stepped CW from 2 MHz to 30 MHz.
5. An experiment to determine characteristics of the concrete ground plane in which one leg of the rhombic antenna was laid out over the ground plane on a styrofoam pad and current measurements made along its length as it was driven from 300 kHz to 1 GHz.

1.4 SCHEDULE

1.4.1 Scheduling: As-Planned/As-Accomplished

The NASA Boeing 757 Low Power On-the-Ground Test was a dynamic program. The original plan called for the test of a Boeing 737 aircraft. When a B-757 was substituted, major impacts on test planning and scheduling resulted. Experiments had to be modified and the aircraft arrival date was not determined until a few weeks before the start of the test. As the data were reviewed, new experiments were indicated and added to the schedule. Consequently, the schedule changed frequently over the course of program development. Attempts to document all the changes would produce confusion rather than clarification. Figure 1-2 illustrates the original test schedule as determined on 1 August 1994 compared to that which was accomplished.

Figure 1-2. NASA B-757 Test Schedule.

1.4.2 Daily Test Schedule

The NASA B-757 test plan, Reference 1, called for a test day which provided for eight hours of data acquisition, an hour at the start of each day for preparation, an hour at the end of the day to secure the site, and a one-hour lunch break. Considering the hours of sunrise and sunset during August through October, it was decided to open the site at 0630 in the morning and have it secured by 1730. Figure 1-3 shows the daily schedule as planned and the parties responsible for activity accomplishment. The daily schedule was actually more flexible than depicted. Frequently, data acquisition started before 0730 and lunch was taken when a convenient break occurred around 1100. On several occasions, data continued to be acquired past 1630 to complete a configuration.

Figure 1-3. NASA B-757 Daily Test Schedule.

2.0 PRE-TEST ACTIVITIES

2.1 DETAILED TEST PLANNING

Reference 1, while a good general test plan for the NASA B-757 test, is not sufficiently detailed to implement at the LESLI site. For example, it does not provide test point identification in a format that lends itself to entering in a CWDAS header, nor does it provide or contain all of the information required to properly prepare instrumentation setups. Therefore, a significant amount of detailed test planning was required by the Phillips Laboratory before the arrival of the aircraft. This section of the report describes those activities.

2.1.1 CW Sweep Designation Definitions

Reference 1 requires 15 separate and distinct CW sweep types which vary the F_{MIN} , F_{MAX} , and Q (number of points) parameters. Previous tests at LESLI have used the sweep designations A, B, C, and D in the CWDAS header to represent the 300 kHz to 100 MHz, 100 MHz to 1 GHz, 1 GHz to 2 GHz, and 2 GHz to 3 GHz amplifiers, respectively. Since there is another field in the header for amplifier identification, this procedure has always been redundant. Sweep designations for the B-757 test were determined by the sweep parameters. Since the sweep number appears as half the data file name, a data reviewer can immediately determine which parameters were used. The value of "Q" was determined for each sweep required by the test plan and Table 2-1 was prepared for use throughout the test. Sweep designations "A" and "B" are the normal LESLI sweeps, sweep designations "J" and "K" represent dwelling at 25.85 MHz and 172 MHz, respectively, and sweep designation "L" is the pulse at 430 MHz.

Table 2-1. Sweep Designation Definitions.

SWEEP DESIGNATION	F_{MIN}	F_{MAX}	No. POINTS	Q	COMMENTS
A	300 kHz	100 MHz	932	60	NORMAL RHOMBIC SWEEP
B	100 MHz	1000 MHz	413	82	NORMAL RHOMBIC SWEEP
C	23 MHz	28 MHz	1000	2502	DIPOLE SWEEP
D	25.7 MHz	26 MHz	1000	5580	DIPOLE SWEEP
E	150 MHz	200 MHz	1000	1595	DIPOLE SWEEP
F	171 MHz	173 MHz	1000	42700	DIPOLE SWEEP
G	350 MHz	500 MHz	1000	1282	DIPOLE SWEEP
H	427 MHz	432 MHz	1000	42650	DIPOLE SWEEP
J	25.85 MHz	25.85 MHz	1	N/A	RHOMBIC DWELL
K	172 MHz	172 MHz	1	N/A	RHOMBIC DWELL
L	430 MHz	430 MHz	1	N/A	RHOMBIC PULSE
M	950 MHz	959 MHz	1000	52700	RHOMBIC SWEEP
N	2 MHz	30 MHz	250	35	RHOMBIC SWEEP DIFF.
P	1 MHz	100 MHz	2	50	GROUND PLANE CHAR.
Q	100 MHz	1 GHz	18	100	GROUND PLANE CHAR.

2.1.2 Field Map Point Identification

Two field map efforts were required; a map of the common mode rhombic antenna had been included in the original plan, and field mapping of the dipole antennas was later levied as an additional task.

Table 7.6-1 of Reference 1 identifies field map locations for the rhombic antenna. Locations were defined according to the LESLI coordinate system in which the "X" direction is along the axis of the antenna, "Y" is up, and "Z" is to the right when facing the antenna termination from the source. The associated text provided that the antenna be swept from 300 kHz to 1 GHz. Table 2-2 was created during the detailed planning process

to provide names for each of the points for data acquisition and processing purposes.

Table 2-2. Common Mode Rhombic Field Map Points.

MAP POINT	X	Y	Z	COMMENTS	ACQUIRED
7FMA	40	5	-2	ACD-4; THREE COMPONENTS	9/12/94
7FMB	40	1	0	ACD-4; THREE COMPONENTS	9/8/94
7FMC	40	3	0	ACD-4; THREE COMPONENTS	9/7/94
7FMD	40	5	0	ACD-4, MGL-6; THREE COMPONENTS EACH	9/8/94
7FME	40	3	2	ACD-4; THREE COMPONENTS	9/7/94
7FMF	40	5	2	ACD-4; THREE COMPONENTS	9/12/94
7FMG	40	5	5	ACD-4, MGL-6; THREE COMPONENTS EACH	9/8/94
7FMH	40	3	8	ACD-4; THREE COMPONENTS	9/7/94
7FMJ	40	5	8	ACD-4; THREE COMPONENTS	9/12/94
7FMK	40	5	10	ACD-4, MGL-6; THREE COMPONENTS EACH	9/9/94
7FML	40	5	12	ACD-4; THREE COMPONENTS	9/9/94
7FMM	40	3	15	ACD-4; THREE COMPONENTS	9/6/94
7FMN	40	5	15	ACD-4; THREE COMPONENTS	9/9/94
7FMP	50	3	0	ACD-4; THREE COMPONENTS	9/1/94
7FMQ	50	3	5	ACD-4; THREE COMPONENTS	9/1/94

The dipole field map locations are contained in Table 7.6-2 of Reference 1.

The coordinate system for this effort was with respect to the dipole antennas. In a system similar to the Rhombic, the positive "X" direction was in a line perpendicular to the dipole when the dipole was in the horizontal orientation. The "Y" direction was up, and "Z" to the right when looking from the antenna in a positive "X" direction. Table 2-3 was developed to name each of the points. As can be seen in the table, only the center frequency was provided in Reference 1. After bandwidth experimentation during antenna checkout, and through informal liaison

with LLNL, it was decided to field map the dipoles over the same frequency ranges used for aircraft tests, sweep designations C, E, and G from Table 2-1.

Table 2-3. Dipole Field Map Points.

MAP POINT	FREQ. MHz	POL	X	Y	Z	COMMENTS	ACQUIRED
DFMA	25	V	2	4	0	ACD-4, MGL-6; THREE COMPONENTS EACH	9/21/94
DFMB	25	V	8	4	0	ACD-4; THREE COMPONENTS	9/21/94
DFMC	25	V	8	2	0	ACD-4; THREE COMPONENTS	9/21/94
DFMD	25	H	2	3	0	ACD-4, MGL-6; THREE COMPONENTS EACH	9/20/94
DFME	25	H	8	3	0	ACD-4; THREE COMPONENTS	9/20/94
DFMF	25	H	8	2	0	ACD-4; THREE COMPONENTS	9/20/94
DFMG	172	V	2	3	0	ACD-4, MGL-6; THREE COMPONENTS EACH	10/21/94
DFMH	172	V	8	3	0	ACD-4; THREE COMPONENTS	10/21/94
DFMJ	172	H	2	3	0	ACD-4, MGL-6; THREE COMPONENTS EACH	10/20/94
DFMK	172	H	8	3	0	ACD-4; THREE COMPONENTS	10/21/94
DFML	430	V	2	3	0	ACD-4, MGL-6; THREE COMPONENTS EACH	10/20/94
DFMM	430	V	8	3	0	ACD-4; THREE COMPONENTS	10/20/94
DFMN	430	H	2	3	0	ACD-4, MGL-6; THREE COMPONENTS EACH	10/20/94
DFMP	430	H	8	3	0	ACD-4; THREE COMPONENTS	10/20/94
DFMQ	25	H	8	3	6	ACD-4; THREE COMPONENTS	9/21/94
DFMR	25	H	8	3	-6	ACD-4; THREE COMPONENTS	9/21/94
DFMS	172	H	8	3	6	ACD-4; THREE COMPONENTS	10/21/94
DFMT	172	H	8	3	-6	ACD-4; THREE COMPONENTS	10/20/94
DFMU	430	H	8	3	6	ACD-4; THREE COMPONENTS	10/20/94
DFMW	430	H	8	3	-6	ACD-4; THREE COMPONENTS	10/20/94

2.1.3 Instrumentation Planning

Twelve basic test points were created in the NASA B-757 and data on these points were taken in many different orientations and configurations. A cable from each point was routed to the internal instrumentation console located in the forward, starboard side of the first class compartment. Each cable could be easily disconnected from the internal instrumentation and connected to an external system.

The original plan called for the PL to provide three multi-input (four), high frequency, NanoFast fiber optic links for routing data to the LESLI CW data acquisition system. Each point could be permanently instrumented, requiring re-instrumentation only to change batteries or configuration and, most importantly, ensuring the test point maintained the same instrumentation setup.

As it turned out, only two links were available when the test started, so a plan had to be devised to maximize link efficiency and to minimize the number of times re-instrumentation would be required. Appendix C of Reference 1 contains the B-757 on-the-ground test matrix and includes all of the required variations. After a review of Appendix C, it was apparent the Test Series J was the key for instrumentation. This test series was to be taken in the nose-on configuration under the common mode rhombic antenna and included many variations on a few key points.

Table 2-4 was developed as the heart of the instrumentation plan. As can be seen in the table, each cockpit and E-bay point was instrumented simultaneously for baseline and variation data acquisition; therefore, only two points had to be changed on each transmitter to effect a complete re-instrumentation. This scheme also permitted acquisition of variation data in the cabin without additional changes to the setup.

Table 2-4. Test Point/Transmitter Selection.

TEST POINT	LOCATION	CABLE DESIG.	PROBE/ SENSOR	XMTR INPUT	COMMENTS
CP1	COCKPIT	T1C3	AD60	NF50	
CP2	COCKPIT	T1C1	AD60	NF20	
CP3	COCKPIT	T1C2	AD60	NF52	
CP4	COCKPIT	T1C4	P132	NF53	
CP5	COCKPIT	T2C1	APRB	NF51	
CP12	COCKPIT	T1C4	P132	NF53	MOVE PROBE FOR TWO MEASUREMENTS
EB1	E-BAY	T2C2	AD60	NF21	
EB2	E-BAY	T2C4	APRB	NF22	
EB3	E-BAY	T2C3	P134	NF23	
C1	CABIN	T3C2	AD60	NF50	AFTER COCKPIT MEASUREMENTS
C2	CABIN	T3C4	P133	NF51	AFTER COCKPIT MEASUREMENTS
C3	CABIN	T3C3	APRB	NF20	AFTER COCKPIT MEASUREMENTS
C4	CABIN	T3C1	APRB	NF21	AFTER E-BAY MEASUREMENTS

2.2 DIPOLE ANTENNA FABRICATION AND CHECKOUT

2.2.1 Dipole Antenna Fabrication

Reference 1 required three dipole antennas, having center frequencies of 25.85 MHz, 172 MHz, and 430 MHz respectively, to be mounted three meters above the ground in both horizontal and vertical orientations for excitation of the aircraft. A new support structure was constructed for the effort. It was designed as a truncated pyramid with instrumentation platforms at one meter intervals ranging from one meter to five meters above the ground. The triangular-shaped base was chosen to provide stability on the cambered surface of the concrete LESLI test pad. The pyramid shape was also chosen to enhance stability and to make it easier for personnel to instrument on each platform (one can lean into the structure while performing tasks on one of the higher platforms). The structure members were built from untreated redwood and each platform was made of exterior

grade plywood. A fiberglass ladder was provided for personnel access. The stand was mounted on locking wheels to ease moving about the test facility. Figure 2-1 is a drawing of the new test stand.

Figure 2-1 LESLI Five-Meter Test Stand

Preliminary test planning called for the PL to fabricate the three dipole antennas using baluns provided by LLNL. As the 172 MHz and 430 MHz antennas were relatively short, LLNL fabricated them in Livermore, with appropriate balun interfaces and mounting structures, and delivered them to the LESLI site. The 25.85 MHz antenna, almost 20 feet in length, required a bit of design effort, including the basic antenna material which

had to interface with the provided balun, and a robust support to keep it steady in the wind, avoid damaging the balun, and suspend it as far away from the test stand as practical. Ten foot lengths of one-half inch copper pipe were chosen as the antenna material because it is light in weight, yet stiff enough to minimize bending and sagging.

Figure 2-2 is a sketch of the antenna mounting which was designed and fabricated. An 8' 4" by 4" fiberglass "I" beam provided the main support. Attachment to the test stand was made by means of 2" X 4" wooden clamps which secured the

Figure 2-2. Dipole Antenna Mount

beam when the antenna was in either the horizontal or vertical orientation. An eight foot length of fiberglass "U" channel support beam was fixed to the "I" beam with a rabbit joint and a cutout was provided to accommodate the balun. The "I" beam, support beam, and balun were all bolted together with 1/4 X 20 machine screws. The balun came equipped with a standard "N" connector for attachment of the drive cable and 6mm X 100 metric studs for antenna leg attachment. Two short pieces of half-inch brass round stock were acquired and drilled and tapped for a 6mm X 100 thread. They were soldered in one end of each 10' copper pipe. In this way, a smooth interface was provided by threading each leg of the antenna directly onto the balun.

Additional antenna support, not shown in the sketch, was provided by placing styrofoam spacers between the antenna legs and support beam to keep from applying torque to the balun studs and by stiffening the whole cross member with nylon tie wraps around the

support beam and antenna legs in several locations. When the antenna was mounted in the horizontal orientation, lengths of parachute cord were tied from the ends of the support beam to the test stand to eliminate sag and torque on the balun studs.

This system worked well in practice. It required two people to mount the antenna on the test stand but, once the "I" beam was partially clamped, it was possible to easily and precisely position the antenna over the desired spot on the ground. Since the baluns for the other two antennas had the same mounting hole arrangement, their mounting hardware was removed and the "I" beam, without the support beam, was also used to mount them.

2.2.2 Dipole Antenna Checkout

2.2.2.1 High Frequency Antennas

The initial checkout of the 172 MHz and 430 MHz antennas was made to verify the performance of the antennas when installed on the test stand and to determine if the antennas could be driven at 200 watts from twenty percent below to twenty percent above the center frequency without VSWR difficulties. Figure 2-3 is the instrumentation setup which

Figure 2-3. Checkout Instrumentation Setup

was used for the checkout. Each antenna, in turn, was mounted on the one-meter platform of the test stand in a horizontal orientation. An MGL-6, B-dot, sensor was mounted on the opposite side of the platform about 1.5 meters away from the antenna and oriented for the primary magnetic field. The drive cable from the high frequency amplifier in the Source Shack was connected to the antenna and the MGL-6 was connected to a high fre-

quency NanoFast fiber optic link which transferred the sensor response data to both network analyzers in the Source Shack, and then to the DAS via a fiber optic HPIB link. The checkout of each antenna was performed in three basic steps:

1. The high frequency amplifier was driven at -6 dBm (9 dB below that required for a match with the low frequency amplifier when it has a 200 watt output) with a "Q" resulting in about 100 points in a sweep from a frequency ten percent below the center frequency to a frequency ten percent above the center frequency of the antenna. The data were reviewed in the DAS for reasonability and to verify agreement between the two network analyzers in the Source Shack.
2. The amplifier was driven at -6 dBm with a "Q" resulting in about 200 points from a frequency twenty percent below the center frequency to a frequency twenty percent above the center frequency of the antenna. The data were reviewed in the DAS to verify that ± 20 percent was the useable bandwidth of the antenna.
3. The amplifier was driven at 3 dBm with a "Q" resulting in 1000 points over the ± 20 percent bandwidth of the antenna. The data were reviewed in the DAS to verify amplifier performance and saved and processed for later review by LLNL.

An LLNL representative was on site for the antenna checkout and requested that the antennas also be checked in the vertical orientation and that cross-polarization data be acquired as well. These data were acquired, saved, processed, and delivered to LLNL.

2.2.2.2 Tuning and Checkout of the 25 MHz Antenna

Paragraph 2.2.1 discusses fabrication of the 25.85 MHz dipole antenna. It was necessary to tune the antenna following fabrication. The theoretical length of a half-wave dipole antenna at that frequency is a little over 19 feet. Each leg of the antenna was trimmed to 9' 9" and the antenna, with a total length of 19' 11", was mounted on the three-meter platform of the test stand, extending away from it by about a meter in the horizontal orientation. An MGL-6 magnetic field sensor was mounted on the other side of the platform in the primary magnetic field orientation. The low frequency amplifier was driven at -3 dBm with a "Q" resulting in 1000 points from a frequency twenty percent below the center frequency to a frequency twenty percent above the center frequency of the antenna. The data were noisy and the amplifier drive was increased to the maximum, 4.5 dBm. The data, as reviewed in the DAS, had peaks around 22 MHz and at about 26.75 and 28.75 MHz. Figure 2-4 is the processed data for this sweep.

Figure 2-4. 25 MHz Antenna Tuning, Initial Response.

Three inches of copper pipe were trimmed from each leg of the antenna and the sweep was repeated. There was, as observed in the DAS, some gain above 23 MHz, but the basic structure of the antenna output was the same. Two more inches were trimmed from each end of the antenna, resulting in a total antenna length of 19' 1". Another sweep was taken. This time, although a slight gain above 23 MHz was observed, the lower end of the response was going down. Since no LLNL representative was on site to review the data, it was decided to cease trimming the antenna at this point until the data could be reviewed. Subsequently, LLNL reviewed the data and concurred that the final trimming had produced the optimum antenna/balun combination. Figure 2-5 is the processed data.

Figure 2-5. 25 MHz Antenna Tuning, Final Response.

2.3 FAA COMPATIBILITY CHECKOUT

A unique aspect of the NASA B-757 test program was a requirement to transmit 430 MHz CW in a pulsed mode from the rhombic antenna to simulate a radar against which the aircraft will be flown. LLNL provided an HP8665A signal generator to provide a 430 MHz source and an HP8112A pulse generator to convert the source into a pulsed mode.

The output of the pulse generator drove the PL high frequency amplifier into the common mode rhombic antenna.

An obvious concern with this technique was that harmonics of 430 MHz would be produced during the pulse generation process which would be amplified and were likely to be in skip bands imposed by the FAA.

Accordingly, an experiment was devised to investigate possible FAA interference. Figure 2-6 is the instrumentation setup which was used for the experiment. The HP8665A and the HP8112A were configured in the Source Shack along with a DSA 602 oscilloscope to monitor the response of the LESLI reference sensor. A Tektronics 2712 spectrum analyzer was first used in the Source Shack and then set up in the DAS to monitor the output of the rhombic antenna. The experiment was conducted in three steps.

Figure 2-6. FAA Check Instrumentation

1. First, the output of the amplifier was input to the spectrum analyzer through 60 dB of attenuation to verify proper operation and check the level of produced harmonics. The third harmonic at 1290 MHz was 36 dB below the primary frequency; this equates to about 13 mW into the antenna when radiating. This harmonic was close the airport TACAN frequency and close attention was paid to it during the remainder of the experiment.
2. The second procedure drove the amplifier into the rhombic antenna, starting at -6 dBm into the amplifier and increasing the amplifier input in 3 dB steps until 3 dBm was achieved. The LESLI reference sensor and rhombic antenna spectrum were monitored during this process. No harmonics were detected by the spectrum analyzer at any power level.

3. Finally, a series of pulse trains, thirty seconds in duration, was made every ten minutes for one hour. It was thought that the actual test procedure would be similar when the onboard instrumentation was being checked in this mode.

The FAA reported no interference during the compatibility check, and it was decided to conduct the onboard experiment at the appropriate time.

2.4 DIPOLE ANTENNA FIELD MAPPING

As can be seen in Figure 1-2, field mapping of the dipole antennas was conducted in two phases. The 25 MHz antenna was mapped on 20 and 21 September, immediately following its tuning and checkout (described in Paragraph 2.2.2.2). The other two dipole antennas were mapped on 19 October through 21 October after the LESLI aircraft data acquisition and ground plane data acquisition activities had been completed and the B-757 had been moved to Pad 4 for cavity experiments.

Table 2-3 lists the dipole field map points and provides their locations with respect to the antenna. The table also includes the date on which data for each point were acquired. General measurement procedures are described in Paragraph 3.1, above. Except for the 25 MHz antenna in the vertical orientation on the four-meter platform, the antennas were mounted on the three-meter platform about 1.5 m from the edge. The reference sensors were mounted behind the antennas on the platform. Their coordinates (Table 2-3) were $X = -2.5$, $Y = 3$, and $Z = 0$ on the three-meter platform and $X = -2.5$, $Y = 4$, and $Z = 0$ on the four-meter platform.

2.5 RHOMBIC ANTENNA FIELD MAPPING

Field mapping of the rhombic antenna was conducted from 1 September through 12 September and was completed ahead of schedule. Table 2-2 lists the field map points and indicates the date on which each was acquired. Figure 2-7 is a scale drawing of the LESLI test pad with the field map points indicated.

plane data from the MGL-7 reference sensor at 10CL and in the field data, it is deemed to be real. Figure 2-8 is a ten-sweep overlay of 10CL measurements.

Figure 2-8. Ten Sweep Overlay of 10CL.

2.6 AIRCRAFT INSTRUMENTATION

The aircraft arrived on 22 September, was positioned in the nose-on orientation on the LESLI pad, and was prepared for testing. The NASA crew installed the sensor box in the cockpit, the Collins VHF radio in the E-Bay, and connected the external antenna to the instrumentation console in the cabin (see Figures 7.2.1 through 7.2.3 of Reference 1). The PL team routed the NanoFast fibers into the aircraft via an overpressure vent in the E-Bay and instrumented two fiber optic links.

The CWDAS program was booted up and several sweeps taken without the amplifiers being energized to verify the instrumentation was operating properly.

Paragraph 7.5 of Reference 1 discusses the probes and sensors which were used throughout the B-757 test. Three of these were Prodyne I-320 current probes. These probes were removed from the aircraft and characterized in the DAS. The resultant .CAL files were put in the calibration library for future data processing and the probes re-installed in the aircraft.

The final aspect of preparation was to move the test stand into place, rig the 25 MHz antenna in the horizontal orientation, and position the reference sensor.

3.0 TEST ACTIVITIES

3.1 DIPOLE MEASUREMENTS

Dipole measurement activity started ahead of schedule on 23 September and was completed on 29 September. Measurements included aircraft ambient noise and aircraft response data for each of the three antennas in both the horizontal and vertical orientations. The measurement matrix for the dipole tests is contained in Tables C-9 through C-15 of Appendix C to Reference 1.

3.1.1 Configuration

The B-757 was positioned on the LESLI pad in the nose-on orientation, with the nose 40 meters from the rhombic antenna insertion point, for the later rhombic antenna tests. The dipole antennas were located in relation to the aircraft as shown by the coordinate system in Figure 3-1. Since the dipole antennas were to be positioned in the modeling space for the modeling effort, it was necessary to have them relatively close to the aircraft

Figure 3-1. Dipole Antenna Position.

when data were acquired for comparison. The dipoles were placed five meters from the centerline of the aircraft and four meters back from the nose. With the exception of the 25 MHz antenna in the vertical orientation, the center of each antenna balun was three meters above the ground. The vertical 25 MHz dipole was positioned four meters in the air to reduce ground effects on the lower leg. These antenna placements provided maximum

coupling to the cockpit and E-bay with significant coupling to the cabin area. The external VHF antenna, located on the dorsal aircraft surface at the forward end of the cabin, received significant energy, as well.

The MGL-6 reference sensor was instrumented on another test stand and positioned on a line forty-five degrees from a line parallel to the aircraft centerline as measured from the dipole antenna. The reference was 3.5 meters from the dipole for the 172 MHz and 430 MHz antennas, and 5.0 meters away for the 25 MHz antenna. The reference was positioned at a height of three meters in all cases.

3.1.2 Measurement Procedures

Figure 3-2 diagrams the instrumentation setup which was used for the dipole tests. All the instrumentation, including NanoFast fiber optic link gain settings, was under computer control by the CWDAS program via a fiber optic GPIB link between the DAS and the Source Shack.

Two HP8753C network analyzers were used to acquire two channels of data on one

sweep. Network analyzer #1 provided the drive to either the low frequency (300 kHz - 100 MHz) amplifier or the high frequency (100 MHz - 1 GHz) amplifier which was under manual control by the Source Shack Operator. The network analyzers were synchronized by a 10 MHz frequency reference.

Figure 3-2. Dipole Instrumentation.

As discussed in Paragraph 2.6, two fiber optic links were installed in the aircraft. The inputs to each transmitter were instrumented as listed in Table 2-4; the fibers were routed to their receivers in the Source Shack and connected to the "A" input of either network analyzer #1 or #2.

A unique feature of this program was the treatment of the reference data. It was desired to take the ratio of the data to the reference and multiply it by the reference during processing to preserve phase information and eliminate sweep-to-sweep variations. The output of the reference NanoFast receiver was sent through a power divider into the "B" input of each network analyzer to acquire ratio data on both channels. The resultant 6 dB loss through the divider was accounted for in the processing.

The DAS operator acquired data according to the procedures in Sections 4.0 and 9.0 of Reference 2. The data were processed in accordance with Paragraph 7.9.2 of Reference 1 and delivered to LLNL.

3.1.3 Skip Bands

Table 2-1 lists the frequency ranges which were used for the dipole tests. There was a requirement levied by the FAA and FCC that the dipole antennas not radiate over certain, specified frequency bands. These bands are termed "skip bands" and are listed in Reference 3. CWDAS was programmed to omit these frequencies when controlling network analyzer #1. Within each range listed in Table 2-1, there were frequencies which were not transmitted.

3.2 ON-BOARD INSTRUMENTATION CHECKOUT SUPPORT

The rhombic antenna was rigged in the common mode on the afternoon of 29 September. Instrumentation noise measurements (measurements in which the probe or sensor is replaced by a fifty-ohm load) were taken for all of the installed data paths pursuant to

Table 2-4 and Table C-16 of Reference 1. The data were processed, QC'd, and delivered to LLNL for review and use in their analyses.

Paragraphs 1.3, and 7.8 of Reference 1 indicate one of the test objectives was to validate performance of the onboard instrumentation in low-level steady state and pulsed CW environments to predict appropriate settings for the future fly-by test. Five days were scheduled for the experiment because the NASA team had not exercised their equipment under field conditions and had no pre-experiment predictions. This procedure had never been performed at LESLI either, so it was decided to do a dry run of the steady state aspect of the experiment while waiting for the LLNL representative to arrive and set up the pulsed mode.

This was a power-on experiment.

The aircraft remained in the nose-on orientation under the common mode rhombic antenna and, on the afternoon of 30 September, the aircraft was powered by means of its APU. Communications were established between the NASA operator in the aircraft and the Source Shack operator via hand-held radios. The Test Director stationed himself in the DAS to monitor the spectrum analyzer and

Figure 3-3. Onboard Instrumentation Check.

to communicate with the FAA, should that become necessary. The Source Shack operator put Network Analyzer #1 on local control and set it up to output a 25.85 MHz sine wave to the amplifier (Figure 3-3). The NASA operator got his system up and running and requested that the amplifier be turned on. The Source Shack operator turned on the amplifier for about thirty seconds, resulting in a steady state 25.85 MHz output from the rhombic antenna which was monitored in the DAS.

The NASA operator made adjustments to his equipment during the thirty second period. After a series of these antenna excitations, he was satisfied that his equipment was properly adjusted. The procedure was repeated for 172 MHz and 430 MHz with similar positive results.

Data were acquired for Test Series G (25.85 MHz) and Test Series H (172 MHz) of Reference 1 on the morning of 3 October. Since the experiments went so well and we were ahead of schedule, instrumentation noise measurements were also acquired at the two frequencies in addition to the test plan requirements.

The LLNL representative configured the pulse-mode instrumentation for 430 MHz (see Figure 2-6). Communications were established between the aircraft and the Source Shack, as above. After a number of pulses were attempted, it was determined that the pulse generator, with the 200W LESLI amplifier driving the rhombic antenna, did not provide adequate signal levels inside the aircraft. The ambient noise was so high that the NASA instrumentation triggered on the noise rather than on the 430 MHz pulse. Though somewhat disappointing, this was a valuable result because it provided NASA with the opportunity to acquire band-pass filtering and/or additional amplification in their instrumentation suite and check it out before the fly-by test.

3.3 COMMON MODE RHOMBIC MEASUREMENTS

Measurements under the common mode rhombic antenna began on 3 October and were completed on 13 October. Measurements included all the tests listed in Tables C-20 and C-21 of Appendix C to Reference 1 and some experiments which were added as the data were reviewed and issues arose which had to be resolved. These included a repeat of the ten degree off-axis measurements (Tests J36, J37, and J38 of Table C-20 to Reference 1), a repeat of the E-Bay sealing experiment (Tests J26, J27, and J28 of Table C-20 to Reference 1), a repeat of the parasitic wire experiment (Tests K23 and K24 of Table C-21 to Reference 1), and a number of measurements to investigate the effects of configuration differences (see Paragraph 3.3.4).

The NASA test team was responsible for aircraft configuration and UIE positioned the B-757 in its various orientations as directed by the test plan. Figure 3-4 is a scale drawing of the LESLI pad with the B-757 in the nose-on orientation for the Test Series J measurements. The coordinate system is indicated in the figure.

B-29

three meters from the antenna insertion point ($X = 43$), and with the nose fifteen meters in the positive "Z" direction.

All the B-757 data under the short rhombic antenna were acquired with the power off. No attempt was made to simulate a power-on condition using circuit breaker settings, jumpers, etc. Settings of circuit breakers were important to test results. Their positions were verified by NASA before the start of each test day. It was also found that the positions of the pilot and co-pilot seats and armrests were important, so the seats were configured in the mid-point stop position with the inboard armrest up for all baseline tests. Except for the variation tests laid out in Tables C-20 and C-21 of Appendix C to Reference 1, all data were acquired with doors and hatches shut, no personnel in the aircraft, and with the static ground off.

3.3.2 Measurement Procedures

Figure 3-5 shows the instrumentation setup used for the rhombic antenna tests. With the exception of the antenna and the reference sensor, it was identical to the setup used for acquisition of dipole antenna data. The antenna, of course, was the rhombic configured in the common mode. The

Figure 3-5. Rhombic Instrumentation.

reference sensor was an MGL-7 positioned on the metal ground plane, ten meters from the antenna insertion on the center line of the antenna.

Data acquisition and processing procedures for the common mode rhombic measurements were identical to those described in Paragraph 3.1.2.

3.3.3 Skip Bands

Paragraph 3.1.3 discusses the requirement to avoid transmitting from the dipole antennas on certain frequencies. The same requirement was levied on the rhombic antenna. The skip bands are listed in Reference 3.

3.3.4 Configuration Issues

Intentional variations in aircraft configuration were an important aspect of the test and are discussed in Reference 1. They included positioning and moving people in the cockpit and cabin, inserting and moving a small metallic box in the cockpit, introducing a small antenna in the cockpit, opening the E-bay door and electromagnetically sealing the E-bay door, covering the windshield with aluminum foil, and connecting the static ground to the aircraft. Data were acquired for all these variations.

Configuration control of a system-level test object like the B-757 is not an easy task; two cases of unintentional configuration variations were observed during the testing of the B-757. A Collins VHF radio was modified with internal instrumentation and installed in place of the existing radio in the E-bay upon aircraft arrival. The Collins radio could not be powered because of the modifications. The standard procedure was to pull the circuit breaker to the radio, located in the cockpit, before powering the aircraft to run daily functional checks.

In Test Series J, the breaker was found to be pulled during a configuration inspection. It was determined the breaker had been in the pulled condition during the previous day's data acquisition. The test point in the VHF radio (EB2) measured the electrical power cable to the box, so it became apparent the status of the breaker was likely to be important. The appropriate measurement was repeated and Figure 3-6 is an overlay of the two plots.

Figure 3-6. Test Point EB2-Overlay Plots.

As evidenced by the figure, the status of the VHF radio circuit breaker made a significant difference in the response of test point EB2 at the frequencies from about 1 MHz to 10 MHz, but had little effect at the higher frequencies. This is not an unexpected result considering the circuit breaker was located in the cockpit and the test point was in the E-bay. All the measurements on this point were repeated when the aircraft returned to the nose-on orientation during Test Series K.

The second out-of-configuration condition occurred during the five-degree rotation experiment in Test Series J. Differences in the raw data from the cockpit which seemed to be excessive in view of the small change in orientation were observed during DAS QC. A configuration check revealed the pilot and co-pilot seats to be in the full forward position rather than the half-way stop. An initial plan was to repeat the five degree rotation

measurements as part of Test Series J but, upon review of the processed data, LLNL determined the ten-degree rotation to be more important. A repeat of this orientation was accomplished.

3.4 DIFFERENTIAL MODE RHOMBIC MEASUREMENTS

A new requirement was identified by LLNL to investigate the response of the aircraft to a horizontal E-field at 3 MHz. After several options were explored, it was decided to use the LESLI rhombic antenna in the differential mode.

3.4.1 Configuration

LLNL provided a 200W balun with an appropriate interface for the rhombic antenna. It was specified from 2.5 MHz to 100 MHz, though it had not been tested. The rhombic antenna was lowered on 11 October and configured for the differential mode. During the hoisting process, the north wire became fouled in its caribiner which caused the hoisting line to be pulled partly off its sheave. As a result, the hoisting line was chafed along a two-foot length. The antenna design engineer was consulted and indicated there was a significant safety margin designed into the hoisting gear. He considered the hoisting line to be serviceable but recommended both lines be replaced when convenient since they have been exposed to the elements for quite a few years.

When hoisting was again attempted on 12 October, the south antenna wire parted at one of the termination resistors. Investigation determined the extension wires had not been connected between the drive end and the termination end of the antenna when converting the antenna to differential mode. The resistor was repaired, the extension wires inserted, and the antenna was hoisted without further incident.

This experiment was the first opportunity to use the rhombic antenna in the differential mode since it was fabricated three years ago. From calculations and experience with the long wire rhombic antenna in differential mode, it was known the E-field is primarily

horizontal on the test pad, but there is a significant vertical component near the antenna wires. Accordingly, an issue was raised as to the type and location for a reference sensor. After some discussion it was decided to continue using the MGL-7 magnetic ground plane sensor located at 10CL. It proved to be adequate for LLNL's needs, though it was not the best choice. If future efforts with the rhombic antenna in the differential mode are anticipated, a stand should be designed and fabricated to mount an MGL-6 magnetic free field sensor over the ground plane. The stand should be designed to allow precise replication of the positioning of the sensor.

The aircraft was oriented nose-on, on the antenna center line, with the nose forty meters from the antenna insertion point as it had been for the common mode measurements (see Figure 3-4). It was configured as it had been for the baseline common mode measurements (all doors and hatches closed, no personnel on board, static ground off, etc).

3.4.2 Measurement Procedures

As mentioned above, the antenna balun was rated from 2.5 MHz to 100 MHz and LLNL was interested in data near 3 MHz, specifically from as low as feasible to 30 MHz. Since the amplifier had internal VSWR protection, a sweep was attempted from 2 MHz to 30 MHz. It was accomplished successfully and LLNL decided data should be acquired with 250 points in that frequency range. Sweep designation "N" in Table 2-1 was the result. Table C-24 of Reference 1 lists the points for which measurements were made under the differential mode rhombic antenna. Data acquisition and processing procedures were as described in Paragraph 3.1.2.

3.5 GROUND PLANE CHARACTERIZATION MEASUREMENTS

As mentioned, a major objective of the B-757 test was to acquire data for validation of coupling code models. Because the concrete pad on which the aircraft was positioned is an imperfect conductor, modelers required the constitutive parameters of the pad to include

the ground in model simulations. This, in turn, generated a requirement for an electromagnetic characterization of the pad.

LLNL developed a plan to acquire the requisite data by sweeping one leg of the rhombic antenna which was positioned at a fixed height (_ inch) above the concrete. Wire currents were measured along the antenna wire at fixed intervals.

3.5.1 Configuration

LLNL acquired strips of 1/2 inch, closed cell, styrofoam, eight inches wide. Two layers of the material were laid on the concrete pad along the centerline of the antenna from $X = 20$ meters to $X = 60$ meters (Figure 3-4), and secured to the concrete with duct tape. The rhombic antenna was lowered and one leg disconnected. Both arms of the tensioning gear were connected to the remaining antenna wire and adjusted so the wire was positioned over the centerline of the antenna. The wire was stretched hand tight and the west end was secured to a stake driven into the ground just off the concrete pad. The termination end was permitted to remain on the ground in the position it assumed when the antenna was lowered. Cutouts were made in the styrofoam at the test point locations (Table 3-1) to accommodate current probes and keep the wire straight during instrumentation. The wire was tightened with the turnbuckles of the tensioning gear to rest evenly on the styrofoam along its length and conform to the camber of the pad.

3.5.2 Measurement Procedures

Reference 1 required current measurements to be taken every thirty centimeters along the antenna wire from $X = 22.5$ meters to $X = 49.2$ meters. Table 3-1 was created to identify the resultant ninety test points (GP01 through GP90).

Table 3-1. Ground Plane Characterization Points.

TEST POINT (GPnn)	X	Y	Z	TEST POINT (GPnn)	X	Y	Z
1	22.50	0	0	46	36.00	0	0
2	22.80	0	0	47	36.30	0	0
3	23.10	0	0	48	36.60	0	0
4	23.40	0	0	49	36.90	0	0
5	23.70	0	0	50	37.20	0	0
6	24.00	0	0	51	37.50	0	0
7	24.30	0	0	52	37.80	0	0
8	24.60	0	0	53	38.10	0	0
9	24.90	0	0	54	38.40	0	0
10	25.20	0	0	55	38.70	0	0
11	25.50	0	0	56	39.00	0	0
12	25.80	0	0	57	39.30	0	0
13	26.10	0	0	58	39.60	0	0
14	26.40	0	0	59	39.90	0	0
15	26.70	0	0	60	40.20	0	0
16	27.00	0	0	61	40.50	0	0
17	27.30	0	0	62	40.80	0	0
18	27.60	0	0	63	41.10	0	0
19	27.90	0	0	64	41.40	0	0
20	28.20	0	0	65	41.70	0	0
21	28.50	0	0	66	42.00	0	0
22	28.80	0	0	67	42.30	0	0
23	29.10	0	0	68	42.60	0	0
24	29.40	0	0	69	42.90	0	0
25	29.70	0	0	70	43.20	0	0
26	30.00	0	0	71	43.50	0	0
27	30.30	0	0	72	43.80	0	0
28	30.60	0	0	73	44.10	0	0
29	30.90	0	0	74	44.40	0	0
30	31.20	0	0	75	44.70	0	0
31	31.50	0	0	76	45.00	0	0
32	31.80	0	0	77	45.30	0	0
33	32.10	0	0	78	45.60	0	0
34	32.40	0	0	79	45.90	0	0
35	32.70	0	0	80	46.20	0	0
36	33.00	0	0	81	46.50	0	0
37	33.30	0	0	82	46.80	0	0
38	33.60	0	0	83	47.10	0	0
39	33.90	0	0	84	47.40	0	0
40	34.20	0	0	85	47.70	0	0
41	34.50	0	0	86	48.00	0	0
42	34.80	0	0	87	48.30	0	0
43	35.10	0	0	88	48.60	0	0
44	35.40	0	0	89	48.90	0	0
45	35.70	0	0	90	49.20	0	0

The initial setup for acquiring the ground plane characterization data was identical to Figure 3-5; i.e., a two-network analyzer setup in which two measurements would be made on each sweep. One-meter coaxial cables were chosen to connect Prodyne I320 current probes to NanoFast high frequency fiber optic links. The cables were positioned orthogonal to the antenna wire. This arrangement minimized both coupling to the

instrumentation cable shields and interference from the NanoFast transmitters, while keeping the cables short enough to prevent high frequency loss.

A dry run was conducted on 17 October. To preserve the required phase information, the first point, GP01, was designated as Reference and all the data were acquired with respect to that point. Accordingly, GP01 was connected to input B of both network analyzers and GP02 and GP03 were connected to network analyzers #1 and #2, respectively. A sweep was taken with the high frequency amplifier (sweep parameters "P" and "Q" of Table 2-1 pertain to the ground plane characterization experiment) and electrical delay was introduced into each data path so the electrical difference between the data path and the reference path was zero. Thus, the phase differences between the paths were zero and phase differences in data would be between the data point and the reference.

The phase information between the two network analyzers did not match well and it was apparent that future analysts could become confused between the two. A decision was made to use a single network analyzer and a single data set per sweep. The electrical delay calculated to produce zero phase between GP01 and GP02 was used for all measurements. The dry run was continued by instrumenting the first thirty points, in turn, acquiring high (low) frequency data, changing amplifiers, and acquiring low (high) frequency data. This process was time consuming and introduced the additional risk of damaging an amplifier connector, but it did have the advantage of acquiring both the sweeps without an instrumentation change.

The data were processed as described in Paragraph 3.1.2 and, upon review, the LLNL representative decided it was more important to acquire the data quickly and safely. Accordingly, on 18 October, all the low frequency and one third of the high frequency data were acquired. The remaining high frequency data were obtained on 19 October.

3.5.3 Skip Bands

The LESLI antenna had never before been used in the configuration required for the ground plane characterization effort. It was unlikely there would be any emissions beyond the site; however, the rhombic skip bands (Reference 3) were used to be safe.

3.6 CROSSTALK

The multi-input NanoFast fiber optic links have a crosstalk rejection of only 30 - 40 dB. This fact has been recognized for some time and has been accounted for in high level pulse testing by instrumenting like-measurements on the same transmitter; e.g., all wire measurements or all bulk cable measurements. In this way, no single transmitter input coupled its response in a dominate fashion to other inputs.

The NASA B-757 test was the first to make extensive use of the NanoFast multi-input capability at LESLI and problems with crosstalk were not anticipated in the low level environment. Each dipole test series (A through F) had a requirement to acquire instrumentation noise for a test point with a strong response and a test point with a weak response. As used at the LESLI facility, instrumentation noise is a measurement taken with the test point's sensor or probe replaced by a 50 load and the antenna excited in the normal manner. All of the other instrumentation, including cables attached to other fiber optic inputs, remains in the same configuration. One is thus able to determine the effects of the instrumentation in making measurements.

After a DAS review of the responses for all the baseline measurements during Test Series C (172 MHz dipole antenna in vertical mode.), Test Point CP4, a current measurement on the vertical wire in the cockpit, was the chosen weak responder. The current probe was disconnected and a 50 load connected in its place at the cockpit-end of the data cable (T1C4) and the noise measurement was taken. It was immediately obvious in the DAS that resonances were in the data which were well above the noise floor. Figure 3-7 depicts the processed data of the response and, as can be seen, there are peaks which

equate to something about 30 meters in length resonating. This was obviously not the 18 inch vertical wire; it was the response of one of the other instrumented points crossing over to the input of Test Point CP4. It was probably the aircraft resonant response as detected by one of the D-dot sensors located in the cockpit.

All other inputs to the Nanofast transmitter were disconnected and the noise measurement was repeated. Figure 3-8 is the response.

Figure 3-7. Test Point CP4 Instrumentation Noise; Other Inputs Connected.

Figure 3-8. Test Point CP4 Instrumentation Noise; Other Inputs Disconnected.

It is 40 dB below the peak responses of Figure 3-7 and has the characteristic noise shape. Time did not permit a thorough investigation to determine which input(s) were causing the problem. Both CP1 and CP3 cockpit D-dot sensors were connected to the same transmitter (see Table 2-4), were strong responders, and exhibited the same resonances for many measurements.

For reasons discussed above, it was not feasible to instrument like-responders on the same transmitters. Data acquisition was repeated for Test Point CP4 in Test Series C with no other inputs connected to the transmitter. Data were subsequently acquired in this manner on all test points having a weak response in a particular test series.

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Appendix C

The Determination of the Constitutive Parameters of a Medium with Application to a Reinforced Concrete Pad

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1. Introduction

This report describes the experimental and analytical program performed to determine the constitutive parameters of the reinforced concrete pad in the test facility used during the Low Power On-the-Ground portion of the NASA Boeing 757 HIRF Tests [1]. These tests were conducted during the period September 20 to October 21, 1994 in the LESLI facility at the Phillips Laboratory, Kirtland AFB, NM.

The on-the-ground tests were designed to meet several objectives including support of a flight test series and the generation of data for the validation of codes and models that could be used to predict the electromagnetic environment in transport aircraft. To satisfy these objectives, tests were to be executed in a known environment and the data compared to modeling results. A critical feature of this testing was the "known environment" which implies knowledge of the parameters which are critical to an effective modeling activity and which could include, among many other things, definitions of the airplane and its physical and electrical configuration, the ground upon which it sits when stationary, the fields impinging on the aircraft, and the radiating or bounding structure in the simulator. We would want to specify the electromagnetic characteristics of the entire space that would likely enter into a mathematical modeling effort so that the model can be made as "close" to physical reality as desired prior to exercising computational algorithms which might introduce their own uncertainties.

Since we are evaluating codes used for determination of the electromagnetic environment in aircraft and since the on-the-ground test involved an airplane parked on a pad in the simulator facility, we would require a definition of the constitutive parameters of the pad. Initially, the test plan called for the pad to be partially covered by a highly conducting covering composed of interconnected aircraft landing mats with a total surface area in excess of 15,000 ft². Difficulties associated with timely delivery of the mats, installation of the panels on the pad, and uncertainties in the quality of the electrical interconnection of the individual panels prevented use of these panels and required situation of the airplane on the bare, reinforced concrete pad. As a result, the need for measurement of the constitutive parameters of the LESLI concrete pad arose.

The evaluation of the constitutive parameters was performed under a number of significant constraints that served to restrict the available options. The constraints were:

- In order to limit costs, the measurement process was to be minimized in time extent without severely compromising the quality of the data
- The measurement process was limited by the availability of the experimental system including the RF sources and the data acquisition system. Ultimately, this limitation confined the pad characterization tests to a one-week period including assembly and disassembly of the test fixtures and equipment, testing and dry runs of the entire system, equipment down-time, and actual acquisition runs for the data.
- Construction details for the pad, constructed over 40 years ago, were not available. Thus, reinforcing rod location, concrete thickness and specifications were unknown.
- The measurement techniques were to be completely noninvasive, namely, the pad could not be cored or probes emplaced below the surface.
- The RF equipment and the data acquisition team's experience in performing ground parameter measurements were somewhat limited. Accurate reflection angle, scattering and polarization measurements as might be required in Brewster angle and wave tilt measurements were possibly beyond the capabilities of the available equipment.

Since the precise detailed structure of the pad is unknown and since a detailed spatial description of the constitutive parameters is not required for the purposes of the code validation exercise in view of the level of precision with which other environmental descriptors are known, a technique which averages material characteristics over some spatial extent has been deemed adequate. In view of these observations, the constraints above, and discussions with experts in this technical area such as Drs. Ray King and George Hagen, a method based on wave propagation along wires closely coupled to the ground structure was chosen. The remainder of this report describes the test and analyses involved in determining the constitutive parameters. In the analysis, arguments are made regarding the adequacy of the quality of the results insofar as their role in the code validation exercise is concerned. It would not be reasonable to expend inordinate resources to greatly reduce uncertainties in the parameters when the uncertainties might only be reflected as second order effects. But, realizing the potential value of this scheme for the determination of constitutive parameters in general situations, some concerns and suggestions for future work are presented.

2. Proposed Approach

The method chosen for the determination of the constitutive parameters is based on the theoretical solution for current propagation on a wire above a homogeneous half-space with arbitrary permittivity ϵ , and conductivity σ . For the purposes of this study, the permeability μ of both half spaces (above and below the ground plane) will be assumed equal to that of free space μ_0 . A solution for the current distribution on an infinitely long wire over ground, with no limitations on the ground constants, has been developed by Chang, Olsen and Kuester [2, 3, 4]. Their analysis leads to a modal expansion of the current on the infinitely long wire in which they found two discrete modes and continuous spectrum components associated with radiation. One of the discrete modes is referred to as the structure attached or transmission line mode, is dominant near the source on a wire close to the ground, and is a slow wave in the case of conducting grounds. The other discrete mode exhibits fast wave characteristics, has substantially less attenuation along the direction of the wire than does the transmission line mode, and is mainly important for large heights above ground.

2.1 Solutions for a Wire Over Ground

In [2], with time variation $\exp[-i\omega t]$, an integral equation for the current on an infinite horizontal wire along the x axis, with radius a and height $z = h$ over a ground plane, is solved for a delta-function source located at $x = 0$. The solution for the current is

$$I(x) = \frac{2}{\pi \zeta_0} \int_{-\infty}^{\infty} \frac{\exp(ikx\gamma)}{M(\gamma)} d\gamma \quad (1)$$

where $M(\gamma)$ is the Fourier transform of the integral equation kernel and $k = (\mu_0 \epsilon_0)^{1/2}$, is the propagation constant in the upper half-space. For a perfectly conducting wire, $M(\gamma)$ is [4]

$$M(\gamma) = \zeta^2 [H_0^{(1)}(\zeta A) - J_0(\zeta A) H_0^{(1)}(2\zeta H)] + P(\gamma, 2H) - \gamma^2 Q(\gamma, 2H) \quad (2)$$

where $H = kh$ and $A = ka$, and $\zeta = (1 - \gamma^2)^{1/2}$ with $\text{Im } \zeta \geq 0$. The functions P and Q are given by the integrals

$$P(\gamma, Z) = \frac{2}{i\pi} \int_{-\infty}^{\infty} \frac{e^{-u_1 Z}}{u_1 + u_2} d\lambda \quad Q(\gamma, Z) = \frac{2}{i\pi} \int_{-\infty}^{\infty} \frac{e^{-u_1 Z}}{n^2 u_1 + u_2} d\lambda \quad (3)$$

where $n = (\epsilon_r + i\sigma / \omega\epsilon_0)^{1/2}$ for ϵ_r and σ the relative dielectric constant and conductivity of the ground and

$$u_1 = (\lambda^2 - \zeta^2)^{1/2}, \quad u_2 = (\lambda^2 - \zeta_n^2)^{1/2}, \quad \text{Re } u_1, u_2 \geq 0$$

$$\zeta_n = (n^2 - \gamma^2)^{1/2}, \quad \text{Im } \zeta_n \geq 0.$$

The current in Equation (1) is represented as a spectrum of exponential waves with a propagation constant $k\gamma$. However, if the integration contour is deformed into the complex γ plane, the current is found to be composed of one or two discrete modes at poles of the integrand where $M(\gamma) = 0$ and three branch cut integrals [4]. For the wire height and frequencies considered here, the important components are a discrete mode with $\gamma = \gamma_p$, where $M(\gamma_p) = 0$, and a branch cut integral from $\gamma = 1$. This discrete mode has the character of an attenuating slow wave and is called the transmission line mode. The component of current in this mode is given by the residue at the pole as

$$I_p(x) = 4i(\mu_0\epsilon_0)^{-1/2} \exp(ik\gamma_p x) / M'(\gamma_p) \quad (4)$$

There can be a second discrete mode, known as the surface-attached mode, which has the nature of a fast wave, but it does not appear significant in the case of our measurements. The branch cut integral yields a component of current with asymptotic form $\exp(ikx)/x^2$, so it is important very near the source but it quickly drops below the transmission line mode. However, at some larger distance the exponential decay of the transmission line mode will always take it below the branch cut term which is decreasing algebraically. Hence, there is a window in x where the transmission line mode is dominant, and this region is of primary interest in our measurements since information about the ground parameters is most easily extracted from γ_p .

In the typical forward solution for the discrete modes, the ground constants ϵ and σ are substituted into Equation (2) and the solution for $M(\gamma) = 0$ is found by numerical iteration. For the problem at hand, namely determination of ϵ_r and σ given the attenuation and phase constant for a measured current distribution on the wire, the inverse problem must be solved. Formally, for a given frequency, wire radius, and height above ground, α and β are determined by fitting the measured current $I(x)$. Then $\gamma_p = (\beta + i\alpha)/k$ is substituted for γ in Equation (2) and the equation is solved numerically for ϵ_r and σ . The final results are then the constitutive parameters for the pad at a set of frequencies (as many as desired).

2.2 The Physical Layout

The concrete pad that is the subject of this analysis is shown in Figure 1. The pad, which is approximately 94 meters in diameter, is composed of reinforced concrete with unknown structural characteristics. The source region is covered with an aluminum plate as shown, which measures approximately 20 meters from the edge of the pad to the triangular plates forming the transition region from aluminum to concrete. For the purposes of the characterization, one of the LESLI rhombic antenna wires was stretched, under some tension, across the pad and continued across the earth surroundings. The wire, with diameter $3/16$ inches (radius = 0.238 cm), was approximately 200 meters in length with the portion beyond the 100 meter mark containing randomly placed loads in an attempt to suppress reflections when used in the rhombic configuration. In an attempt to isolate the wire from the pad over a considerable portion of its length, the wire was placed on a dielectric support. The closed cell Styrofoam support was composed of two strips each $1/4$ inch thick and 8 inches wide to form a $1/2$ inch by 8 inch support structure. The support was secured to the concrete with duct tape. A cross section view of the arrangement of the wire, Styrofoam support, aluminum plane, and concrete pad is shown in Figure 2. The Styrofoam support material was characterized using a network analyzer and a stripline fixture, and its relative dielectric constant was measured to be approximately 1.03 over the range of frequencies from 50 MHz to 1 GHz. The wire was tensioned with turnbuckles and secured to a stake beyond the edge of the concrete pad. The remainder of the wire, containing the randomly located loads, was allowed to remain on the ground in the random configuration it assumed when lowered to the ground. Cutouts were made in the Styrofoam support strip to accommodate the current probes. Ultimately, the axis of the wire was $5/8$ inches (1.5875 cm) with an uncertainty of $1/8$ inch above the ground plane. The current was measured with Prodyne I320 current probes that were connected to NanoFast high frequency fiber optic links by one-meter long coaxial cables that were orthogonal to the wire to minimize coupling and high frequency losses. The signals were routed to a fiber optic (F-O) receiver for optical to electrical conversion and then to an HP automatic network analyzer. Ultimately the network analyzer output was routed to a recording computer. The system is shown in Figure 3.

2.3 The Measurement Process

To execute the tests, the wire was driven against the aluminum ground plane and the current distribution was measured at selected points along the wire. From this measured

Figure 1. Pad characterization wire layout

Figure 2. Pad Characterization Wire Layout - Cross Sectional View

Figure 3. Ground characterization instrumentation

current distribution the attenuation and phase constants were determined using methods described later. The method used in data acquisition was to simultaneously measure the current at two points along the structure over the entire range of frequencies with one point (Point 1) always located at the first measurement site closest to the source, viz., $x = 22.5$ meters. For the purposes of this study, the frequency range was from approximately 1 MHz to approximately 1 GHz. Starting at a point 22.5 meters from the feed point on the aluminum plane that coincides with the rhombic apex, the current was measured at 30 cm intervals for a total of 90 points. The locations, with the reference probe at 22.5 meters (Point 1), are given by

$$x \text{ (meters)} = 22.5 + 0.3(n-1), \quad n = \{1, 90\}$$

Based on the premise that the current distribution for a wire very close to the ground is dominated, especially near the source, by a complex exponential $\exp(ik\gamma x)$ with γ defined by zeroes of $M(\gamma)$ in the complex plane, it becomes clear that relative measurements of current are adequate for evaluation of attenuation and phase constants. For example, the ratio of current at Point n to the current at Point 1 when the currents are measured simultaneously, or are the results of identical source conditions at the feedpoint, is simply

$$I(x_n)/I(x_1) = \exp(ik\gamma(x_n - x_1)) \quad (5)$$

Clearly the reference signal strength is normalized out of the analysis and evaluation of the attenuation and phase constant becomes straightforward, in principle. The data was collected by stepping through all frequencies of interest in a spatial-pairwise scheme $[I(x_n)$ and $I(x_1)]$ for all n . Hence, we measure and store $I(x_n, \omega_j) / I(x_1, \omega_j)$, $n = \{2, 90\}$, and $j = \{1, J\}$, i.e., we record the normalized current (as well as each component, in reality) at fixed positions for stepped frequency sweeps. Ultimately, we use this data in a different format, namely, we use the normalized current at fixed frequency for stepped position to determine α and β . The structure of this data matrix is represented graphically in Figure 4 where $I(x, \omega)$ is represented by I_{ij} and the data is acquired along columns (fixed position) and processed along rows (fixed frequency). This then allows the determination of the normalized attenuation and phase constants as a function of frequency. Using these, one then performs the inverse evaluation of the constitutive parameters as described later. Some uncertainties arise regarding this approach to the determination of the constitutive parameters. Namely, it is unknown, a priori, if this method is robust and unaffected by the presence of noise in the measured data. The literature abounds with non-robust methods for evaluation of the parameters in complex exponentials. In addition to the impact of measurement noise in the data, the impact of other uncertainties such as the importance of

Figure 4. Data Acquisition and Processing Paths

precision in the height of the wire above the ground plane, is unknown. All these uncertainties could be corrected with some further work in which numerical testing is offered as a potential fix to this dilemma.

3. Experiment and Data

3.1 The Acquired Data

An example of the data, as acquired, is shown in Figure 5 for two points along the wire, namely, Point 1 (the reference) and Point 20. For fixed position, the data represent the spectrum of the current and the plot is an example of the vertical strip in Figure 4. During the acquisition phase, ninety such data records were generated, i.e., current as a function of frequency for fixed position. In order to remove the source strength from the data, the current magnitude was normalized to the reference current at Point 1 and such a result is shown in Figure 6. The poor data behavior beyond 250 MHz is due in large part to the signal level at Point 20 having fallen below the noise floor in the measurement system. In the vicinity of this anomalous behavior, the current at Point 20 was more than 60 dB below the current at Point 1. And, in this frequency range, the current at Point 1 had already fallen more than an order of magnitude below its value at low frequencies. These combined effects could easily drive the signal below the system measuring capabilities. Also, there are instances where the current at Point 20 exceeds that at Point 1. This can be due to uncertainties in the measurements or the presence of a standing wave on the structure.

For the purposes of data analysis, the records were processed to provide an additional set of records which portray the current as function of position for fixed frequency. This presentation is representative of the horizontal strip in Figure 4 and a visual example of the data for such a "strip" is shown in Figure 7. The data in Figure 7 exhibit a substantial amount of variation on a point to point basis thus leading to questions regarding the source of this structure in the current distribution. Observations were made that the peaks did not move with changes in frequency, thus ruling out a strong standing wave on the line as the cause for these peaks. An investigation was made of the possibility that perturbations and inclusions in the concrete in the vicinity of the peaks might cause the excursions. Visual inspection of the pad and a study of photographs of the pad with the wire in place did not provide an obvious clue as to the cause. The possibility of rebar-induced perturbations in

Figure 5. Current magnitude spectrum at Points 1 and 20

Figure 6. Normalized current magnitude spectrum at Point 20

Figure 7 Normalized current as a function of position along the wire at 30 MHz

the fields and currents was also offered. However, modeling was performed using NEC [6] to analyze an end-driven wire very close ($h=5/8$ inches) to a ground ($\epsilon_r = 6$, $\sigma = 0.006$ S/m) with a single strand of perfectly conducting rebar that was buried at six inches. The effects on the wire current distribution were negligible except when the wire and rebar were parallel and aligned in the vertical plane. In the parallel case, the current showed perturbations in the average values of α and β but nothing in its behavior as localized as seen in the measured data. Nothing could be detected which was capable of causing such a rapid change in current. Also, the pad was constructed of concrete squares and the wire was oriented diagonally across the squares. Given common concrete building practices, the rebar was most likely oriented parallel to the sides of the squares and orthogonal to edges so that it is unlikely that the rebar and wire were parallel. Other possibilities were considered, including measuring equipment malfunction.

A 3-D view of the data in the 10 to 275 MHz range over the sampled extent of the wire allows a visualization of the previous discussions and is shown in Figure 8. The spectral behavior of the current (without normalization), its spatial behavior and its decay rates in these two variables is evident. The presence of the "spikes" or peaks in the current as a function of position mentioned earlier is also evident. Note that the "spikes" occur at identical positions independent of frequency and manifest themselves in this figure as ridges or striations at a constant position coordinate. Since the data acquisition for a single run was effected at a fixed position with frequency stepped, an offset or malfunction throughout a run could manifest itself as a frequency independent perturbation at a fixed location. A few sources of such error were considered. A malfunctioning or improperly placed or configured current probe could produce such perturbations. The current probes were of the "clothespin" type, that is, they were spring-loaded clamps that fit around the wire. These were repositioned for each run with only the reference at Point 1 unperturbed during the data acquisition process. Another possibility was inadvertent or improperly applied attenuators in the fiber optic link.¹ Such a situation could be realized if the stepping attenuator system which was electronically controlled was sporadically "sticking" and reporting an incorrect value to the data acquisition system. At the present time, the identification of the source of the variability of the data has not been successful.

¹ J. H. Millard, Private Communication

Figure 8. Magnitude of current on the wire as a function of position and frequency

3.2 Extraction of Attenuation and Phase Constants

As explained in Section 2.1, the component of current of diagnostic value is the transmission line mode which is dominant in a window from the source to a point where it drops below the branch cut mode. Hence, we need to locate this region on the wire and estimate the attenuation and phase constants. Given that the current can be represented by

$$I(x, \omega) = I_0 \exp [i(\beta(\omega) + i\alpha(\omega))(x - x_i)] , \quad k\gamma = \beta + i\alpha \quad (6)$$

an exponential fit to the acquired data (or a normalized version of the data) or a linear fit to the log of the data can provide values for the normalized attenuation and phase constants. Using the complex natural logarithm of the data, one has

$$-[\alpha(\omega) - i\beta(\omega)](x - x_i) + \ln(I_0) = \ln(I(x, \omega)) \quad (7)$$

so that, for two points along the structure at x_i and x_j at a fixed frequency ω_n , one can solve for $\alpha(\omega_n) - i\beta(\omega_n)$

$$\alpha(\omega_n) - i\beta(\omega_n) = [\ln(I(x_i, \omega_n)) - \ln(I(x_j, \omega_n))] / (x_j - x_i) \quad (8)$$

Keep in mind that these are complex natural logs. Using the real and imaginary parts of the equation with the current represented by $I(x, \omega) \exp(j\phi(x, \omega))$, with $\phi(x, \omega)$ the phase at x and ω , it is a simple matter to extract $\alpha(\omega_n)$ and $\beta(\omega_n)$ and present them in common log notation thus allowing easy conversion to a dB scale

$$\alpha(\omega_n) = 2.3025 [\log|I(x_i, \omega_n)| - \log|I(x_j, \omega_n)|] / (x_j - x_i) \quad (9)$$

$$\beta(\omega_n) = [\phi(x_i, \omega_n) - \phi(x_j, \omega_n)] / (x_i - x_j) \quad (10)$$

In the face of the variability of the data, a Least Squares (LSQ) fit to the data was performed. A linear fit was performed to the log magnitude and phase of the data, individually. Also, a complex exponential was LSQ fit to the complex data. The differences were minimal and the following relates to separate fits to the magnitude and phase information as represented in Equations (9) and (10).

The difficulty in performing LSQ fits to the data for the wire above ground arises from two sources: 1) the measurement system had its limitations and beyond a certain spatial point the data could become “noisy” as the noise floor was encountered and 2) contributions to the current other than the transmission line mode could become dominant at sufficiently large distances at high frequencies. Since the branch cut term decays as x^{-2} , it always prevails over the transmission line mode at sufficiently large distances and manifests itself as a flattening of the current magnitude distribution with distance from the source. In fact,

modeling of the physical configuration under consideration has confirmed such characteristics. But, the noise floor could provide a similar behavior. Since it does not matter that we identify the structure's cause but only avoid it in our LSQ fits, the initial data fitting involved some "eyeballing" of the data. This required inspection of the log(current magnitude) and of the phase to perform a fit to that part which looked "roughly linear". The danger here is that small errors in the resulting value of attenuation and phase constant could ultimately lead to large errors in the ϵ_r and σ if the method of solution was not robust.

Examples of the process of evaluating α and β are illustrated in Figures 9 through 12. In Figures 9 and 10 the magnitude and phase data for 30 MHz are shown. Also shown in the Figures 9 and 10 are the linear fits to the log magnitude and phase over the entire range (including all points from 2 through 90), respectively. Figures 11 and 12 show the respective plots for a frequency of 100 MHz. There, the magnitude and phase deviate from linear beyond certain points along the wire. Over the linear portions in both cases one can see the rapidly attenuating slow wave characteristic of the transmission line mode. Of course, when the magnitude begins to decay at a slower rate we may be seeing either the surface attached mode, the branch cut contribution, or evidence of the noise floor. When the phase deviates from linear and slow wave, we begin to see a wave that is increasing in velocity and may eventually reach the velocity in the upper medium or become the fast wave whose existence is predicted theoretically. The orderly behavior of the phase suggests that the cause of the flattened current distribution is not the noise floor but rather the branch cut. Ultimately, however, this issue does not impact our analysis as it is the transmission line mode that provides attenuation and phase constants that are most important in the evaluation of the relative dielectric constant and conductivity.

3.3 Determination of Relative Dielectric Constant and Conductivity

The process of solving for ϵ_r and σ has already been touched upon. Once values for α and β in the transmission line mode are obtained for a given frequency, the value of $\gamma_p = \beta + i\alpha$ is determined. An iterative solution of the equation $M(\gamma_p) = 0$ for n , the index of refraction for the medium, yields ϵ_r and σ since $n = (\epsilon_r + i\sigma/(\omega\epsilon_0))^{1/2}$. The values of ϵ_r and σ can range from 1 and 0, respectively, to infinity, although real ground will have a much more limited range. For $\epsilon_r = 1$ and $\sigma = 0$, the values of α and β will be nearly $\alpha = 0$ and $\beta = k$.

Figure 9. Log magnitude of normalized current and linear LSQ fit over Points 2 to 90

Figure 10. Phase of normalized current and linear LSQ fit over Points 2 to 90

Figure 11. Log magnitude of normalized current and linear LSQ fit over Points 2 to 66

Figure 12. Phase of normalized current and linear LSQ fit over Points 2 to 30

As ϵ_r and σ are increased, α and β will both start to increase for the attenuating slow wave of the transmission line mode. However, as ϵ_r and σ continue to increase α and β will eventually return to nearly $\alpha = 0$ and $\beta = k$, which holds for a wire over perfectly conducting ground. Hence α and β are limited to a range that can only be determined by solving $M(\gamma_p) = 0$ for a given wire height.

A graphical illustration of the process of determining ϵ_r and σ from α and β is found in Figures 13 and 14. The curves were generated by solving the forward problem (given ϵ_r and σ , solve $M(\gamma_p) = 0$ for γ_p and therefore for α/k and β/k) with the results plotted as α/k and β/k versus σ with ϵ_r as a parameter for wire diameter of 3/16 inches and height of 5/8 inches at 10 MHz. An experimentally determined pair α/k and β/k determine horizontal lines on Figures 13 and 14, and values for ϵ_r and σ representing a solution must fall on these lines in both figures. If no such consistent solution can be found, the cause must be error in the measurement or the experimental parameters. While this graphical approach yields insight into the solution process and its sensitivity to errors, the actual solutions for ϵ_r and σ were obtained by purely numerical solution of the equation $M(\gamma_p) = 0$.

Since α and β were determined by fitting noisy measured data, and since it was possible that inaccurate values of ϵ_r and σ could be obtained that were out of the physically possible range, constraints were imposed during the solution process. This increased efficiency and ensured physical realizability of the results. For the cases of interest, the solutions were constrained to lie in a range considered reasonable for concrete materials even with dense rebar inclusions, namely, $1 < \epsilon_r < 40$ and $0.0001 < \sigma < 0.01$.

The frequency range over which an accurate determination of the attenuation and phase constants was possible was constrained due to several causes. First, the spatial extent over which the current was probed was limited (approximately 26.7 meters) and, at low frequencies, the attenuation in the current was small and difficult to measure accurately. At high frequencies the current decayed quite rapidly so that the linear regions in the log magnitude and phase plots were quite small. In both cases, difficulties were encountered in accurately evaluating attenuation constants and phase factors. In the high frequency case, the LSQ fit was strongly dependent on the chosen range of fit with attendant uncertainties in the constants that were obtained. The behavior seen in Figures 11 and 12 is illustrative of the problem of the shrinking linear region even though, at 100 MHz, it is quite mild. On

Figure 13. Normalized attenuation constant vs. conductivity for various ϵ_r at 10 MHz

Figure 14. Normalized phase constant vs. conductivity for various ϵ_r at 10 MHz

the other hand, the behavior of the log magnitude of the current at 250 MHz which is shown in Figure 15 leads to much greater difficulty in defining the linear region and thus leads to greater uncertainty in establishing the value for the attenuation constants. The phase constant determination is also difficult at high frequencies. Figure 16 is the phase plot over 17 points on the wire at 250 MHz. Clearly, the phase change per cell is quite large and errors are possible. Given the available data and the inability to redo portions of the experiment, a range was determined over which the uncertainties in the values for α and β was considered small. For the purposes of our analysis this range was defined as approximately $5 \text{ MHz} < f < 150 \text{ MHz}$. The lower limit was also consistent with concerns of the experiment personnel regarding their ability to make accurate measurements on the pad in view of previous experience with adverse ground loops and other low frequency limitations. Figure 17 and 18 represent the normalized constants (α/k and β/k) versus frequency as determined from the experimental data.

The data for α and β were used to determine the effective relative dielectric constant and the conductivity of the half space beneath the wire. The process was reasonably robust in the area defined for confidence in estimates of attenuation and phase constants. Outside this range, the process might not return a solution (values of ϵ and σ were not available which would simultaneously satisfy $M(\gamma_p) = 0$). In some cases, "near" solutions were available in that a given value of ϵ_r would not yield a unique value of σ but $M(\gamma)$ was almost equal to zero for a range of σ . These data were not used in this analysis.

4. Analysis

In order to extend our estimates for ϵ_r and σ beyond the range where reliable values of α and β were determined, a theoretical model was used as the underpinning for the results. Such models have been developed in the literature and, for orientational-polarization effects, one has the Debye equations [7,8]

$$\epsilon_r = \epsilon_{\text{inf}} + (\epsilon_{\text{rs}} - \epsilon_{\text{rs}}) / (1 + \omega^2\tau^2) \quad (11)$$

$$\sigma = \omega\tau (\epsilon_{\text{rs}} - \epsilon_{\text{rs}}) / (1 + \omega^2\tau^2) \quad (12)$$

where ϵ_{inf} is the optical limit for the permittivity, ϵ_{rs} is the dc value, and τ is the orientational relaxation time for this model. Plots versus frequency of ϵ_r and σ extracted from the

Figure 15. Current Magnitude in dB and LSQ fit at 250 MHz

Figure 16. Phase of current on wire and LSQ fit over 17 points at 250 MHz

Figure 17. Normalized attenuation constant versus frequency

Figure 18. Normalized phase constant versus frequency

measured current are shown in Figures 19 and 20, respectively. The anomalous behavior of σ in the range 60 to 80 MHz is not well understood. Also shown in each figure is a least squares fit to the model for the behavior of the constitutive parameters versus frequency. In the LSQ fits performed for the data in hand, the values of ϵ_{rs} , ϵ_{inf} and τ were not the same for the fits of the two sets of data. Clearly, such agreement for the two models would be expected for a perfect model as would ϵ_r and σ pairs in agreement with the Kronig-Kramers relationships [9]. For the curves shown, however,

$$\epsilon_r = 4.2418 + 6.1943 / (1 + 1.129 \cdot 10^{-17} \cdot \omega^2) \quad (13)$$

$$\sigma = 4.416 \cdot 10^{-11} \cdot \omega / (1 + 1.354 \cdot 10^{-17} \cdot \omega^2) \text{ for the full range of data} \quad (14)$$

$$\sigma = 3.6385 \cdot 10^{-11} \cdot \omega / (1 + 1.135 \cdot 10^{-17} \cdot \omega^2) \text{ for the restricted data} \quad (15)$$

The restricted data set is composed of the full range of data with frequencies below 18 MHz excluded. The behavior of the permittivity over the frequency range shown is orderly and constrained while that of the conductivity is more variable. Also, the models seem to fit the behavior of the permittivity better than the conductivity. The impact of these issues on propagation in the upper half space is adequately reflected in the variation of the reflection coefficients with variations in the lower medium's wavenumber (or index of refraction, n) which depends on ϵ_r and σ . This wavenumber arises repeatedly in the analyses and is a key determinant of the reflected and transmitted waves at the interface of the materials when a plane wave, for instance, is incident. The wavenumbers in the pad medium and free space, respectively, are given by

$$k_i = k_0 n = k_0 [\epsilon_r (1 + i\sigma/(\omega\epsilon_0\epsilon_r))]^{1/2}$$

$$k = k_0 = \omega[\mu_0\epsilon_0]^{1/2} \quad (16)$$

Two limiting types of propagation in the lower half space are possible, i.e., the conditions under which propagation is conduction or displacement current dominated. Conduction current domination will occur when $\sigma \gg \omega \epsilon_0 \epsilon_r$ and will result in a propagation constant that is essentially independent of the relative dielectric constant in the ground, ϵ_r . On the other hand, displacement current will dominate when $\sigma \ll \omega \epsilon_0 \epsilon_r$ and will result in propagation characteristics relatively insensitive to conductivity, σ , and frequency, ω . The "boundary" between these two regions can be said to be approximately

$$\sigma = \omega \epsilon_0 \epsilon_r$$

Figure 21 shows such boundaries for frequencies of $f = 10, 20, 50, 100, 400$, and 1000 MHz. Also shown in the figure is a contour connecting elements of the set of $\{\epsilon, \sigma\}$ pairs that have been determined experimentally. The sequencing, which is in ascending values

Figure 19. Relative dielectric constant versus frequency - experimental data and curve fit

Figure 20. Conductivity versus frequency - experimental data and curve fits

Figure 21. Displacement/Conduction boundaries and experimental $\{\epsilon_r, \sigma\}$ with frequencies

of conductivity, does not convey any physical information. The important feature to be observed in the figure is the range of the $\{\epsilon, \sigma\}$ set and the fact that the propagation is displacement current dominated at frequencies above about 20 to 50 MHz. Another feature is that for the material under study, using average values over the frequency range (f_1, f_2) of Equations (13) and (14),

$$\langle \epsilon_r(f_1, f_2) \rangle = 4.24 + 2.93 \cdot 10^8 \cdot [\tan^{-1}(2.11 \cdot 10^8 \cdot f_2) - \tan^{-1}(2.11 \cdot 10^8 \cdot f_1)] / (f_2 - f_1)$$

$$\langle \sigma(f_1, f_2) \rangle = 2.595 \cdot 10^5 \cdot \ln[(1 + 5.29 \cdot 10^{-16} \cdot f_2^2) / (1 + 5.29 \cdot 10^{-16} \cdot f_1^2)] / (f_2 - f_1)$$

one finds that average values of $\epsilon_r \sim 7$ and $\sigma \sim 0.005$ appear to be reasonable over the 10 to 100 MHz range. Of course, for frequencies above 50 MHz the values of the conductivity may be of secondary importance.

To further support the observations based on the behavior of the propagation constant or wavenumber in the pad material, attention was directed towards the Fresnel reflection coefficients at the pad interface. These reflection coefficients are given by

$$R_H = [\mu_1 k_0 \cos \theta - \mu_0 (k_1^2 - k_0^2 \sin^2 \theta)^{1/2}] / [\mu_1 k_0 \cos \theta + \mu_0 (k_1^2 - k_0^2 \sin^2 \theta)^{1/2}] \quad (17)$$

$$R_E = [\mu_0 k_1^2 \cos \theta - \mu_1 k_0 (k_1^2 - k_0^2 \sin^2 \theta)^{1/2}] / [\mu_0 k_1^2 \cos \theta + \mu_1 k_0 (k_1^2 - k_0^2 \sin^2 \theta)^{1/2}] \quad (18)$$

with θ measured from the normal to the surface, the subscript E denoting the electric field vector in the plane of incidence, subscript H denoting the electric field vector perpendicular to the plane of incidence, and the subscript 1 denoting the subsurface material (concrete, steel, soil, etc.). Figures 22 to 26 are contour plots of the reflection coefficient magnitude in $\epsilon_r - \sigma$ space for select frequencies in the range of interest. The values of the contours (magnitude of R) are not as important and are not shown. Rather, the curves are meant to convey that the reflection coefficients (both R_E and R_H) for the range of incidence angles are mainly functions of ϵ_r and are therefore displacement current dominated. The implication is that for frequencies greater than about 32 MHz (or thereabouts), the precise definition of σ is not as important as an accurate definition of ϵ_r .

The expressions used in the LSQ fits (Equations (13) and (14)) were plotted parametrically over the range of 0 MHz to 1 GHz. A version of Figure 21 with the LSQ-fit curve is shown in Figure 27. The fit is reasonable for the purposes of understanding the impact of $\{\epsilon_r, \sigma\}$. Clearly, the constitutive parameter values lead to strong displacement current

16 MHz

32 MHz

64 MHz

128 MHz

256 MHz

512 MHz

Figure 22. $R_E = R_H$ for normal incidence ($\theta = 0$) (Vertical axes are conductivity in Siemens/m and horizontal axes are relative dielectric constant)

16 MHz

32 MHz

64 MHz

128 MHz

256 MHz

512 MHz

Figure 23. R_H for incidence at 45 degrees (Vertical axes are conductivity in Siemens/m and horizontal axes are relative dielectric constant)

Figure 24. R_g for incidence at 45 degrees (Vertical axes are conductivity in Siemens/m and horizontal axes are relative dielectric constant)

Figure 25. R_H for grazing angle of incidence (85 degrees from normal incidence) (Vertical axes are conductivity in Siemens/m and horizontal axes are relative dielectric constant)

Figure 26. R_E for grazing angle of incidence (85 degrees from normal incidence) (Vertical axes are conductivity in Siemens/m and horizontal axes are relative dielectric constant)

Figure 27. Experimental data and LSQ fit for the constitutive parameters

effects and the system is generally displacement current dominated. Plots of the relative dielectric constant and conductivity are shown in Figures 28 and 29 for frequencies up to about 300 MHz to illustrate that the region of variability of the parameters is rather confined.

Another indicator of the importance of conduction or displacement current effects is the index of refraction for the medium, i.e.,

$$n = [\epsilon_r + i\sigma/(\omega\epsilon_0)]^{1/2} \quad (19)$$

Clearly, σ becomes unimportant when n can be adequately represented by

$$n \sim [\epsilon_r]^{1/2} \quad (20)$$

Figure 30 shows curves representing the magnitude of Equations (19) and (20) and illustrates that above about 40 MHz, the differences are less than 3%. Above about 150 MHz, the index of refraction has effectively lost its dependence on frequency, and above 100 MHz, it has lost its strong dependency on σ . The index of refraction is, however, strongly affected by the values used for the relative dielectric constant throughout the entire frequency range.

Finally, the magnitude of the reflection coefficient was considered as a measure of the importance of σ . For our purposes, only the normal incidence coefficient was evaluated using the index of refraction in Equation (19) and the approximation ($\sigma = 0$) given by Equation (20). Figure 31 is a plot of the two representations for $R_E = R_H$ for normal incidence. The deviation in the magnitude is less than about 5% for all frequencies. The reflection coefficient is effectively independent of frequency above 150 MHz and nearly so above 80 MHz. It is nearly independent of σ above 50 MHz.

The previous discussions have considered only the relative importance of ϵ_r and σ in the determination of parameters defining wave propagation in the medium. In the following we consider the magnitude of the index of refraction evaluated from the constitutive parameters resulting from our measurements, and look at its comparison to the magnitude of the index obtained from our models for the constitutive parameters based on LSQ fits to our data. Figure 32 is a plot of the magnitude of n versus frequency using the model for ϵ_r and σ as compared to the magnitude as determined from ϵ_r and σ obtained from processing

Figure 28. Relative dielectric constant versus frequency per Equation (13)

Figure 29. Conductivity (Siemens/m) versus frequency per Equation (14)

Figure 30. Two representations for the index of refraction versus frequency

Figure 31. Two representations for the normal incidence reflection coefficient vs. frequency

Figure 32. Magnitude of index of refraction as obtained from raw data and from models

our experimental data. The agreement over the range from 18 MHz or so through 126 MHz is quite reasonable and provides some confidence in using the models for prediction at higher frequencies. The apparent discrepancy between the model and the experimentally-based results may be in part due to the difficulty in determining α and β , and ultimately ϵ_r and σ , from the experimental data.

The relative sensitivity of the reflection coefficient to variations in the index of refraction for the special condition where $\mu_1 = \mu_0$ will be considered to provide some indication of the effects of errors in the process. A full error analysis is beyond the scope of this report. With

$$R_H = [\cos\theta - (n^2 - \sin^2\theta)^{1/2}] / [\cos\theta + (n^2 - \sin^2\theta)^{1/2}] \quad (21)$$

$$R_E = [n^2 \cos\theta - (n^2 - \sin^2\theta)^{1/2}] / [n^2 \cos\theta + (n^2 - \sin^2\theta)^{1/2}] \quad (22)$$

consideration will be given to

$$(1 / R_H) (\partial R_H / \partial n) = 2 n \cos\theta (n^2 - 1)^{-1} (n^2 - \sin^2\theta)^{-1/2} \quad (23)$$

$$(1 / R_E) (\partial R_E / \partial n) = 2 n \cos\theta (n^2 - \sin^2\theta)^{-1/2} (n^2 - 2 \sin^2\theta) / (n^4 \cos^2\theta - n^2 + \sin^2\theta) \quad (24)$$

An approximation for the fractional change due to changes in n is

$$|\Delta R_H / R_H| = 2 |n \cos\theta (n^2 - 1)^{-1} (n^2 - \sin^2\theta)^{-1/2} \Delta n| \quad (25)$$

$$|\Delta R_E / R_E| = 2 |n \cos\theta (n^2 - \sin^2\theta)^{-1/2} (n^2 - 2 \sin^2\theta) / (n^4 \cos^2\theta - n^2 + \sin^2\theta) \Delta n| \quad (26)$$

Over the range from 20 to 120 MHz (the range of the experimental data in Figure 32), we find that $|\Delta R_H / R_H| \leq 0.6 |\Delta n|$ and $|\Delta R_E / R_E| \leq 1.5 |\Delta n|$. The maximum value in the latter result is an overestimated bound except in the vicinity of the Brewster angle.

Removed from the Brewster angle, the result for R_E is in keeping with the result for R_H .

In view of the observations made in this section, the constitutive parameters determined from experimental data over a limited frequency range and the models based on these limited data appear to yield reliable values outside the range of the useable experimental data.

5. Conclusions and Summary

5.1 General Comments

The approach taken herein has proven to be a viable method to determine the constitutive parameters of a medium using noninvasive techniques. There have not been reports in the literature of attempts to perform such constitutive parameter extraction other than in the form of passing comments [10]. The method presented here is based on sound theoretical bases. Some approximations and assumptions have been made in the analysis, e.g., that $\mu_1 = \mu_2 = \mu_0$, $\sigma_{\text{wire}} = \infty$, homogeneity of the ground, absence of reflected waves on the wire (effective infinite length), perturbations of the measured current distributions by the measuring system are minimal, and the calibration factors for the measuring system are accurate. The method, while not necessarily robust, has yielded valuable information regarding the characteristics of the ground pad and has uncovered some of the capabilities and shortcomings of the approach. Some comments will be included in a later section.

Since the test program was conducted in a one-week period which did not allow for repeats of the data acquisition/analysis process or even for modifications of the process given observations based on analysis of the data, improvements in the experimental setup to permit improved estimates of the constitutive parameters have not been possible. Nonetheless, a reasonable representation of the constitutive parameters of the reinforced concrete pad in the LESLI facility at the Phillips Lab has been achieved.

The constitutive parameters determined by this process are to be used in a program where the realistic ground is to be part of a computer model used in code validation. The test object, a Boeing 757 parked on a reinforced concrete pad, has a fuselage which is seven or more feet above the ground and the test points, except for a top-mounted external blade antenna, are located internal to the fuselage. It has always been expected that the ground will have its most pronounced effect on the structure of the field illuminating the airplane and will most likely have little effect on secondary scattering where the illuminating wave impinges on the airplane, scatters, impinges on the ground, scatters, and impinges on the airplane (thus "perturbing" the illuminating field). In a full wave analysis, this separation or consideration of the order of scattering is not an issue. We only make these comments to reflect on the relative importance of the ground characteristics in the ultimate solution.

5.2 Data Summary

The experimental data in the form of current distributions on a wire over ground were collected over a frequency range from approximately 1 MHz to 1 GHz at 90 spatial points spaced at 30 cm intervals. Reasonably accurate estimates of attenuation and phase constants were obtained for frequencies between 10 MHz and 126 MHz. Below this range, the spatial extent of sampling did not permit accurate estimates of the attenuation constant while beyond this frequency range, the sampling density and the limited support of the transmission line mode did not permit accurate estimates of the phase and attenuation constants, respectively. Over the frequency range, the constants led to estimates of ϵ_r and σ which were “reasonable” and within the range of physical realizability. Outside the range, the estimates for the constitutive parameters were decidedly less reliable. The estimates from the reliable range were used in a least squares fit to the Debye equations to yield expressions for the constitutive parameters and their average values over range $\{f_1, f_2\}$:

$$\epsilon_r = 4.2418 + 6.1943 / (1 + 1.129 \cdot 10^{-17} \cdot \omega^2)$$

$$\sigma = 4.416 \cdot 10^{-11} \cdot \omega / (1 + 1.354 \cdot 10^{-17} \cdot \omega^2)$$

$$\langle \epsilon_r(f_1, f_2) \rangle = 4.24 + 2.93 \cdot 10^8 \cdot [\tan^{-1}(2.11 \cdot 10^8 \cdot f_2) - \tan^{-1}(2.11 \cdot 10^8 \cdot f_1)] / (f_2 - f_1)$$

$$\langle \sigma(f_1, f_2) \rangle = 2.595 \cdot 10^5 \cdot \text{Ln}[(1 + 5.29 \cdot 10^{-16} \cdot f_2^2) / (1 + 5.29 \cdot 10^{-16} \cdot f_1^2)] / (f_2 - f_1)$$

Analysis of the experimental data allowed the identification of areas where the displacement current effects dominated. Certainly, displacement current effects were dominant above 50 MHz and it was evident from the reflection coefficient analysis that it was effectively independent of conductivity above 50 MHz and effectively independent of frequency above 100 MHz. Thus concern regarding the conductivity was secondary as its impact would be felt only below 50 MHz.

5.3 Concerns and Suggested Future Work on the Process

As mentioned previously, time and operational constraints did not permit a more in-depth study of the constitutive parameters and the technique used for their determination. In the future, this technique deserves an extended investigation as it represents a viable method for noninvasive determination of ϵ_r and σ . Specifically, several issues should be carefully studied to assess their impact on accuracy. In the following, several suggestions are made for future uses of the method and several areas are recommended for study.

Spatial Sampling

Prior to testing, an analysis was executed to bound the sampling density required to get reliable data over the interval 10 MHz to 400 MHz subject to the operational constraints of time and equipment availability. At the low frequencies it was anticipated that the difficulties would arise from the total attenuation that would be experienced over the entire sampling range. At the high frequencies it was expected that the difficulty would arise from the length of the interval over which the transmission line mode was dominant and the number of samples in this interval. In both cases the accuracy of the measurement system was a concern as was its dynamic range. While relative measurements ($I(x)/I(x_0)$) were adequate for our purposes, the system was limited by its inability to make accurate measurements of either component below -80 dBm or thereabouts. It was originally felt that sampling at four samples per wavelength was adequate so that the method could produce high quality results at 250 MHz at a sample spacing of 30 cm. Also, the total sampling range was 26.7 meters and it was estimated that sampling over a wavelength at low frequencies (approximately 11 MHz) would be adequate to assess the attenuation constant. In the presence of noise, reflections, and other fluctuations in the current distribution, the determination of attenuation constant at low frequencies was difficult. The attenuation observed over the entire sampling range was small. At high frequencies, these problems were compounded by the small interval over which the transmission line mode was dominant, the dynamic range of the measurement system, and the small number of samples per wavelength.

In future exercises, it would be beneficial to start the sampling closer to the source to increase the reference signal level and to maximize the length over which the transmission line mode dominates. This will help to extend the high frequency limit. Also, the sampling density should be increased in the high frequency regime in order to generate more samples per wavelength. For the low frequency range, the length over which sampling takes place should be made as large as possible so that the current is sampled over several wavelengths. In the face of limited resources, rather than having uniform sampling over the entire measurement range, it will be beneficial to sample more densely near the source for high frequency coverage and less densely for low frequency coverage. This suggests a nonuniform sampling scheme and may imply a logarithmic sampling rate with more density near the source and less farther away.

Reflections

The presence of reflections on the line must be minimized. The current distribution must be entirely that of a transmission line mode on an infinite line. The extraction of reflected waves from unknown locations could make the process difficult if not impossible. Proper loading of finite length lines or sufficient length could make this issue insignificant.

Height

At present the impact of uncertainties on the accuracy of parameter estimates is unknown, in detail. Certainly the uncertainties here (plus or minus 1/8" at a height of 5/8") have not caused major difficulties but the overall impact should be studied.

System Effects

The effects of the measurement probes, e.g., the current probes and their cables, on the accuracy of the current distribution measurement should be looked at in detail.

Mathematical Issues

The process, which is a classical inversion problem, may not be robust. Small errors in α and β could lead to significant errors in ϵ_r and σ although such problems were not overwhelming in this case. This aspect should be studied to lend a measure of usefulness to this technique. In the range of displacement current domination, when a consistent solution may not be available because of great uncertainties in σ due to its limited impact on the current distribution, are there methods to obtain reasonable estimates of ϵ_r which would suffice? Are alternate methods available? Likewise, similar questions must be answered for the case when conduction current dominates.

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