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Bearing and System Sensitivity Measurements on the GPS Fixed Interference Monitoring Detection System (FIMDS)

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*Subsequent to the original October 4, 2002 submission of this report, the FAA's Office of Spectrum Policy and Management (ASR-1) requested additional bearing and sensitivity testing in the VHF-Band. Revision A, dated January 31, 2003, incorporates the VHF test results, and are contained herein as well as other suggestions by ASR-1. A "Summary of Revisions" from the original report is also contained herein.

16. Abstract

This paper documents the testing activities and their results which have taken place at the Federal Aviation Administration's William J. Hughes Technical Center (WJHTC) in order to assess the Direction Finding (DF) capabilities of the Cubic AA2030 DF Antenna Array and DF4400 Processor in the GPS L1 band and in the *VHF air-to-ground Communications band.

Bearing and system sensitivity data was collected for two DF Processor modes (AM & FMN) as the DF array was varied in azimuth from 0-360 degrees in 45-degree increments. L-Band testing utilized four different interferer heights (7.2 ft., 11.3 ft., 16 ft., and 21 ft.) at two RF frequencies (1560 & 1590 MHz). The VHF interferer height was 7.0 ft. radiating at 127.025 MHz.

Utilizing a simulated interferer as the transmit source, the bearing on the DF processor was recorded. The system sensitivity was measured by reducing the interferer's RF power level sufficiently to induce a +/- 6-degree jitter in the original bearing reading. The Field Strength incident on the DF array was then measured with a calibrated antenna and spectrum analyzer. Utilizing the Antenna Factor and test cable loss, the raw spectrum analyzer reading was converted to Field Strength in units of dBuV/meter, and then to system sensitivity in uV/m. The results were compared to the vendor's specification of 20 uV/m (L-Band) and 0.8 uV/m (VHF-Band).

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Executive Summary

This paper documents the testing activities and their results which have taken place at the Federal Aviation Administration's William J. Hughes Technical Center (WJHTC) in order to assess the Direction Finding (DF) capabilities of the Cubic AA2030 DF Antenna Array and DF4400 Processor in the GPS L1 band and in the *VHF air-to-ground Communications band.

Bearing and system sensitivity data was collected for two DF Processor modes (AM & FMN) as the DF array was varied in azimuth from 0-360 degrees in 45-degree increments. L-Band testing utilized four different interferer heights (7.2 ft., 11.3 ft., 16 ft., and 21 ft.) at two RF frequencies (1560 & 1590 MHz). The VHF interferer height was 7.0 ft. radiating at 127.025 MHz.

Utilizing a simulated interferer as the transmit source, the bearing on the DF processor was recorded. The system sensitivity was measured by reducing the interferer's RF power level sufficiently to induce a +/- 6-degree jitter in the original bearing reading. The Field Strength incident on the DF array was then measured with a calibrated antenna and spectrum analyzer. Utilizing the Antenna Factor and test cable loss, the raw spectrum analyzer reading was converted to Field Strength in units of dBuV/meter, and then to system sensitivity in uV/m. The results were compared to the vendor's specification of 20 uV/m (L-Band) and 0.8 uV/m (VHF-Band).

L-BAND RESULTS

The bearing accuracy data at boresite, represented by the 11.3 foot Transmit Antenna height, was in compliance with the vendor specified 12 degrees of bearing error. The best bearing accuracy performance was at the 16-foot antenna height, while the worst performance was turned in at the 7.2-foot antenna height.

The system sensitivity as specified by the vendor is 20 uV/m, however it is unclear if this applies only at boresite or for other angles of incidence as well. Test results indicate that the 11.3 and 16 foot transmit antenna heights were in compliance. The 21 foot data was in compliance with the exception of only two data points, while the 7.2 foot data was the worst performer, with several data points exceeding the 20 uV/m system sensitivity specification.

VHF-BAND RESULTS

The boresite VHF bearing accuracy as specified by the vendor is 2.5 degrees of bearing error. All of the bearing data was in compliance, with the exception of the 180 and 225-degree azimuth angles.

The system sensitivity as specified by the vendor is 0.8 uV/m. The test results ranged from 1.9 uV/m to 2.9 uV/m, and therefore were not in compliance. The high system sensitivity readings may have resulted from a congested VHF ambient environment.

***NOTE** – Subsequent to the original October 4, 2002 submission of this report, the FAA's Office of Spectrum Policy and Management (ASR-1) requested additional bearing and sensitivity testing in the VHF-Band. Revision A, dated January 31, 2003, incorporates the VHF test results, and are contained herein as well as other suggestions by ASR-1. A "Summary of Revisions" from the original report is also contained herein.

SUMMARY of JANUARY 31, 2003 REVISIONS

1. Modified original Executive Summary to incorporate the VHF Testing.

2. Added "Summary of January 31, 2003 Revisions" to denote the Revision A changes.

3. Modified original Table of Contents to incorporate the VHF Testing.

4. Modified original "List of Figures" to incorporate the VHF Testing.

5. Modified original "List of Tables" to incorporate the VHF Testing.

6. Modified original Section 1.0 "Background" to incorporate the VHF Testing.

7. Modified original Section 2.0 "Introduction" to incorporate the VHF Testing.

8. Modified original Section 3.0 "System Description and Theory of Operation" to change reference from Figure 6 to Figure 10.

9. Added new Figure 5: "HK-012 Coaxial Dipole Mounted on Fiberglass Mast".

10. Added new Figure 6: "Biconical Mounting Bracket for Adaptation to Fiberglass Mast".

11. Added new Figure 7: "SAS-200/530 Biconical Antenna and Mounting Bracket".

12. Modified original Figure 5 Block Diagram to include "L-Band" prefix and renumbered as Figure 8.

13. Modified original Figure 7 Block Diagram to include the calibrated antenna, Antenna Factor data, and test cable entering the spectrum analyzer; renumbered as Figure 9, and added "L-Band" prefix.

14. Renumbered original Figure 6 as new Figure 10 "Control Box at Base of AA2030 Array".

15. Renumbered original Figure 8 as new Figure 11 "Test Equipment Connections (rear view)".

16. Renumbered original Figure 9 as new Figure 12 "Test Equipment Positioned in Rear of Van".

17. Modified original Figure 10 to include "L-Band" prefix and renumbered as new Figure 13 "L-Band Field Strength Test Configuration".

18. Added new VHF Block Diagram of Figure 14 depicting the VHF Test Configuration of AA2030 DF Antenna and 4400 Processor.

19. Added new VHF Block Diagram of Figure 15 depicting the VHF Bearing and System Sensitivity Detailed Test Configuration.

SUMMARY of JANUARY 31, 2003 REVISIONS
(con't.)

20. Added new Figure 16: "VHF-Band Field Strength Test Configuration".

21. Renumbered original Figure 11 as new Figure 17 "Bearing Displayed on DF Processor".

22. Modified Original Figures 12 through 15 by adding "L-Band" prefix and renumbering as new Figures 18 through 21 respectively.

23. Added new Figure 22: "VHF-Band Interfering Antenna at 7.0 feet (boresite)".

24. Added new Figure 23: "VHF RF Background Centered at 127.025 MHz".

25. Renamed original Table 1 as "L-Band Insertion Loss Measurements".

26. Added new Table 2 "VHF-Band Insertion Loss Measurements".

27. Renamed original Table 2 as "L-Band Test Antenna Data", and renumbered as new Table 3.

28. Added new Table 4 "VHF-Band Test Antenna Data".

29. Modified original Table 3 "List of Test Equipment Utilized in Measurements" to include the two VHF Test Antennas, and renumbered as new Table 5.

30. Renamed Original Table 4 from "Transmit Antenna" to "L-Band Interfering Antenna", and renumbered as new Table 6.

31. Added new Table 7 "Spectrum Analyzer Settings for Field Strength Measurements".

32. Modified original Table 5 to include 128 new calculations under the new column heading "Signal Strength (Isotropic Antenna)", renumbered as new Table 8, and added the prefix "L-Band" to distinguish from new VHF-Band data.

33. Added new Table 9 to report the VHF-Band Bearing and Sensitivity results.

34. Added new heading Section 4.2.1 "L-Band Test" under Section 4.2 "Test Antenna Bracket Fabrication".

35. Added new Section 4.2.2 "VHF-Band Test" under Section 4.2 "Test Antenna Bracket Fabrication".

36. Added new heading Section 4.3.1 "L-Band Test" under Section 4.3 "Test Frequencies".

37. Added new Section 4.3.2 "VHF-Band Test Frequencies".

SUMMARY of JANUARY 31, 2003 REVISIONS (con't.)

38. Added new heading sub-Section 4.4.1 "L-Band Test" under Section 4.4 "Far Field Calculation".

39. Added new Section 4.4.2 "VHF-Band Test Far Field Calculation".

40. Added new Appendix Figure A6: "VHF-Band Plot of Insertion Loss of 15 ft. RG-393 Cable".

41. Added new Appendix Figure A7: "VHF-Band Plot of Insertion Loss of 35 ft. RG-393 TX Cable".

42. Added new Appendix Figure A8: "VHF-Band Plot of Insertion Loss of 74 ft. Cubic RF Cable".

43. Added new Appendix Figure B3: "Plot of Return Loss vs. Frequency for Rohde & Schwarz Coaxial Dipole HK-012".

44. Added new Appendix Figure B4: "Plot of Return Loss vs. Frequency for AH Systems Biconical SAS-200/530".

45. Added the Prefix "L-Band" to existing Appendix Figures A1 through A5, to distinguish from "VHF-Band" test measurements.

46. Added new heading Section 5.1 "L-Band Bearing and 6 Degree Jitter Measurements".

47. Added new heading Section 5.2 "L-Band Field Strength Measurements at DF Antenna".

48. Added new Section 5.3 "VHF-Band Bearing and 6 Degree Jitter Measurements".

49. Added new Section 5.3.1 "Fiberglass Mast and Transmitter Portion".

50. Added new Section 5.3.2 "DF Array and Receiving Portion".

51. Added new Section 5.4 "VHF-Band Field Strength Measurements at DF Antenna".

52. Added new Section 5.4.1 "Transmit Portion".

53. Added new Section 5.4.2 "Receive Portion".

54. Renumbered original Section 5.3 "Miscellaneous Measurements" as new Section 5.5.

55. Modified original Section 5.3.1 as new Section 5.5.1 "L and VHF-Band Insertion Loss Measurements" to incorporate VHF data.

SUMMARY of JANUARY 31, 2003 REVISIONS (con't.)

56. Modified original Section 5.3.2 as new Section 5.5.2 "L and VHF-Band VSWR Measurements" to incorporate VHF data.

57. Renumbered original Section 5.4 as new Section 5.6 "Test Equipment List".

58. Added new sub-Section 6.1 heading "L-Band Bearing and 6 Degree Jitter Measurements" under Section 6.0 "Testing Methodology".

59. Modified original Section 6.2 to include "L-Band" prefix, added new paragraph to explain Signal Strength referenced to an isotropic radiator, and added text to reference new Table 7.

60. Added new Section 6.3 "VHF-Band Bearing and 6 Degree Jitter Measurements".

61. Added new Section 6.4 "VHF-Band Field Strength Measurements and System Sensitivity".

62. Modified heading of original Section 7.1 as "Description of Table 8 L-Band Data Columns", renumbered Notes 4, 5, and 6 to Notes 6, 7, and 8 respectively, changed all references from Table 5 to Table 8, and added derivation of equation for new data columns 12 and 13 "Signal Strength (Isotropic Radiator)".

63. Added new Section 7.2 "Description of Table 9 VHF-Band Data Columns".

64. Added new heading Section 8.1 "L-Band Test Results".

65. Renumbered original Section 8.1 as new Section 8.1.1 "Bearing Data".

66. Renumbered original Section 8.2 as new Section 8.1.2 "System Sensitivity Data".

67. Added new Section 8.1.3 "Signal Strength Relative to Isotropic Radiator".

68. Added new Section 8.2 "VHF-Band Test Results".

69. Added new Section 8.2.1 "Bearing Data".

70. Added new Section 8.2.2 "System Sensitivity Data".

71. Added new Section 8.2.3 "Signal Strength Relative to Isotropic Radiator".

72. Added new heading Section 9.1 "L-Band Conclusions".

73. Added new Section 9.2 "VHF-Band Conclusions".

74. Modified original Section 10.1 "Issues and Concerns" to include text describing new Figure 23.

75. Modified original Section 10.2 "Recommendations" to include VHF comments.

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1.0 BACKGROUND

The widespread use of the Global Positioning Satellite (GPS) system as a navigational aide has resulted in the proliferation of GPS receivers in order to access the satellite signal. However, the low-level characteristics of the satellite signals render the GPS system extremely vulnerable to sources of Radio Frequency Interference (RFI), which may degrade the accuracy or impede the availability of the system. The FAA's Office of Spectrum Policy and Management (ASR-1) has undertaken a program to safeguard this navigational band for aviation users. As such, ASR-1 has tasked the William J. Hughes Technical Center's Spectrum Engineering Group (ACB-240) to evaluate the Direction Finding (DF) capabilities of the Cubic Fixed Interference Monitoring Detection System (FIMDS) by performing a series of bearing accuracy and system sensitivity measurements in the GPS L1 Band. Pending satisfactory completion of these tests, the FIMDS has the potential to be deployed nationwide as part of an interference monitoring network, dedicated to detecting and locating emitters in the GPS L1 band. In this manner, the FAA will help insure the safety of the aviation community by insuring that a continuous, reliable, and accurate GPS navigation signal is available to all users.

Following the original release of this report, dated October 4, 2002, ASR-1 also requested additional bearing and sensitivity measurements be performed in the VHF air-to-ground communications band. The original report has been revised to include these VHF test results.

2.0 INTRODUCTION

This report documents the testing activities that have taken place at the FAA's William J. Hughes Technical Center (WJHTC) in order to evaluate the DF capabilities of the Cubic AA2030 DF Antenna Array and DF4400 Processor system. The testing was conducted in two phases, and this report is organized to document both.

Testing commenced in the Spring of 2002, with phase one designed to measure the bearing accuracy of the DF Antenna/DF Processor system combination in response to a simulated interferer in the GPS L1 frequency band.

The second phase of testing involved measuring the system sensitivity of the DF array and Processor combination, and was accomplished in two steps. First, the transmit power of the L1 emitter was decreased sufficiently to induce a +/- 6 degree jitter in the original DF Processor bearing readings. The signal generator level was recorded, and the signal level at the RF input to the DF Processor was measured with a spectrum analyzer. Next, the DF array was replaced with a calibrated antenna, test cable, and spectrum analyzer. With the L1 interferer output power maintained at the level that had caused the 6-degree bearing jitter in phase one, the received signal level was measured.

Working backwards from the raw spectrum analyzer reading, the antenna factor and cable loss were used to calculate the field strength in dBuV/meter. This value was then converted to uV/m, and represents the sensitivity of the DF system. In this manner, the bearing accuracy and system sensitivity were measured as the interfering source antenna height and elevation angle were varied, along with the azimuth angle of the DF array. The DF Processor mode was alternated between Amplitude Modulation (AM) and Frequency Modulation Narrow Band (FMN). Also, two different offset GPS L1 RF frequencies were used (1560 & 1590 MHz) in order to mitigate potential interference to GPS users.

Additional testing in the VHF-Band was requested by ASR-1 in the Fall of 2002, and was completed in January 2003. The bearing and sensitivity data was collected in the same manner as the L-Band data, with the exception that a single antenna height was utilized, and the RF test frequency was 127.025 MHz.

The following sections discuss the details of both testing phases, including test configurations and methodology, data gathered, sample calculations, and a discussion of the results. Also presented is a section on issues, concerns, and recommendations for future work.

3.0 SYSTEM DESCRIPTION AND THEORY OF OPERATION

The AA2030 DF antenna array, pictured in the foreground of Figure 1, stands 11.4 feet high and weighs 113 lbs. The antenna itself is a stacked adcock, fixed site array, comprised of a VHF and two UHF antenna arrays. The system is designed to provide 360 degree interference monitoring and to supply inputs to a DF System from 20 MHz to 3000 MHz. The antenna is comprised of three main sections, the UHF section, the VHF array, and the control box. The VHF array is an 8-element dipole adcock array, and receives signals from 20 to 200 MHz. The UHF section is comprised of two arrays, both enclosed in the same housing, which attaches to the upper mast section. The low UHF array is a four-element bow tie, and operates from 200 to 1000 MHz. The high UHF array is a four element log-periodic array, and operates from 1400 to 3000 MHz. The VHF and the high UHF are the arrays utilized in this test. Note that the three different antenna arrays cannot operate simultaneously. The serial data sent from the DF Processor selects the appropriate antenna based on the frequency selected on the Processor's receiver. The control box is located at the bottom of the VHF mast section (Refer to Figure 10). It supplies the connection between the system equipment and the antenna, and contains the VHF combiner.

The antenna has internal RF pre-amplifiers and signal processing, which combine received signals containing encoded bearing information, and routes them to the DF Processor's receiver via the RF coaxial cable. The DF Processor, via the eight-conductor control cable, supplies all power and control signals for the antenna.

The DF system employs a modified three channel Watson-Watt technique of direction finding, which is an amplitude comparison method. All of the DF directional information processing is done in the antenna, and is derived from the amplitude response pattern of two direction antenna inputs, using a third “sense” channel to resolve the 180-degree ambiguity. The three channels are:

Axial Channel:	Difference of N-S elements
Transverse Channel:	Difference of E-W elements
Sense Channel:	Sum of all elements

The DF information is contained in the relative magnitude of information in the transverse and axial channels. The DF Processor provides two modulating audio tones via the control cable, to modulate the axial and transverse channel signals. The two processed signals are then combined with the sense channel information, providing a single RF input to the receiver via the RF cable.

Figure 1: AA2030 DF Array Under Test at WJHTC Building 176

4.0 TEST PREPARATIONS

4.1 Mounting the AA2030 DF Array

A wooden undercarriage (Refer to Figure 1) in the shape of a cross "+" consisting of four handles and five wheels was designed by ACB-240 personnel for mounting the Cubic DF array. This facilitated movement of the large and cumbersome DF array as different azimuth angles were tested. Each of the four "legs" of the undercarriage was marked with spray paint to identify the four principal azimuth directions of North (0 degrees), South (180 degrees), East (90 degrees), and West (270 degrees). Likewise, corresponding North, South, East, and West markings were spray painted on the ground. This enabled the array's azimuth orientation to be identified at any point in the test, and also assisted in obtaining reliable and repeatable test results by insuring the array was physically rotated to the same position at each azimuth angle.

4.2 Test Antenna Bracket Fabrication

4.2.1 L-Band Test

In order to utilize the adjustable height military mast to support the simulated L-Band interferer, an antenna bracket and an "L-shaped" antenna mounting pipe were fabricated in-house to adapt the AH Systems SAS-200/518 LP antenna to the mast. These are shown in Figures 2 and 3.

Figure 2: SAS-200/518 Antenna and Mounting Bracket

Figure 3: L-shaped Mounting Pipe for Adaptation to Military Mast

A second antenna bracket for mounting the calibrated AH Systems SAS-200/510 LP antenna to the fiberglass mast for the L-Band Field Strength measurements was designed and fabricated in-house. The bracket and antenna are shown in Figure 4 below.

Figure 4: SAS-200/510 Antenna and Mounting Bracket

4.2.2 VHF-Band Test

In order to mount the Rohde & Schwarz HK-012 simulated VHF interferer to the fiberglass mast, an antenna-mounting pipe was fabricated in-house. This mounting pipe bolts to the underside of the ground-plane cage, and it's smaller diameter inserts into the fiberglass mast, as shown in Figure 5.

Figure 5: HK-012 Coaxial Dipole Mounted on Fiberglass Mast

A fourth antenna bracket for mounting the calibrated AH Systems SAS-200/530 Biconical antenna to the fiberglass mast for the VHF Field Strength measurements was also designed and fabricated in-house. This Biconical antenna and its mounting bracket are shown in Figures 6 and 7 below.

Figure 6: Biconical Mounting Bracket for Adaptation to Fiberglass Mast

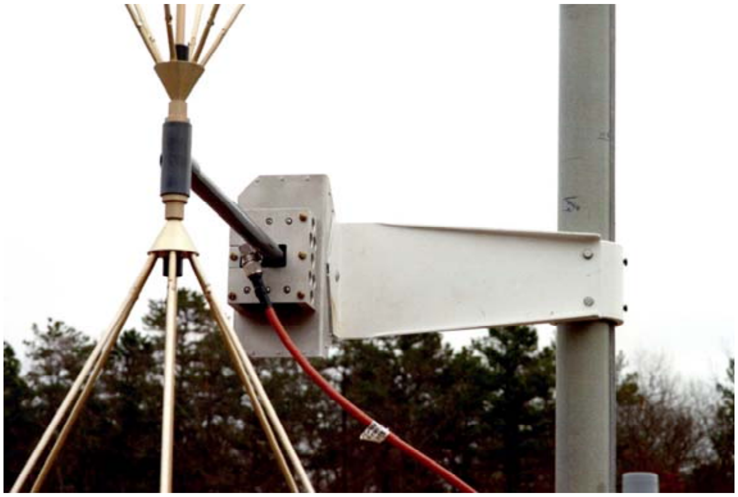


Figure 7: SAS-200/530 Biconical Antenna and Mounting Bracket

4.3 Test Frequencies

4.3.1 L-Band Test

The desired test frequency for the bearing and system sensitivity measurements is GPS L1, or 1575 MHz. However, as these measurements were conducted outdoors, it was decided that two test frequencies, offset +/- 15 MHz from L1, would be utilized rather than L1 itself. This would help mitigate potential interference to GPS users that might be in the local area while the tests are being conducted. Therefore, the two test frequencies are 1560 and 1590 MHz.

4.3.2 VHF-Band Test

The VHF-Band test frequency is 127.025 MHz, and is authorized by ASR-1 for testing purposes at the WJHTC.

4.4 Far-Field Calculation

4.4.1 L-Band Test

Prior to making any measurements on the Cubic DF Array, the Far Field was calculated using:

$$\textbf{Far Field} = 2D^2/\lambda \qquad \textbf{(1)}$$

where D = the largest dimension (worse case) of the DF array element, and λ = the wavelength of operation.

Ideally, in order to properly determine "D", the dimension of the longest array element of the high UHF array needs to be measured. However, the antenna elements comprising the high UHF LP array are enclosed in a radome at the top of the antenna configuration. Gaining access to the elements to physically measure them was impossible without disassembling the radome. This procedure was not advisable, as the radome was environmentally sealed with a weatherproof gasket. Any disassembly might damage the sealing and weather resistant properties of the radome gasket, thereby increasing the potential for moisture to enter the radome and possibly detune the enclosed antennas. Therefore, the outside height of the radome, D = 20.5", was measured, and taken as the worse case dimension of the array element's length.

The wavelength, λ, can be determined from the formula:

$$\mathbf{f = c/\lambda} \qquad \textbf{(2)}$$

where f = frequency and c = the speed of light. Rearranging (2) to solve for wavelength we arrive at:

$$\boldsymbol{\lambda = c/f} \qquad \textbf{(3)}$$

Calculate the wavelength for 1560 MHz: Substituting $c = 3(10)^8$ meters/sec and f = 1560 MHz into (3), and converting meters to inches we obtain:

$\lambda = c/f = (3(10)^8$ meters/sec)/1560 MHz = 0.1887 meters = <u>7.43"</u>

Likewise, **calculate the wavelength for 1590 MHz:** Substituting $c = 3(10)^8$ meters/sec and f = 1590 MHz into (3), and converting meters to inches we obtain:

$\lambda = c/f = (3(10)^8$ meters/sec)/1590 MHz = 0.1923 meters = <u>7.57"</u>

Now substituting D = 20.5" determined earlier along with the wavelengths determined above into (1), the Far Field distance for each frequency can be approximated:

For 1560 MHz: Far Field = $2D^2/\lambda = 2(20.5")^2/7.43"$ = <u>9.43 feet</u>

For 1590 MHz: Far Field = $2D^2/\lambda = 2(20.5")^2/7.57"$ = <u>9.25 feet</u>

As seen from these calculations, the worse case Far Field distance for the two test frequencies is 9.4 feet. Therefore, a separation distance of 15 feet was chosen between the test antenna and the Cubic DF antenna to insure that the test data was collected well into the Far Field while conducting these measurements. Testing in the Far Field is desirable in order to insure a planar wave front and to minimize any near field effects.

4.4.2 VHF-Band Test

Following the identical procedure utilized in the L-band calculation, the longest dimension "D" of the VHF array was measured to be D = 66".

The wavelength, λ, at 127.025 MHz , can be determined from formula (3):

$$\lambda = c/f = (3(10)^8 \text{ meters/sec})/127.025 \text{ MHz} = 2.36 \text{ meters} = \underline{93''}$$

Now substituting D = 66" determined above along with λ = 93" into (1), the VHF Far Field distance is approximated as:

$$\text{Far Field} = 2D^2/\lambda = 2(66")^2/93" = \underline{7.8 \text{ feet}}$$

As seen from this calculation, the Far Field distance was determined to be 7.8 feet. To insure the VHF test data was collected well into the Far Field, and to maintain consistency with the data collected at L-Band, a separation distance of 15 feet was chosen between the test antenna and the Cubic DF antenna.

5.0 TEST CONFIGURATIONS

All testing was performed outdoors in the open area behind WJHTC Building 176.

5.1 L-Band Bearing and 6 Degree Jitter Measurements

5.1.1 Military Mast and Transmitter Portion

Figure 8 illustrates the Far Field test configuration block diagram utilized to measure the bearing and system sensitivity of the Cubic AA2030 DF array. A military mast capable of being adjusted in height was erected behind WJHTC Building 176, and anchored into position using its six guy wires. An "L-shaped" antenna-mounting pipe was inserted into the top of the antenna mast, and secured into position using a setscrew. Next, a second antenna bracket, which enables the test antenna elevation angle to be varied, was mounted to the base of the AH Systems Log Periodic (LP) antenna (Model SAS-200/518), and the entire assembly was slid over the mounting pipe and secured in place at the proper elevation angle using the setscrew designed into the mounting bracket. Refer to Figures 2 and 3 shown earlier. A 90-degree N-type adapter was attached to the antenna, which provided the connection for the 35-foot RG-393 test cable. This cable remained unchanged and was used throughout all the testing. The source end of the test cable was attached to the Agilent E4433B Signal Generator (ESG), which provided the simulated CW interfering test signals. The test cable was secured with tie wraps along the mounting pipe and the military mast.

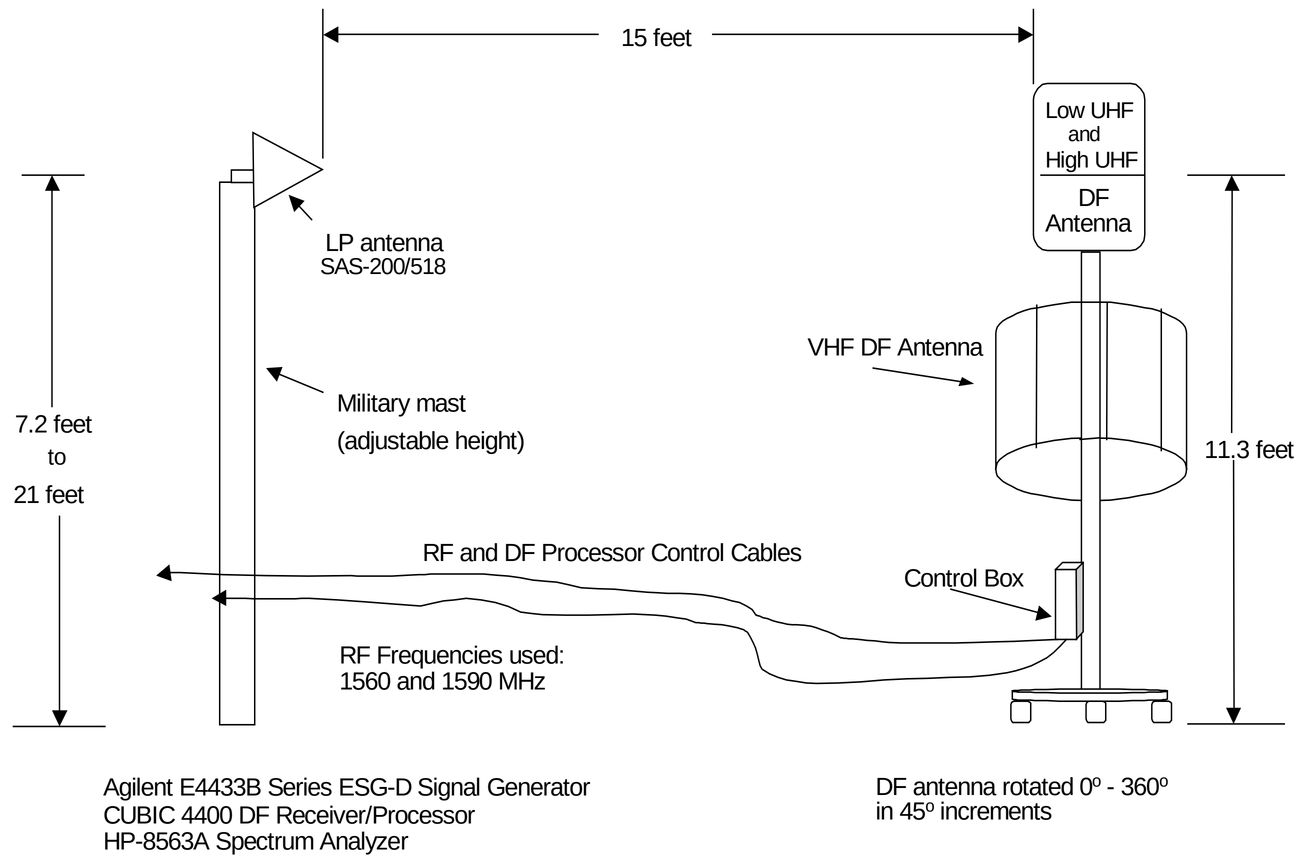


FIGURE 8: L-Band AA2030 DF Antenna and 4400 Processor Test Configuration

5.1.2 DF Array and Receiving Portion

The Cubic AA2030 DF array was rolled into place, such that the face of the array's radome and the tip of the AH Systems SAS-200/518 antenna were 15 feet apart, which was the far field distance determined earlier in Section 4.4.1. To aid in aligning the two antennas in azimuth, the green arrow on the Cubic array's radome, indicating that antenna's north mark (0 degrees), was aligned with the tip of the AH Systems test antenna. Next, the military mast was raised to the proper height for the particular angle of incidence being tested. For example, at boresite, the military mast was raised such that the TX antenna was even with and aimed directly at the center of the Cubic's array radome, or 11.3 feet. A detailed block diagram of the test configuration is shown in Figure 9.

The 74-foot Belden RG-8 RF cable and the 100-foot Alpha Wire Control cable were properly connected to the Cubic AA2030 Control Box at the base of the antenna array, as seen in Figure 10.

Figure 10: Control Box at Base of AA2030 Array

The other end of the control cable was connected to the "Antenna Power" connector on the rear of the DF Processor. The receiving end of the RF cable was first fed into the Narda directional coupler, and the coupler in turn was connected directly to the rear of the Processor at the "Antenna Signal" connector. A 3-ft section of RG-214 was used to connect the 10 dB coupling port of the Narda directional coupler to the HP 8563A Spectrum Analyzer. The DF Processor runs off DC voltage, therefore the Astron RS-20A DC Power Supply was used to power the processor. The cable connecting the power supply with the processor was modified by soldering two terminal lugs, one on the positive lead and one on the negative lead, in order to facilitate the connections at the rear of the power supply. Figure 11 shows a rear view of the test equipment connections.

As the tests were conducted outside, a 100-foot extension cord was used to supply AC power from an outdoor outlet at the base of one of the Remote Communication Air-to-Ground (RCAG) towers. A six-outlet fuse-protected power strip was connected to the equipment side of the extension cord, and provided power to the Agilent E4433B source,

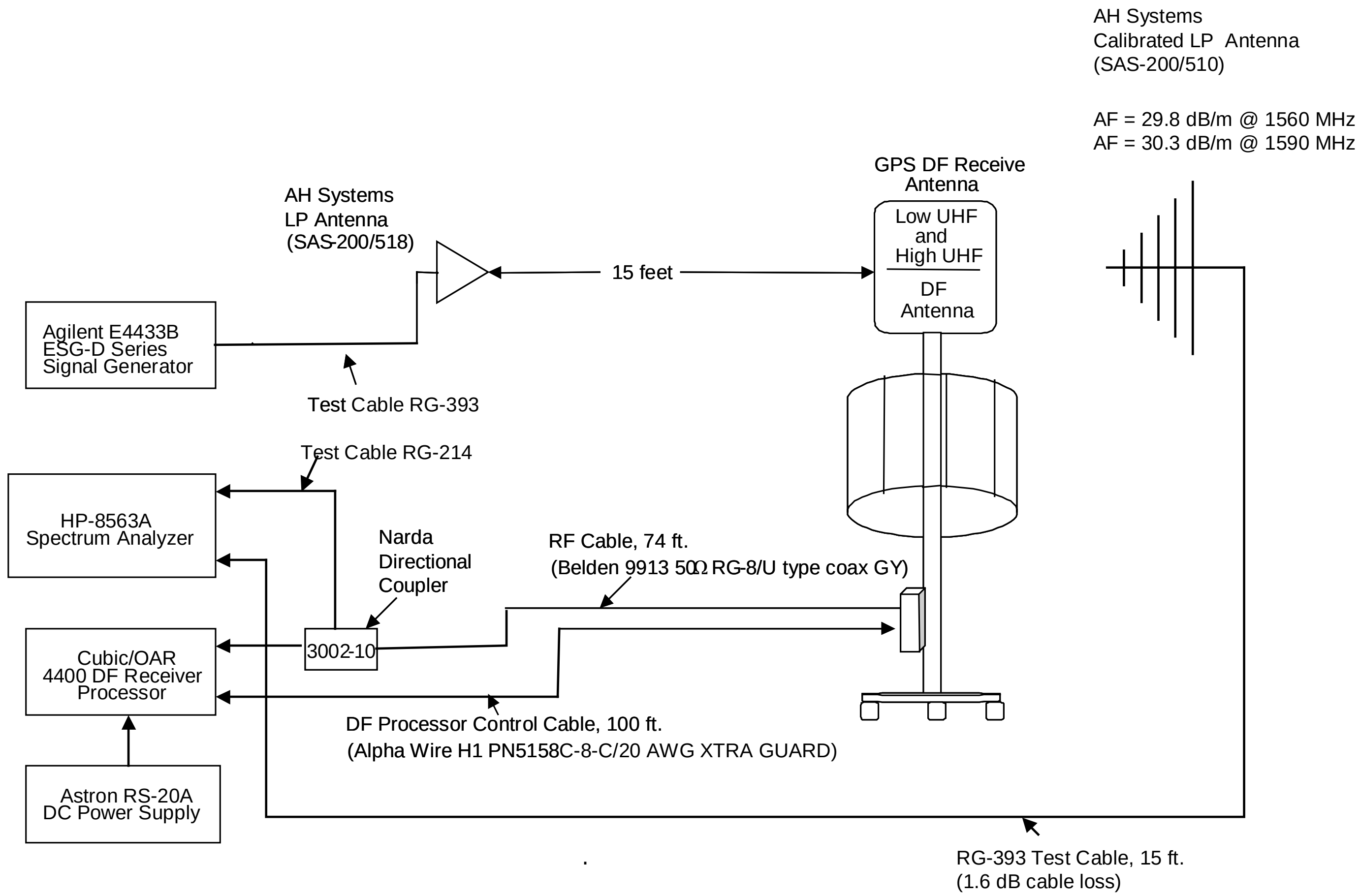


FIGURE 9: L-Band Bearing and System Sensitivity Detailed Test Configuration

Figure 11: Test Equipment Connections (rear view)

Astron RS-20A DC power supply, and HP 8563A Spectrum Analyzer. The 100-foot extension cord enabled the entire test configuration to be configured far enough away from Building 176 and it's associated RCAG towers, so as to minimize the potential for RF reflections during the test.

All the test equipment, both the receive and transmit portions, were assembled in the rear hatch area of the Division's government van, as shown in Figure 12. This precaution was taken to protect all the equipment from direct exposure to the sun. Early on, all the test equipment had been assembled outdoors on a test table in the direct sunlight. However, the DF Processor had difficulty staying locked on the interfering signal, making it impossible to collect data. Removing the equipment from direct exposure to the sunlight and placing it in the rear of the van eliminated this problem.

Figure 12: Test Equipment Positioned in Rear of Van

5.2 L-Band Field Strength Measurements at DF Antenna

Upon completion of collecting the bearing and 6-degree jitter data, it was desired to measure the RF Field Strength incident on the DF array which had caused the 6-degree bearing jitter.

5.2.1 Transmit Portion

The transmit configuration for the Field Strength measurements remained exactly the same as in the L-Band Bearing and 6 Degree Jitter measurements (Section 5.1.1).

5.2.2 Receive Portion

To measure the Field Strength, a second antenna mast capable of mounting a calibrated antenna was erected in exactly the same position as the Cubic DF array. The array was rolled far enough out of the way in order to accommodate installation of the second antenna mast, and also to minimize the potential for RF reflections from the array during this portion of the test. To facilitate the installation and provide support for the new mast, a seven-foot piece of uni-strut metal fence post was driven into the ground. The new mast, constructed of fiberglass and capable of expanding to 15 feet via additional 5-foot sections, was secured to the fence post using large hose clamps and wooden 2 x 4's, and raised to the proper height using cinder blocks and wood shims. An antenna bracket was fabricated by the WJHTC sheet metal shop to adapt the AH Systems calibrated LP antenna (Model SAS-200/510) to the fiberglass mast (Refer to Figure 4). This bracket allowed the calibrated antenna to be positioned anywhere along the length of the fiberglass mast, and also permitted the antenna's elevation angle to be varied. A 15-foot RG-393 test cable was attached to the calibrated LP antenna, with the other end connected to the HP 8563A Spectrum Analyzer. The actual field strength test configuration is shown in Figure 13.

Figure 13: L-Band Field Strength Test Configuration

As observed in Figure 13, the test equipment was positioned on a test table, midway between the transmit LP antenna (SAS-200/518) and the calibrated receive LP antenna (SAS-200/510), so the operator could simultaneously vary the ESG's output, monitor the Spectrum Analyzer, and record the data.

5.3 VHF-Band Bearing and 6 Degree Jitter Measurements

5.3.1 Fiberglass Mast and Transmitter Portion

Figure 14 illustrates the Far Field test configuration block diagram utilized to measure the bearing and system sensitivity of the Cubic AA2030 DF array. A fiberglass mast was erected behind WJHTC Building 176, and was anchored into position using a newly installed uni-strut fence post. A straight-shaped antenna-mounting pipe was bolted to the inside of the Rohde & Schwarz Coaxial Dipole Antenna. The mounting pipe section of the assembly was slid inside the fiberglass mast, and the antenna was secured in place such that the center of the coaxial dipole was at the proper elevation of 7 feet. Refer to Figure 5 shown earlier. The 35-foot RG-393 test cable was attached to the N-female connector on the antenna, and the source end of the test cable was attached to the Agilent E4433B Signal Generator (ESG), which provided the simulated CW interfering test signals. The test cable was secured in place with tie wraps along the fiberglass mast.

5.3.2 DF Array and Receiving Portion

The Cubic AA2030 DF array was rolled into place, such that the face of the VHF array and the radiating element of the Rohde & Schwarz HK-012 antenna were 15 feet apart, which was the far field distance determined earlier in Section 4.4.2.

A detailed block diagram of the VHF test configuration is shown in Figure 15. All of the previous connections made in the L-Band test were again repeated for this portion of the test. The notable exception being that a directional coupler was not utilized in the VHF test. Benefiting from "Lessons Learned" on the L-Band Test, it was not necessary to monitor the RF level at the DF Processor which induced the 6-degree jitter reading. The only important parameter to be monitored was the RF source level which had caused the 6-degree jitter. Therefore, the receiving end of the 74-foot RG-8 RF cable was connected directly to the rear input of the Processor at the "Antenna Signal" connector.

5.4 VHF-Band Field Strength Measurements at DF Antenna

Upon completion of collecting the VHF bearing and 6-degree jitter data, it was desired to measure the RF Field Strength incident on the DF array which had caused the 6-degree bearing jitter.

5.4.1 Transmit Portion

The transmit configuration for the Field Strength measurements remained exactly the same as in the VHF-Band Bearing and 6 Degree Jitter measurements (Section 5.3.1).

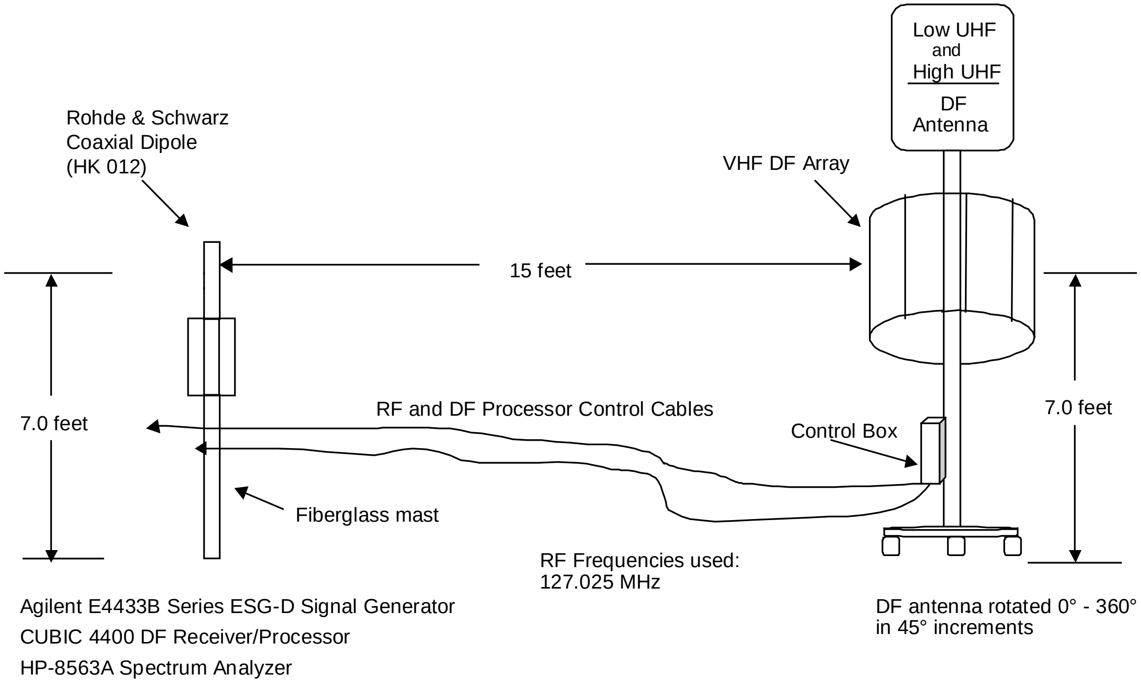


FIGURE 14: VHF-Band Test Configuration of AA2030 DF Antenna and 4400 Processor

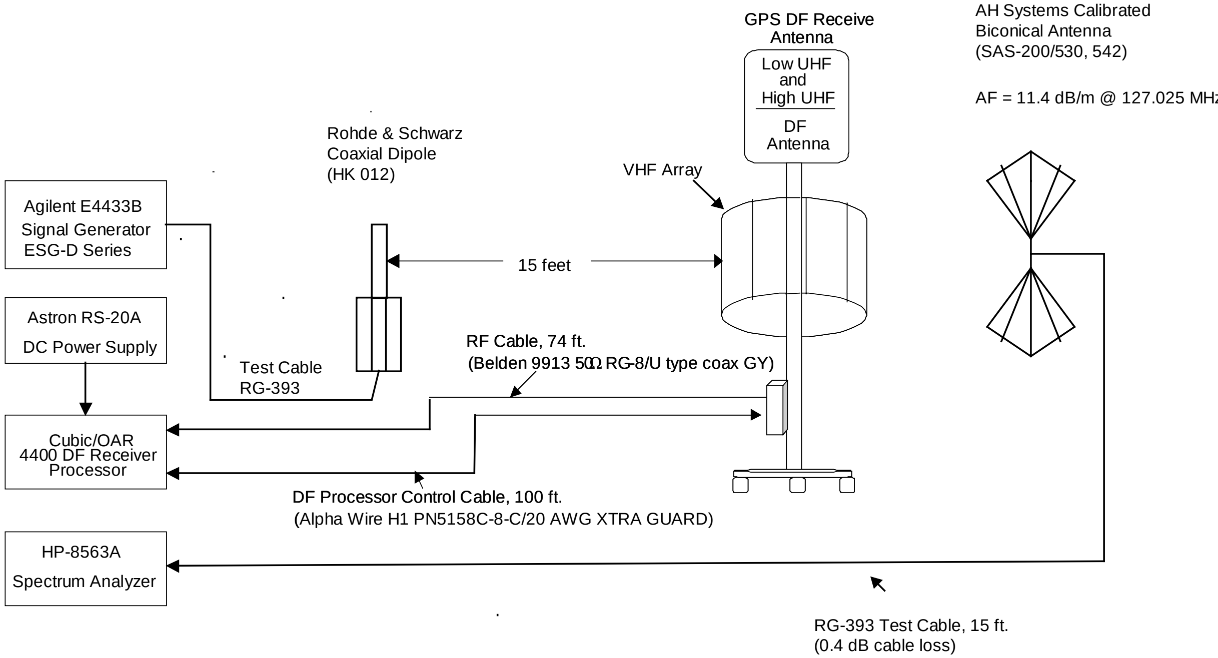


FIGURE 15: VHF-Band Bearing and System Sensitivity Detailed Test Configuration

5.4.2 Receive Portion

As was done in the L-Band test, a second fiberglass antenna mast was installed in exactly the same position as the Cubic DF array in order to measure the Field Strength. A second uni-strut metal fence post was driven into the ground. The new mast was secured to the fence post using large hose clamps, and raised to the proper height using wood shims. An antenna bracket was fabricated by the WJHTC sheet metal shop to adapt the AH Systems calibrated folding Biconical antenna (Model SAS-200/530) to the fiberglass mast (Refer to Figures 6 and 7). This bracket allowed the calibrated antenna to be positioned anywhere along the length of the fiberglass mast, and also permitted the antenna's elevation angle to be varied. A 15-foot RG-393 test cable was attached to the calibrated Biconical antenna, with the other end connected to the HP 8563A Spectrum Analyzer. The actual field strength test configuration is shown in Figure 16.

Figure 16: VHF-Band Field Strength Test Configuration

As observed in Figure 16, the test equipment was positioned on a test table, adjacent to the calibrated receive Biconical antenna (SAS-200/530), so the operator could simultaneously vary the ESG's output, monitor the Spectrum Analyzer, and record the data.

5.5 Miscellaneous Measurements

5.5.1 L and VHF-Band Insertion Loss Measurements

The Agilent 8753ES Network Analyzer was utilized to measure the insertion loss of the test cables and the Narda directional coupler. The HP 7470A Plotter provided a hardcopy of the insertion loss measurement plots, and these are presented in Appendix A. Table 1 summarizes the L-Band insertion loss measurements performed at both test frequencies, describes where the device is used in the test configuration, and lists the report section where the insertion loss plot can be found.

Table 1
L-Band Insertion Loss Measurements

Device Tested	Where Used	Plot Found in Section	Insertion Loss (dB)	
			1560 MHz	1590 MHz
Narda 3002-10 coupling port & 3 ft. RG-214 cable comb.	Splits DF Processor Rx signal into spectrum analyzer for measurement	A1	-9.4	-9.5
Narda 3002-10 coupler (thru)	Feeds Rx signal into DF Processor	A2	-0.6	-0.6
15 ft. RG-393 cable	Field strength measurements	A3	-1.6	-1.6
35 ft. RG-393 cable	Tx cable for interferer	A4	-3.8	-3.8
74 ft. Belden RG-8 cable	Connects DF array to DF Processor	A5	-5.8	-5.8

Similarly, Table 2 summarizes the VHF-Band insertion loss measurements for the three RF cables utilized in that test.

Table 2
VHF-Band Insertion Loss Measurements

Device Tested	Where Used	Plot Found in Section	Insertion Loss (dB) 127.025 MHz
15 ft. RG-393 cable	Field strength measurements	A6	-0.4
35 ft. RG-393 cable	TX cable for interferer	A7	-0.8
74 ft. Belden RG-8 cable	Connects DF array to DF Processor	A8	-1.1

5.5.2 L and VHF-Band VSWR Measurements

The 8753ES Network Analyzer was also used to measure the Voltage Standing Wave Ratio (VSWR) of all four test antennas: the 1-18 GHz LP (Model SAS-200/518) used as the L-Band interfering transmit antenna, the 300-1800 MHz calibrated LP (Model SAS-200/510) used in the L-Band field strength measurements, the Rohde & Schwarz 100-163 MHz Coaxial dipole used as the VHF-Band interfering transmit antenna, and the 20-500 MHz calibrated folding Biconical (Model SAS-200/530), used in the VHF-Band field strength measurements. The HP 7470A Plotter provided a hardcopy of the return loss (VSWR) measurement plots, and these are presented in Appendix B. The measured return loss was converted to a VSWR reading by changing from the "Log Magnitude" display on the Analyzer to a "VSWR" display. Table 3 summarizes the L-Band VSWR data, the vendor-supplied antenna gain and antenna factor, and the report section where the VSWR plot is located. Similarly, Table 4 summarizes the VHF-Band Antenna VSWR data, gain, antenna factor, and the appropriate report section for the VSWR plot.

Table 3
L-Band Test Antenna Data

Antenna Type (LP = Log Periodic)	Plot Found in Section	VSWR		Gain (dBi)		Antenna Factor (dB/meter)	
		1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz
LP (1-18 GHz) Model SAS-200/518	B1	1.6	1.7	6.6	6.6	NA	NA
LP (300-1800 MHz) Model SAS-200/510	B2	3.8	4.7	[1]4.75	[1]4.5	[2]29.8	[2]30.3

NOTE (1): The Antenna Gain data supplied by the vendor was given as 5.3 dBi at 1500 MHz, and 4.4 dBi at 1600 MHz. These data points were plotted on graph paper, and the Antenna Gain was interpolated to be 4.75 dBi at 1560 MHz and 4.5 dBi at 1590 MHz.

NOTE (2): The Antenna Factor data supplied by the vendor was given as 28.9 dB/meter at 1500 MHz, and 30.5 dB/meter at 1600 MHz. These data points were plotted on graph paper, and the Antenna Factor was interpolated to be 29.8 dB/meter at 1560 MHz and 30.3 dB/meter at 1590 MHz.

Table 4
VHF-Band Test Antenna Data

Antenna Type	Plot Found in Section	VSWR	Gain (dbi)	Antenna Factor (dB/meter)
Coaxial Dipole (100-163 MHz) Model HK-012	B3	1.7	2.0	NA
Biconical (20-500 MHz) Model SAS-200/530, 542	B4	1.6	[3]0.9	[4]11.4

NOTE (3): The Antenna Gain data supplied by the vendor was given as 1.02 dBi at 120 MHz, and 0.84 dBi at 130 MHz. These data points were plotted on graph paper, and the Antenna Gain was interpolated to be 0.9 dBi at 127 MHz.

NOTE (4): The Antenna Factor data supplied by the vendor was given as 10.8 dB/meter at 120 MHz, and 11.7 dB/meter at 130 MHz. These data points were plotted on graph paper, and the Antenna Factor was interpolated to be 11.4 dB/meter at 127 MHz.

5.6 Test Equipment List

Table 5 below lists all the test equipment utilized in the L and VHF-Band measurements, along with the vendor's name, model, and serial number.

Table 5
List of Test Equipment Utilized in Measurements

Equipment	Vendor	Model No.	Serial No.
DF Antenna Array (20-3000 MHz)	Cubic	AA2030	507
Control Box (Part # 0255490-3)	Cubic	AA2030	507
DF Processor (Part # 0255464-2)	Cubic	DF4400	560
Spectrum Analyzer (9 kHz-22 GHz)	HP	8563A	3240A02271
Power Supply (13.8 VDC)	Astron Corp	RS-20A	202020109
ESG Source (250 kHz-4.0 GHz)	Agilent	E4433B	US41312477
Network Analyzer (30 kHz-6 GHz)	Agilent	8753ES	US39172063
Coaxial Directional Coupler (NSN: 4931-00-682-4601)	Narda	3002-10	71904
Log Periodic Antenna (1-18 GHz)	AH Systems	SAS-200/518	303
Log Periodic Antenna (300-1800 MHz)	AH Systems	SAS-200/510	869
Coaxial Dipole Antenna (100-163 MHz)	Rohde & Schwarz	HK-012	351421
Folding Biconical Antenna (20-500 MHz)	AH Systems	SAS-200/530	562
Plotter	HP	7470A	2210A09786

6.0 TESTING METHODOLOGY

6.1 L-Band Bearing and 6 Degree Jitter Measurements

With the equipment configured for a boresite test as outlined in Section 5.1 and Figures 8 and 9 (test antenna height at 11.3 ft. and DF array at 0 degrees azimuth), the ESG source was set to emit a 0 dBm CW signal at 1560 MHz. The DF Processor mode was set to "AM" (amplitude modulation), and both it and the Spectrum Analyzer were tuned to receive the 1560 MHz signal. The bearing displayed on the DF Processor was observed and recorded in ***Table 8, Column 4***, **"Bearing: 1560 MHz".** Figure 17 shows an example of the bearing displayed on the DF Processor.

While monitoring the bearing indicator, the ESG source output was then reduced from 0 dBm until the observed DF Processor bearing began to deviate (jitter) +/- 6 degrees from the bearing previously recorded. The ESG source level was recorded, and the Spectrum Analyzer was used to measure the signal level at the RF input to the DF Processor.

Figure 17: Bearing Displayed on DF Processor

(This reading was corrected 10 dB to account for the coupling port and 3-ft. RG-214 test cable loss.) The ESG source was then reset to 0 dBm output, and its frequency adjusted to 1590 MHz. Likewise, the DF Processor was also set to 1590 MHz, and its mode was set to "FMN" (Frequency Modulation Narrow-Band). The readings of bearing and 6-degree jitter were again recorded as outlined above. Next, the DF array was rotated in azimuth 45 degrees in order to present another azimuth angle to the interferer, and the bearing and 6 degree jitter measurements were repeated for the AM and FMN modes, and at both test frequencies (1560 and 1590 MHz). In this fashion, test data was collected at the boresite configuration as the DF array's azimuth angle was rotated from 0 to 360 degrees in 45-degree increments.

[5]Once the boresite data was collected, the military mast was adjusted to the other antenna heights of 7.2 ft., 16 ft., and 21 ft., in order to simulate an interferer with varying angles of incidence on the DF array. Bearing and 6 degree jitter data was collected at each antenna height, at both test frequencies (1560 & 1590 MHz), for two DF Processor modes (AM & FMN), and at eight different azimuth angles in 45-degree increments. As the transmit antenna's height was varied, a new elevation angle was calculated, and the LP antenna adjusted accordingly in order to maintain its beam peak on the center of the DF array's radome. Table 6 summarizes the change in elevation angle and range of the SAS-200/518 transmit antenna as its height was varied.

Table 6
L-Band Interfering Antenna
Elevation Angle and Range vs. Mast Height

TX Antenna Height (ft.)	Elevation Angle (degrees)	Range (ft.)
11.3	0	15
7.2	+15.7	15.6
16	-17.3	15.7
21	-32.8	17.8

Figures 18, 19, 20, and 21 show the various test antenna height configurations.

Figure 18: L-Band Interfering Antenna at 7.2 feet

Figure 19: L-Band Interfering Antenna at 11.3 feet (boresite)

Figure 20: L-Band Interfering Antenna at 16 feet

Figure 21: L-Band Interfering Antenna at 21 feet

NOTE (5): The interfering antenna height of 7.2 ft. is ***below*** boresite of the DF array. The idea to test this angle of incidence originated from the potential of the DF array to be strategically deployed in such a fashion where it is mounted high atop a tower or building. In that scenario, the DF array may very well be receiving signals below, as well as above, boresite.

6.2 L-Band Field Strength Measurements and System Sensitivity

Upon completion of collecting the bearing and 6-degree jitter data, the RF Field Strength incident on the L-Band DF array which had caused the 6-degree bearing jitter was measured. With the equipment configured as outlined in Section 5.2 and Figure 13, the ESG source was set to the output level which had caused the 6-degree jitter in the bearing data collected in Section 6.1. This was done for both test frequencies (1560 and 1590 MHz), and the corresponding received signal levels were measured on the Spectrum Analyzer and recorded in ***Columns 6 and 7 of Table 8***, labeled **"raw SA reading".** The HP 8563A Spectrum Analyzer settings are shown under the "L-Band" column of Table 7 below. These settings represent the Spectrum Analyzer's state at the time of the most sensitive Field Strength measurement.

Table 7
Spectrum Analyzer Settings for Field Strength Measurements

HP 8563A Setting	L-Band	VHF-Band
Center Frequency (f_c), MHz	1560/1590	127.025
Span, kHz	10	10
Attenuation (ATTEN), dB	0	0
Reference Level (RL), dBm	-80	-50
Resolution Bandwidth (RBW), Hz	10	300
Video Bandwidth (VBW), Hz	10	30
Sweep Time, sec	5.9	2.8

The raw Spectrum Analyzer reading in units of dBm was converted to Field Strength in units of dBuV/m by utilizing the appropriate Antenna Factor of the calibrated antenna (from Table 3), along with the 15-foot RG-393 test cable loss of 1.6 dB (from Table 1). The Field Strength data, or System Sensitivity, for both frequencies is presented in ***Columns 8 and 9 of Table 8***, labeled **"Field Strength @ DF Antenna (System Sensitivity)".**

The System Sensitivity in units of uV/m at both test frequencies was determined by converting the Field Strength in dBuV/m to uV/m. This data is presented in ***Columns 10 and 11 of Table 8,*** labeled **"Field Strength @ DF Antenna (System Sensitivity)".**

Lastly, the Signal Strength referenced to an isotropic radiator was determined by converting the Field Strength in dBuV/m for both frequencies to dBm (iso). This data is presented in ***Columns12 and 13 of Table 8***, labeled **"Signal Strength (Isotropic Antenna)".**

A detailed description of each data column of Table 8, along with sample calculations, is presented below in Section 7.1.

6.3 VHF-Band Bearing and 6 Degree Jitter Measurements

With the equipment configured for a boresite test as outlined in Section 5.3 and Figures 14 and 15 (test antenna height at 7.0 ft. and DF array at 0 degrees azimuth), the ESG source was set to emit a 0 dBm CW signal at 127.025 MHz. The DF Processor mode was set to "AM" (amplitude modulation), and both it and the Spectrum Analyzer were tuned to receive the 127.025 MHz signal. The bearing displayed on the DF Processor was observed and recorded in ***Table 9, Column 4***, **"Bearing".** Recall earlier that Figure 17 showed an example of the bearing displayed on the DF Processor.

While monitoring the bearing indicator, the ESG source output was again reduced from 0 dBm until the observed DF Processor bearing began to deviate (jitter) +/- 6 degrees from the bearing previously recorded. The ESG source level that induced this jitter was recorded. The ESG source was then reset to 0 dBm output, and the DF Processor mode was set to "FMN" (Frequency Modulation Narrow-Band). The readings of bearing and 6-degree jitter were again recorded as outlined above. Next, the DF array was rotated in azimuth 45 degrees in order to present another azimuth angle to the interferer, and the bearing and 6 degree jitter measurements were repeated for the AM and FMN modes at the 127.025 MHz test frequency. In this fashion, test data was collected at the boresite configuration as the DF array's azimuth angle was rotated from 0 to 360 degrees in 45-degree increments. Figure 22 shows the actual test configuration.

Figure 22: VHF-Band Interfering Antenna at 7.0 feet (boresite)

6.4 VHF-Band Field Strength Measurements and System Sensitivity

Upon completion of collecting the bearing and 6-degree jitter data, the RF Field Strength incident on the VHF-Band DF array which had caused the 6-degree bearing jitter was measured. With the equipment configured as outlined in Section 5.4 and Figure 16, the ESG source was set to the output level which had caused the 6-degree jitter in the bearing data collected in Section 6.3. This was done at 127.025 MHz, and the corresponding received signal levels were measured on the Spectrum Analyzer and recorded in ***Column 5***

of Table 9, labeled **"raw SA reading".** The HP 8563A Spectrum Analyzer settings are shown under the "VHF-Band" column of Table 7 (presented earlier). These settings represent the Spectrum Analyzer's state at the time of the most sensitive Field Strength measurement.

The raw Spectrum Analyzer reading in units of dBm was converted to Field Strength in units of dBuV/m by utilizing the 11.4 dB/m Antenna Factor of the calibrated antenna (from Table 4), along with the 15-foot RG-393 test cable loss of 0.4 dB (from Table 2). The Field Strength data, or System Sensitivity, is presented in ***Column 6 of Table 9***, labeled **"Field Strength @ DF Antenna (System Sensitivity)".**

The System Sensitivity in units of uV/m was determined by converting the Field Strength in dBuV/m to uV/m. This data is presented in ***Column 7 of Table 9,*** labeled **"Field Strength @ DF Antenna (System Sensitivity)".**

Lastly, the Signal Strength referenced to an isotropic radiator was determined by converting the Field Strength in dBuV/m to dBm (iso). This data is presented in ***Column 8 of Table 9***, labeled **"Signal Strength Isotropic Antenna".**

A detailed description of each data column of Table 9, along with sample calculations, is presented below in Section 7.2.

7.0 TEST RESULTS AND SAMPLE CALCULATIONS

The bearing, field strength, and system sensitivity data is summarized in Table 8 for the L-Band test and Table 9 for the VHF-Band test. The data is organized according to the azimuth angle tested. The following paragraphs describe each of the data columns, and also supply a sample calculation where appropriate. It is recommended that the descriptions below be used in conjunction with the Test Procedures described in Section 6.0 to gain a complete understanding of how the data in Tables 8 and 9 was compiled.

7.1 Description of Table 8 L-Band Data Columns

Column 1, "Azimuth": This column indicates the azimuth position of the DF array, in degrees, relative to the interfering antenna and the North, South, East, and West markings spray-painted on the ground as a reference.

Column 2, "TX Antenna Height": Data in this column indicates the height of the interfering antenna in feet. At 11.3 feet, the transmit antenna is ***at boresite*** with the DF array. At 7.2 feet, the transmit antenna is actually ***below*** the DF array's boresite, and is angled up towards the array. Transmit antenna heights of 16 and 21 feet are ***above*** the DF array's boresite, therefore the transmit antenna is actually looking down at the array. Recall the transmit antenna's elevation angle and range as a function of antenna height is summarized in Table 6.

Table 8
L-Band Bearing, Field Strength, and Sensitivity Data for Cubic AA2030 Antenna Array and 4400 DF Processor
(AA2030 Antenna Height is 11.3 ft; Range @ boresite = 15 ft; Far Field = 9.4 ft.)

Azimuth	TX Ant.		Bearing		raw SA reading		Field Strength @ DF Antenna (System Sensitivity)				Sig.Strength (Isotropic Ant.)	
	Height	Mode	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz
(deg)	(ft.)		(deg)	(deg)	(dBm)	(dBm)	(dBuV/m)	(dBuV/m)	(uV/m)	(uV/m)	dBm (iso)	dBm (iso)
0	11.3	AM	356	4	-126	-126	12.4	12.9	4.2	4.4	-130.3	-129.9
0	11.3	FMN	356	4	-126	-123	12.4	15.9	4.2	6.2	-130.3	-126.9
0	7.2	AM	355	359	-118	-119	20.4	19.9	10.5	9.9	-122.3	-122.9
0	7.2	FMN	354	0	-117	-120	21.4	18.9	11.8	8.8	-121.3	-123.9
0	16	AM	2	4	-125	-124	13.4	14.9	4.7	5.6	-129.3	-127.9
0	16	FMN	2	4	-126	-124	12.4	14.9	4.2	5.6	-130.3	-127.9
0	21	AM	358	2	-119	-121	19.4	17.9	9.3	7.9	-123.3	-124.9
0	21	FMN	359	1	-119	-120	19.4	18.9	9.3	8.8	-123.3	-123.9
45	11.3	AM	51	45	-126	-125	12.4	13.9	4.2	5.0	-130.3	-128.9
45	11.3	FMN	51	45	-125	-125	13.4	13.9	4.7	5.0	-129.3	-128.9
45	7.2	AM	100	112	-98	-106	40.4	32.9	104.7	44.2	-102.3	-109.9
45	7.2	FMN	100	112	-98	-105	40.4	33.9	104.7	49.6	-102.3	-108.9
45	16	AM	47	47	-124	-126	14.4	12.9	5.3	4.4	-128.3	-129.9
45	16	FMN	47	47	-125	-125	13.4	13.9	4.7	5.0	-129.3	-128.9
45	21	AM	38	50	-116	-118	22.4	20.9	13.2	11.1	-120.3	-121.9
45	21	FMN	38	50	-114	-117	24.4	21.9	13.2	12.5	-118.3	-120.9
90	11.3	AM	98	94	-126	-125	12.4	13.9	4.2	5.0	-130.3	-128.9
90	11.3	FMN	98	94	-127	-126	11.4	12.9	3.7	4.4	-131.3	-129.9
90	7.2	AM	100	98	-116	-126	22.4	12.9	13.2	4.4	-120.3	-129.9
90	7.2	FMN	100	98	-116	-116	22.4	22.9	13.2	14.0	-120.3	-119.9
90	16	AM	90	91	-126	-126	12.4	12.9	4.2	4.4	-130.3	-129.9
90	16	FMN	90	91	-126	-126	12.4	12.9	4.2	4.4	-130.3	-129.9
90	21	AM	81	111	-115	-115	23.4	23.9	14.8	15.7	-119.3	-118.9
90	21	FMN	81	111	-115	-117	23.4	21.9	14.8	12.5	-119.3	-120.9
135	11.3	AM	127	129	-126	-127	12.4	11.9	4.2	3.9	-130.3	-130.9
135	11.3	FMN	127	129	-126	-127	12.4	11.9	4.2	3.9	-130.3	-130.9
135	7.2	AM	162	146	-120	-119	18.4	19.9	8.3	9.9	-124.3	-122.9
135	7.2	FMN	161	145	-109	-111	29.4	27.9	29.5	24.8	-113.3	-114.9
135	16	AM	129	129	-125	-126	13.4	12.9	4.7	4.4	-129.3	-129.9
135	16	FMN	129	128	-125	-125	13.4	13.9	4.7	5.0	-129.3	-128.9
135	21	AM	147	137	-115	-115	23.4	23.9	14.8	15.7	-119.3	-118.9
135	21	FMN	146	137	-115	-116	23.4	22.9	14.8	14.0	-119.3	-119.9

Table 8 (con't)
L-Band Bearing, Field Strength, and Sensitivity Data for Cubic AA2030 Antenna Array and 4400 DF Processor
(AA2030 Antenna Height is 11.3 ft; Range @ boresite = 15 ft; Far Field = 9.4 ft.)

Azimuth	TX Ant.		Bearing		raw SA reading		Field Strength @ DF Antenna (System Sensitivity)				Sig.Strength (Isotropic Ant.)	
	Height	Mode	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz	1560 MHz	1590 MHz
(deg)	(ft.)		(deg)	(deg)	(dBm)	(dBm)	(dBuV/m)	(dBuV/m)	(uV/m)	(uV/m)	dBm (iso)	dBm (iso)
180	11.3	AM	179	184	-127	-125	11.4	13.9	3.7	5.0	-131.3	-128.9
180	11.3	FMN	179	184	-127	-124	11.4	14.9	3.7	5.6	-131.3	-127.9
180	7.2	AM	182	177	-115	-126	23.4	12.9	14.8	4.4	-119.3	-129.9
180	7.2	FMN	182	176	-116	-117	22.4	21.9	13.2	12.5	-120.3	-120.9
180	16	AM	173	179	-124	-123	14.4	15.9	5.3	6.2	-128.3	-126.9
180	16	FMN	173	179	-124	-124	14.4	14.9	5.3	5.6	-128.3	-127.9
180	21	AM	154	163	-115	-121	23.4	17.9	14.8	7.9	-119.3	-124.9
180	21	FMN	150	163	-116	-119	22.4	19.9	13.2	9.9	-120.3	-122.9
225	11.3	AM	220	219	-122	-120	16.4	18.9	6.6	8.8	-126.3	-123.9
225	11.3	FMN	220	218	-123	-120	15.4	18.9	5.9	8.8	-127.3	-123.9
225	7.2	AM	206	208	-109	-122	29.4	16.9	29.5	7.0	-113.3	-125.9
225	7.2	FMN	206	208	-109	-111	29.4	27.9	29.5	24.8	-113.3	-114.9
225	16	AM	226	221	-127	-127	11.4	11.9	3.7	3.9	-131.3	-130.9
225	16	FMN	226	221	-126	-126	12.4	12.9	4.2	4.4	-130.3	-129.9
225	21	AM	235	195	-112	-116	26.4	22.9	20.9	14.0	-116.3	-119.9
225	21	FMN	235	195	-112	-116	26.4	22.9	20.9	14.0	-116.3	-119.9
270	11.3	AM	265	269	-120	-119	18.4	19.9	8.3	9.9	-124.3	-122.9
270	11.3	FMN	265	269	-121	-119	17.4	19.9	7.4	9.9	-125.3	-122.9
270	7.2	AM	270	265	-115	-117	23.4	21.9	14.8	12.5	-119.3	-120.9
270	7.2	FMN	270	265	-116	-117	22.4	21.9	13.2	12.5	-120.3	-120.9
270	16	AM	258	263	-126	-127	12.4	11.9	4.2	3.9	-130.3	-130.9
270	16	FMN	257	263	-125	-127	13.4	11.9	4.7	3.9	-129.3	-130.9
270	21	AM	219	226	-119	-116	19.4	22.9	9.3	14.0	-123.3	-119.9
270	21	FMN	218	226	-118	-116	20.4	22.9	10.5	14.0	-122.3	-119.9
315	11.3	AM	325	324	-120	-120	18.4	18.9	8.3	8.8	-124.3	-123.9
315	11.3	FMN	324	324	-121	-120	17.4	18.9	7.4	8.8	-125.3	-123.9
315	7.2	AM	342	358	-109	-119	29.4	19.9	29.5	9.9	-113.3	-122.9
315	7.2	FMN	342	358	-108	-109	30.4	29.9	33.1	31.3	-112.3	-112.9
315	16	AM	315	306	-124	-124	14.4	14.9	5.3	5.6	-128.3	-127.9
315	16	FMN	315	306	-125	-126	13.4	12.9	4.7	4.4	-129.3	-129.9
315	21	AM	308	289	-115	-115	23.4	23.9	14.8	15.7	-119.3	-118.9
315	21	FMN	308	289	-115	-116	23.4	22.9	14.8	14.0	-119.3	-119.9

Column 3, "Mode": This is the mode of operation, AM or FMN, selected on the DF Processor.

Columns 4 and 5, "Bearing": This is the bearing reading, in degrees, on the DF Processor in response to a 0 dBm signal from the ESG source. Two columns are used under **"Bearing"** to record the DF Processor's performance at both 1560 and 1590 MHz.

Columns 6 and 7, "raw SA Reading": This is the RF signal level, in dBm, measured with the Spectrum Analyzer and calibrated antenna at the same location as the DF array, with the ESG source output returned to the level which had caused the 6-degree jitter on the DF Processor.[6,7]

NOTE (6): The ESG output level which induced the 6-degree jitter on the DF Processor was also recorded. However, this raw data is not contained in Table 8.

NOTE (7): The RF signal level input to the DF Processor at the 6-degree jitter point was measured with the Spectrum Analyzer and recorded. However, this raw data is not contained in Table 8.

Columns 8 and 9, "Field Strength @ DF Antenna (System Sensitivity)": This data is the RF Field Strength (System Sensitivity), in units of dBuV/m, present at the DF array which induced the 6-degree jitter on the DF Processor. In order to calculate the Field Strength (FS) at the DF array, we introduce equation (4) below:

FS = SA (dBm) + 107 dB (50 Ω systems) + AF (dB/meter) + Cable Loss (dB) (4)

where SA = Spectrum Analyzer and AF = Antenna Factor.

To calculate the Field Strength at 1560 MHz for the AM mode, substitute the raw Spectrum Analyzer reading of –126 dBm ***(Table 8, Column 6, row 1)***, the Antenna Factor of 29.8 dB/meter (Table 3), and the 1.6 dB RG-393 cable loss (Table 1) into equation (4):

FS = -126 dBm + 107 dB + 29.8 dB/meter + 1.6 dB = 12.4 dBuV/meter

[8]Similarly, to calculate the Field Strength at 1590 MHz for the AM mode, substitute the raw Spectrum Analyzer reading of –126 dBm ***(Table 8, Column 7, row 1)***, the Antenna Factor of 30.3 dB/meter (Table 3), and the 1.6 dB RG-393 cable loss (Table 1) into equation (4):

FS = -126 dBm + 107 dB + 30.3 dB/meter + 1.6 dB = 12.9 dBuV/meter

The Field Strength data is entered into ***Columns 8 and 9 of Table 8*** for 1560 and 1590 MHz respectively.

NOTE (8): The 1590 MHz example was given in order to illustrate the fact that different Antenna Factors were used at each test frequency when calculating the Field Strength.

Columns 10 and 11, "Field Strength @ DF Antenna (System Sensitivity)": This data is the RF Field Strength (System Sensitivity) of the AA2030 Array and the DF4400 Processor combination, found by converting the Columns 8 and 9 data to uV/m using equation (5):

$$\mathbf{dBuV/m = 20\ log_{10}\ (uV/m)} \quad \textbf{(5)}$$

To calculate the System Sensitivity (SS) at 1560 MHz for the AM mode, we substitute the Field Strength of 12.4 dBuV/m from ***Column 8 of Table 8*** into equation (5) and solve for uV/meter:

SS = 20 $\log_{10}$ (uV/m) = 12.4 dBuV/m = 4.2 uV/meter

The System Sensitivity data in uV/m is entered into ***Columns 10 and 11 of Table 8*** for 1560 and 1590 MHz respectively.

Columns 12 and 13, "Signal Strength (Isotropic Antenna)": This data is the RF Field Strength referenced to an isotropic radiator (antenna), found by converting the Field Strength data in dBuV/m from Columns 8 and 9 into dBm (iso). To derive the proper equation for this calculation, we present the following two equations:

AF (dB/m) = 20 log f (MHz) – 29.8 dB – G (dB) (6)

FS (dBuV/m) = AF (dB/m) + CL (dB) + SA (dBuV) (7)

where G = Antenna Gain, SA = Spectrum Analyzer, AF = Antenna Factor, and CL = Cable Loss. We also know that:

SA (dBuV) = SA (dBm) + 107 dB (8)

Substituting (8) into (7) we obtain:

FS (dBuV/m) = SA (dBm) + 107 dB (50 Ω systems) + AF (dB/meter) + CL (dB) (9)

For an isotropic antenna, G = 1 or 0 dB, and making this substitution into (6) we obtain:

AF (dB/m) = 20 log f (MHz) – 29.8 dB (10)

Next, substituting (10) into (9) we obtain:

FS (dBuV/m) = SA (dBm) + 107 dB + 20 log f (MHz) – 29.8 dB + CL (dB) (11)

Finally, in (11) we let SA (iso) = SA (dBm) due to the G = 1 substitution above, and solving for SA (iso) we arrive at:

SA (iso) = FS (dBuV/m) - 20 log f (MHz) –77.2 dB - CL (dB) (12)

Therefore, to calculate the Signal Strength referenced to an isotropic radiator at 1560 MHz for the AM mode, substitute the System Sensitivity of 12.4 dBuV/m ***(Table 8, Column 8,***

row 1), the frequency of 1560 MHz, and the 1.6 dB RG-393 cable loss (Table 1) into equation (12):

SA (iso) = 12.4 (dBuV/m) – 20 log 1560 MHz –77.2 dB – 1.6 (dB) = <u>-130.3 dBm (iso)</u>

The signal strength referenced to an isotropic radiator data is entered into ***Columns 12 and 13 of Table 8*** for 1560 and 1590 MHz respectively.

7.2 Description of Table 9 VHF-Band Data Columns

Column 1, "Azimuth": This column indicates the azimuth position of the DF array, in degrees, relative to the interfering antenna and the North, South, East, and West markings spray-painted on the ground as a reference.

Column 2, "TX Antenna Height": This column indicates the interfering antenna height, which remained constant at 7.0 feet.

Column 3, "Mode": This is the mode of operation, AM or FMN, selected on the DF Processor.

Columns 4 "Bearing": This is the bearing reading, in degrees, on the DF Processor in response to a 0 dBm signal from the ESG source.

Column 5, "raw SA Reading": This is the RF signal level, in dBm, measured with the Spectrum Analyzer and calibrated antenna at the same location as the DF array, with the ESG source output returned to the level which had caused the 6-degree jitter on the DF Processor.[9]

NOTE (9): The ESG output level which induced the 6-degree jitter on the DF Processor was also recorded. However, this raw data is not contained in Table 9.

Column 6 "Field Strength @ DF Antenna (System Sensitivity)": This data is the RF Field Strength (System Sensitivity), in units of dBuV/m, present at the DF array which induced the 6-degree jitter on the DF Processor. In order to calculate the Field Strength (FS) at the VHF DF array, we recall equation (4) presented earlier in the L-Band case, and substitute the raw Spectrum Analyzer reading of –113.2 dBm ***(Table 9, Column 5, row 1)***, the Antenna Factor of 11.4 dB/meter (Table 4), and the 0.4 dB RG-393 cable loss (Table 2) into equation (4):

FS = -113.2 dBm + 107 dB + 11.4 dB/meter + 0.4 dB = <u>5.6 dBuV/meter</u>

The Field Strength data in dBuV/meter is entered into ***Column 6 of Table 9.***

Column 7, "Field Strength @ DF Antenna (System Sensitivity)": This data is the RF Field Strength (System Sensitivity) of the AA2030 Array and the DF4400 Processor combination, found by converting the Column 6 data to uV/m. To calculate the System Sensitivity (SS) for the AM mode, we recall equation (5) presented earlier in the L-Band case, and substitute the Field Strength of 5.6 dBuV/m from ***Column 6 of Table 9*** into equation (5) and solve for uV/meter:

Table 9
VHF-Band Bearing, Field Strength, and Sensitivity Data for Cubic AA2030 Antenna Array and 4400 DF Processor
(AA2030 Antenna Height is 7.0 ft.; Range @ boresite = 15 ft.; Far Field = 7.8 ft.)

Azimuth (deg)	TX Antenna Height (ft.)	Mode	Bearing (deg)	raw SA reading (dBm)	Field Strength @ DF Antenna (System Sensitivity)		Signal Strength Isotropic Antenna dBm (iso)
					(dBuV/m)	(uV/m)	
0	7.0	AM	0	-113.2	5.6	1.9	-114.1
0	7.0	FMN	0	-112.3	6.5	2.1	-113.2
45	7.0	AM	45	-109.5	9.3	2.9	-110.4
45	7.0	FMN	45	-109.5	9.3	2.9	-110.4
90	7.0	AM	89	-112.3	6.5	2.1	-113.2
90	7.0	FMN	89	-112.3	6.5	2.1	-113.2
135	7.0	AM	135	-112.3	6.5	2.1	-113.2
135	7.0	FMN	135	-111.3	7.5	2.4	-112.2
180	7.0	AM	176	-111.3	7.5	2.4	-112.2
180	7.0	FMN	176	-112.3	6.5	2.1	-113.2
225	7.0	AM	217	-109.5	9.3	2.9	-110.4
225	7.0	FMN	217	-110.0	8.8	2.8	-110.9
270	7.0	AM	269	-112.3	6.5	2.1	-113.2
270	7.0	FMN	269	-112.3	6.5	2.1	-113.2
315	7.0	AM	314	-113.2	5.6	1.9	-114.1
315	7.0	FMN	314	-112.3	6.5	2.1	-113.2

$$SS = 20 \log_{10} (uV/m) = 5.6 \text{ dBuV/m} = \underline{1.9 \text{ uV/meter}}$$

The System Sensitivity data in uV/m is entered into ***Column 7 of Table 9.***

Column 8, "Signal Strength (Isotropic Antenna)": This data is the RF Field Strength referenced to an isotropic radiator (antenna), found by converting the Field Strength data in dBuV/m from Column 6 into dBm (iso). To calculate these values, we utilize equation (12) derived earlier in the L-Band case, and substitute the AM mode System Sensitivity of 5.6 dBuV/m ***(Table 9, Column 6, row 1)***, the frequency of 127.025 MHz, and the 0.4 dB RG-393 cable loss (Table 2) into equation (12):

$$SA\text{ (iso)} = 5.6 \text{ (dBuV/m)} - 20 \log 127.025 \text{ MHz} - 77.2 \text{ dB} - 0.4 \text{ (dB)} = \underline{-114.1 \text{ dBm (iso)}}$$

The signal strength referenced to an isotropic radiator data is entered into the last Column, ***Column 8, of Table 9.***

8.0 DATA ANALYSIS AND DISCUSSION

8.1 L-Band Test Results

The L-Band bearing and system sensitivity data collected on the Cubic DF array is presented in Table 8. Data was collected at both 1560 and 1590 MHz, for two modes (AM and FMN) of DF Processor operation, at four different antenna heights, as the array was varied in azimuth from 0-360 degrees in 45-degree increments.

8.1.1 Bearing Data

Reference (1) states that the system has a typical DF bearing accuracy of 12 degrees rms measured at 0 degrees elevation (boresite) over the entire 360 degrees of azimuth. The 0 degree elevation data (boresite) in Table 8 is represented in the Transmit Antenna Height column by 11.3 feet, which corresponds to the first two rows of data for each azimuth angle section. Upon examining this data, we find the vendor's claim to hold true. All of the boresite data in Table 8 had a bearing error less than 12 degrees. The worst offenders were at 315 degrees azimuth, which had a bearing error of 10 degrees at 1560 MHz (AM mode), 9 degrees of error at 1590 MHz (AM mode), and an error of 9 degrees at both frequencies in the FMN mode. Following this data, the next worst bearing error was 8 degrees, which occurred twice. The first was at 90 degrees azimuth for both modes at 1560 MHz, and the second was at 135 degrees azimuth, again for both modes at 1560 MHz. When comparing bearing error with frequency at boresite, the 1560 MHz data had a total bearing error of 93 degrees, while the 1590 MHz data had a total error of 69 degrees. Clearly, bearing performance was better at the higher frequency on boresite.

By far, the worst individual bearing errors occurred at the Transmit Antenna height of 7.2 ft. at 45 degrees azimuth. At 1560 MHz, bearing errors of 55 degrees occurred in both processor modes. Also, at the same height but at 1590 MHz, bearing errors of 67 degrees were recorded for both modes.

The best individual bearing error was zero degrees (no error), and this occurred at several different azimuth and antenna height combinations, as seen in Table 8.

Using antenna height as the criteria, the best overall performer (least amount of bearing error at both modes and both frequencies) was the Transmit Antenna height of 16 feet. The 16-foot height outperformed even the boresite data, having a total error of 130 degrees, compared to 162 degrees of total error at boresite (11.3 ft.). The 21-foot height was next, recording a total error of 544 degrees, and the worst performer was the 7.2-foot height with a bearing error of 599 degrees total.

The largest change in bearing reading with frequency (1560 to 1590 MHz) was 40 degrees, and this occurred at the 21 ft. antenna height at 225 degrees azimuth, for both modes.

A potential source of error in the bearing data can be traced to possible misalignment of the two antennas in relationship to one another, as they were aligned visually.

8.1.2 System Sensitivity Data

The specifications in Reference (1) state a system sensitivity of 20 uV/m. However, it is not entirely clear from Reference (1) if this applies to all elevation angles of incidence, or just on boresite. Upon examining the system sensitivity data in columns 10 and 11 of Table 8, we find the majority of the data to be in compliance with the 20 uV/m specification, with a few exceptions. All of the sensitivity data for transmitter heights 11.3 and 16 feet was in compliance. All of the 21-foot antenna height sensitivity data was in compliance, with two exceptions, both occurring at azimuth angle 225 degrees. Here, the sensitivity recorded at 1560 MHz in both modes was 20.9 uV/m, only 0.9 uV/m out of specification.

As was the case with the bearing accuracy data, the 7.2-foot antenna height was also the worst performer in system sensitivity. Four azimuth angles had sensitivity data exceeding 20 uV/m, including 45, 135, 225, and 315 degrees. At 45 degrees, both modes recorded sensitivities of 104.7 uV/m at 1560 MHz. Also at 45 degrees, the 1590 MHz AM mode sensitivity was 44.2 uV/m, and the FMN mode sensitivity was 49.6 uV/m. At 135 degrees azimuth, the FMN mode sensitivities at both test frequencies exceeded the 20 uV/m specification. The sensitivity at 1560 MHz was 29.5 uV/m, while the sensitivity at 1590 MHz was 24.8 uV/m. At 225 degrees azimuth, the sensitivity was 29.5 uV/m for both modes at 1560 MHz. At 1590 MHz, only the FMN mode was out of specification at 24.8 uV/m. The last azimuth angle to exceed the 20 uV/m specification was 315 degrees. Here again, both modes at 1560 MHz exceeded the specification, 29.5 uV/m for AM, and 33.1 uV/m for FMN. At 1590 MHz, only the FMN mode was out of compliance, with a system sensitivity of 31.3 uV/m.

To present a different perspective in examining the system sensitivity data, an average sensitivity was calculated for both frequencies. The 1590 MHz average system sensitivity was found to be 10.4 uV/m, slightly better than the 1560 MHz average system sensitivity of 13.4 uV/m. Overall, averaging all 128 readings in Table 8 resulted in an average system sensitivity of 11.9 uV/m, well within the specified 20 uV/m.

The best individual sensitivity was 3.7 uV/m, which occurred four times at 1560 MHz.

The worst individual sensitivity measurement was by far 104.7 uV/m, which occurred twice at the 7.2-foot antenna height, 45 degrees azimuth, 1560 MHz, for both DF Processor modes.

The largest change in sensitivity with frequency also occurred at the 7.2-foot antenna height and at 45 degrees azimuth. The AM mode sensitivity was 104.7 uV/m at 1560 MHz, and then it dropped to 44.2 uV/m at 1590 MHz, a difference of 60.5 uV/m. The FMN mode sensitivity was also 104.7 uV/m at 1560 MHz, and then it dipped to 49.6 uV/m at 1590 MHz, a difference of 55.1 uV/m.

8.1.3 Signal Strength Relative to Isotropic Radiator

This new data appears in the last two columns of Table 8. At 1560 MHz, the most sensitive performer was –131.3 dBm (iso), which occurred four distinct times at 90 degrees azimuth (FMN Mode at 11.3 feet), 180 degrees azimuth (both Modes at 11.3 feet), and 225 degrees azimuth (AM Mode at 16 feet). The least sensitive result was –102.3 dBm (iso), recorded at 45 degrees azimuth (both Modes at 7.2 feet).

At 1590 MHz, the most sensitive reading recorded was –130.9 dBm (iso), occurring at 135 degrees azimuth (both Modes at 11.3 feet), 225 degrees azimuth (AM Mode at 16 feet), and 270 degrees azimuth (both Modes at 16 feet). The least sensitive result was –108.9 dBm (iso), recorded at 45 degrees azimuth (FMN Mode at 7.2 feet).

The average signal strength referenced to an isotropic radiator was –124.4 dBm (iso) at 1590 MHz, which was slightly better than the –123.5 dBm (iso) at 1560 MHz. Utilizing all 128 data points, the total average sensitivity referenced to an isotropic radiator was calculated to be –124.0 dBm (iso).

8.2 VHF-Band Test Results

The bearing and system sensitivity data collected on the Cubic DF array is presented in Table 9. Data was collected at 127.025 MHz for two modes (AM and FMN) of DF Processor operation, at the single antenna height of 7 feet, as the array was varied in azimuth from 0-360 degrees in 45-degree increments.

8.2.1 Bearing Data

Reference (1) states that the system has a typical DF bearing accuracy of 2.5 degrees rms, measured at an ideal site at 0 degrees elevation (boresite) over the entire 360 degrees of azimuth. All of the VHF data presented in Table 9 was collected at boresite, represented by the 7 foot interfering transmit antenna height. Upon examining this data, we find the vendor’s claim to hold true for all but two azimuth angles. At 180 degrees azimuth the bearing error was 4 degrees in both modes, and at 225 degrees azimuth the bearing error was 8 degrees in both modes. These two azimuth angles were the worst offenders.

The best individual bearing error was of course zero degrees (no error), and this occurred for both processor modes at several different azimuth angles including 0, 45, and 135 degrees.

The next best performers after these were 1 degree of error in both modes, at azimuth angles of 90, 270, and 315 degrees.

Utilizing all 16 VHF bearing readings, a total bearing error of 1.9 degrees was calculated, which is within the vendor's specified 2.5 degrees of error.

There was no change in bearing accuracy between the two modes of operation.

A potential source of error in the bearing data can be traced to possible misalignment of the two antennas in relationship to one another, as they were aligned visually.

8.2.2 System Sensitivity Data

The specifications in Reference (1) state a system sensitivity of 1.0 uV/m at 75 MHz, and 0.7 uV/m at 140 MHz. These two points were plotted on graph paper, and the sensitivity was interpolated to be 0.8 uV/m at 127 MHz. Upon examining the system sensitivity data in column 7 of Table 9, we find none of the data to be in compliance with the 0.8 uV/m specification.

The best sensitivity readings were 1.9 uV/m, which occurred twice at two different azimuth angles. The first was in the AM Mode at 0 degrees, and the second was for the AM Mode at 315 degrees azimuth. These 1.9 uV/m sensitivity readings were 1.1 uV/m above specification.

The worst sensitivity readings were 2.9 uV/m, which occurred in both Modes at 45 degrees, and for the AM Mode at 225 degrees azimuth. These 2.9 uV/m sensitivity readings were 2.1 uV/m above specification.

Utilizing all 16 sensitivity readings from Column 7, an average sensitivity for all azimuth angles was calculated and found to be 2.3 uV/m. This result is 1.5 uV/m above specification.

Sensitivity seemed to remain fairly constant between Modes. The largest change in sensitivity for a constant azimuth angle occurred at 135 and 180 degrees, where a difference of 0.3 uV/m occurred between the AM and FMN Modes.

8.2.3 Signal Strength Relative to Isotropic Radiator

This data appears in the last column of Table 9, with –114.1 dBm (iso) the most sensitive reading occurring in the AM Mode at both 0 and 315 degrees azimuth. The least sensitive reading was –110.4 dBm (iso), occurring in both Modes at 45 degrees azimuth, and in the AM Mode at 225 degrees azimuth.

An average signal strength relative to an isotropic radiator was calculated utilizing all 16 data points, and was found to be –112.5 dBm (iso).

9.0 CONCLUSION

The test program and results designed to evaluate the bearing accuracy and system sensitivity of the AA2030 DF array and DF4400 Processor have been presented. A list of conclusions follows:

9.1 L-Band Conclusions

1. The boresite bearing accuracy data was in agreement with the 12 degree bearing accuracy design specification as set forth by Cubic in Reference (1).

2. The data indicated that bearing accuracy appears to be a function of the interfering signal's antenna height and angle of incidence. The best performance in bearing error was at the 16 ft. antenna height, followed by 11.3 ft. (boresite), 21 ft., with the worst performance at 7.2 ft.

3. The Continuous Wave (CW) mode on the DF Processor did not produce accurate bearing readings, as the bearing indication was often 180 degrees off from the bearing of the actual interfering signal.

4. A 20 uV/m vendor specified system sensitivity is indicated in Reference (1), however, it is not entirely clear if this requirement is valid for all elevation angles of incidence, or just on boresite. The 20 uV/m specification was satisfied at the 11.3-foot (boresite) and 16 foot interfering antenna heights. The 21-foot height had only two data points, both at 20.9 uV/m, slightly out of compliance. The 7.2-foot antenna height was the worst performer, having 12 data points greater than 20 uV/m.

5. An average of all 128 system sensitivity readings was calculated, and was found to be 11.9 uV/m, and therefore in compliance with the 20 uV/m specification. This average was further broken down to performance by frequency, with a sensitivity of 10.4 uV/m at 1590 MHz slightly outperforming the 13.4 uV/m sensitivity at 1560 MHz.

6. At the 6 degree jitter point, knowing the RF input to the DF Processor, the Field Strength at the DF antenna, and the RF cable loss, a calculation of the AA2030 array's Antenna Factor was made on boresite for 1560 MHz, and was found to be 13.4 dB/meter.

7. The DF array is vertically polarized, and this testing gives no indication of how this system will respond to horizontally or circularly polarized signals in the GPS L1 band.

8. The DF Processor was adversely affected by high outdoor temperatures (low 90 °F) and direct sunlight, as the Processor would not maintain lock on the interfering signals.

9. The AA2030 array is not rated to provide DF capability at GPS L5 (1176 MHz).

10. By frequency, the two most sensitive signal strengths referenced to an isotropic radiator, were –131.3 dBm (iso) at 1560 MHz and –130.9 dBm (iso) at 1590 MHz. The two least sensitive signal strengths were –102.3 dBm (iso) at 1560 MHz and –108.9 dBm (iso) at 1590 MHz.

11. By frequency, the average signal strength referenced to an isotropic radiator was –124.4 dBm (iso) at 1590 MHz, which was slightly better than the –123.5 dBm (iso) at 1560 MHz. The total average sensitivity referenced to an isotropic radiator was calculated to be –124.0 dBm (iso).

12. All of the measurements described were performed outdoors, and therefore subject to ambient manmade noise and other RF interference.

9.2 VHF-Band Conclusions

1. The boresite bearing accuracy data was mostly in agreement with the 2.5 degree bearing accuracy specification as set forth by Cubic in Reference (1) at all but two azimuth angles, 180 and 225 degrees.

2. A 0.8 uV/m vendor specified system sensitivity (interpolated) is indicated in Reference (1) for the VHF-Band. The measured system sensitivities ranged from 1.9 – 2.9 uV/m, therefore none of the VHF sensitivity data was in compliance with the 0.8 uV/m specification.

3. An average sensitivity for all azimuth angles was calculated utilizing all 16 VHF sensitivity readings, and found to be 2.3 uV/m. This result is 1.5 uV/m above specification.

4. Sensitivity remained basically unchanged between Modes for a constant azimuth angle, with the largest change in sensitivity being 0.3 uV/m at 180 degrees azimuth.

5. The sensitivity data referenced to an isotropic radiator ranged from –114.1 dBm (iso) to -110.4 dBm (iso). The average signal strength relative to an isotropic radiator was calculated to be –112.5 dBm (iso).

6. The VHF DF array is vertically polarized, and this testing gives no indication of how this system will respond to horizontally or circularly polarized signals in the VHF-Band.

7. All of the measurements described were performed outdoors, and therefore subject to ambient manmade noise and other RF interference. RF background measurements with a spectrum analyzer indicated the presence of several VHF-Band emitters. Refer to the plot of Figure 23.

10.0 ISSUES, CONCERNS, AND RECOMMENDATIONS

10.1 Issues and Concerns

In addition to the AM and FMN DF Processor modes, sensitivity and bearing data was also collected in the CW mode on boresite. However, this bearing data was often 180 degrees out of phase with the bearing of the actual interfering signal. Also, the system sensitivity readings at the 6 degree jitter point were well below those measured in the AM and FMN modes. For this reason, after the boresite configuration, CW mode Processor data was no longer collected and is not presented in Table 8. However, it was "spot-checked" periodically at other antenna heights, with the results basically the same as described above.

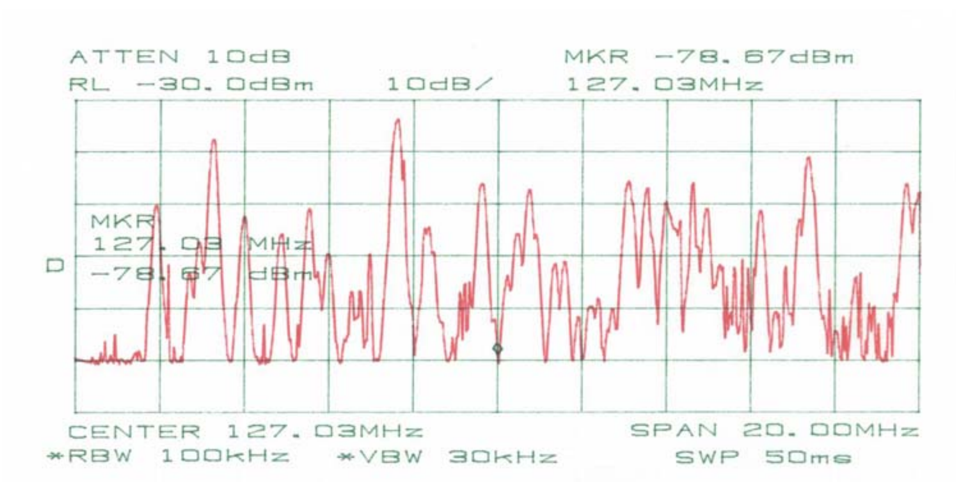
High outdoor temperatures and exposure to direct sunlight seemed to adversely affect the DF Processor's performance. When testing on April 17, 2002, temperatures reached the low 90 °F, and the Processor would not maintain lock on the interfering signals, making it impossible to obtain a bearing or sensitivity reading. Consequently, future testing was conducted with all the test equipment placed in the rear hatch of the ACB-240 Division van, in order to provide some amount of shade. This appeared to solve the problem.

The polarization of the DF array is vertical. This leads one to ask 'how, if at all, will horizontally or circularly polarized interfering signals be detected?'

No tests were run to determine the AA2030 array's DF capability at GPS L5 (1176 MHz). Upon examining Reference (1), the AA2030 array is not specified to receive RF signals at this frequency. The low UHF array's (4 element bow-tie) rated frequency is from 150 to 1000 MHz, while the high UHF array (4 element LP) kicks in at 1400 MHz. The AA2030 does not provide coverage in the proposed GPS L5 Band.

All of the measurements described were performed outdoors, in the vicinity of the Atlantic City International Airport, and therefore subject to ambient manmade noise and other RF interference. The VHF-Band in particular was populated with several RF emitters. Background measurements of the ambient RF environment indicated numerous emitters were present in the VHF-band. A background plot of the RF environment is shown in Figure 23.

Figure 23: VHF RF Background Centered at 127.025 MHz



10.2 Recommendations

Ideas for future work might include evaluating how two equi-distant, equal-amplitude, but different azimuth interferers would be displayed on the DF Processor. Conversations with Cubic suggest that the Processor will display a bearing midway between the two interfering signals. Other variations on this configuration can also be tested, such as increasing the power of one interferer over the other, or by moving one emitter in closer than the other, etc., and observing the bearing indicator.

As mentioned above, other ideas for future work might include using a horizontally or circularly polarized emitter, and observing the DF Processor's performance to interferers having polarizations other than vertical.

It is recommended that future tests be conducted in an anechoic chamber in order to properly baseline the DF array's performance and control the test environment.

It is recommended that future DF bearing measurements be conducted by connecting a computer to the serial output of the DF Processor to collect the data, and then running a statistical analysis on the bearing data to determine the 6 degree RMS standard deviation. The collected data would be more accurate, as it would replace visually monitoring the DF Processor bearing display, and recording the readings by hand. The collected data could then be saved in a data file for future analysis.

Additional modes on the DF Processor can also be tested, including Upper Sideband (USB), Lower Sideband (LSB), and Wideband FM (WBFM).

The VHF-Band bearing and sensitivity data was collected only at boresite. Future work might include collecting data as the interfering antenna's height is varied, as was done with the L-Band data collection.

11.0 ACKNOWLEDGEMENT

The author would like to recognize Jim Vena, Hank Weber, and other members of the WJHTC NAS Architectural and Engineering Branch (ACX-043) for their assistance and suggestions in designing and fabricating the two antenna mounting brackets, as well as providing the fence post support to anchor the fiberglass antenna mast.

Also to be acknowledged is Mr. Earl Bossaller of Cubic Communications, for his insights on testing the AA2030 DF Array.

12.0 REFERENCES

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2. Cubic Communications, "Operation and Maintenance Instructions, Operational Level, DF Receiver/Processor 4400", Technical Manual, Issue 2.2, July 19, 1999, Change 1, February 4, 2000.

3. AH Systems, Inc., "3 meter Calibration, Gain and Antenna Factors for Log Periodic Model SAS-200/518", fax from Hogue, Tammy, November 24, 1998.

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5. AH Systems, Inc., “10 meter Calibration, Gain and Antenna Factors for Folding Biconical Model SAS-200/530,542”, February 24, 2000.

6. Rohde & Schwarz, “VHF Coaxial Dipole, HK 012 Documentation”, no date.

7. Hewlett Packard, “Spectrum Analysis-Field Strength Measurement”, Application Note 150-10, Spectrum Analyzer Series, June 1984.

8. Hewlett Packard, “HP 8663A Portable Microwave Spectrum Analyzer”, Technical Data, via e-mail from Steve Sanelli, Agilent Applications Engineer, dated October 1989.

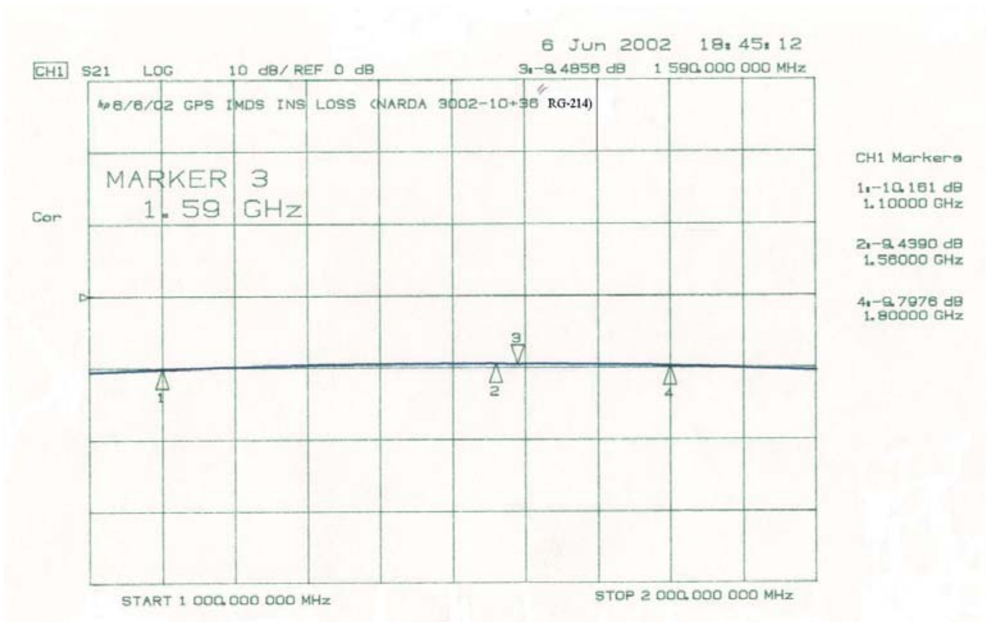
9. Cubic Communications, “DF Antennas: Theory of Operation”, Power Point presentation from Earl Bossaller, September 13, 2002.

Appendix A: Insertion Loss Measurements

The actual insertion loss measurement plots from the 8753ES Network Analyzer for the Narda directional coupler and all the test cables are shown below in Sections A1 thru A5.

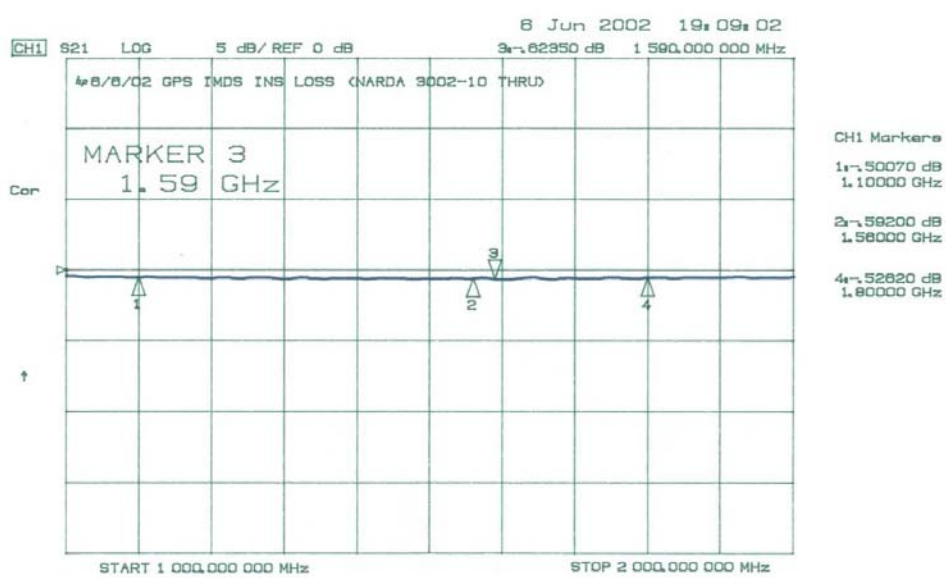
A1 L-Band Narda 10 dB Coupling Port and 3 ft. RG-214 Cable Combination (DF Processor RX signal into Spectrum Analyzer)

Figure A1: L-Band Plot of Insertion Loss thru Coupling Port and 3 ft. RG-214 Cable



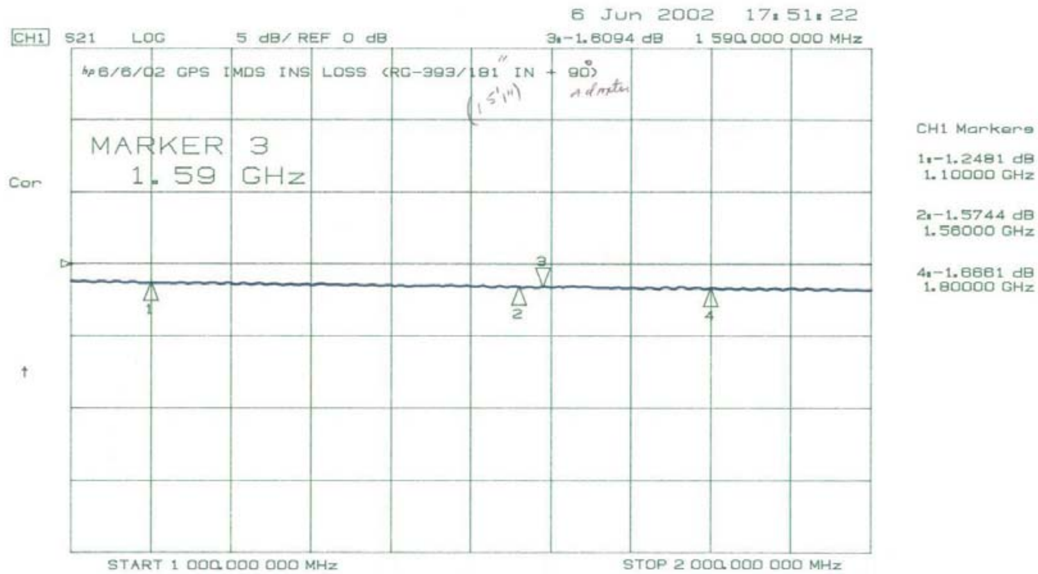
A2 L-Band Narda Directional Coupler (RX signal into DF Processor)

Figure A2: L-Band Plot of Insertion Loss thru Narda Directional Coupler



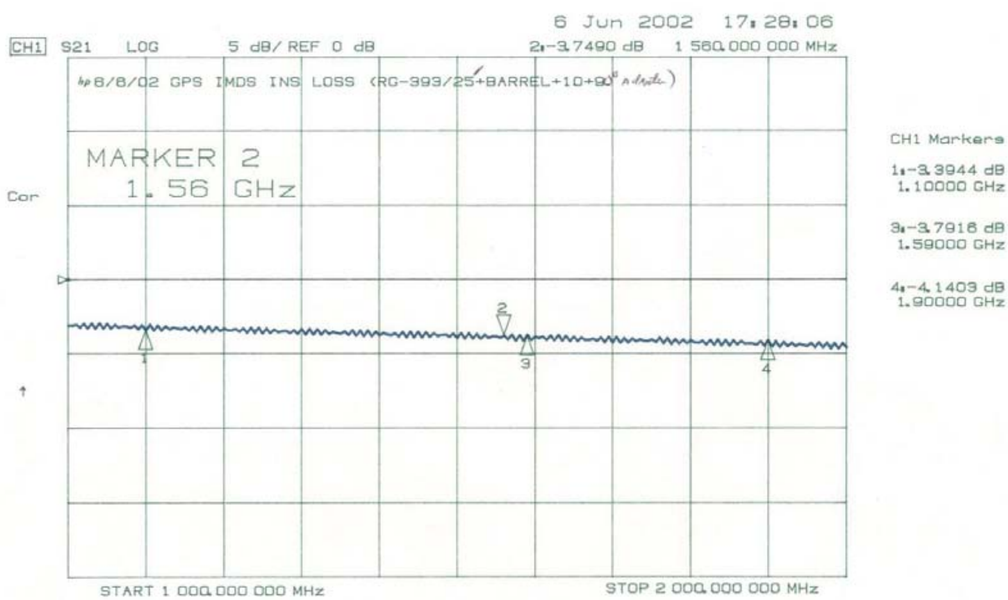
A3 L-Band 15 ft. RG-393 Cable (RX cable for Field Strength Measurements)

Figure A3: L-Band Plot of Insertion Loss of 15 ft. RG-393 Cable



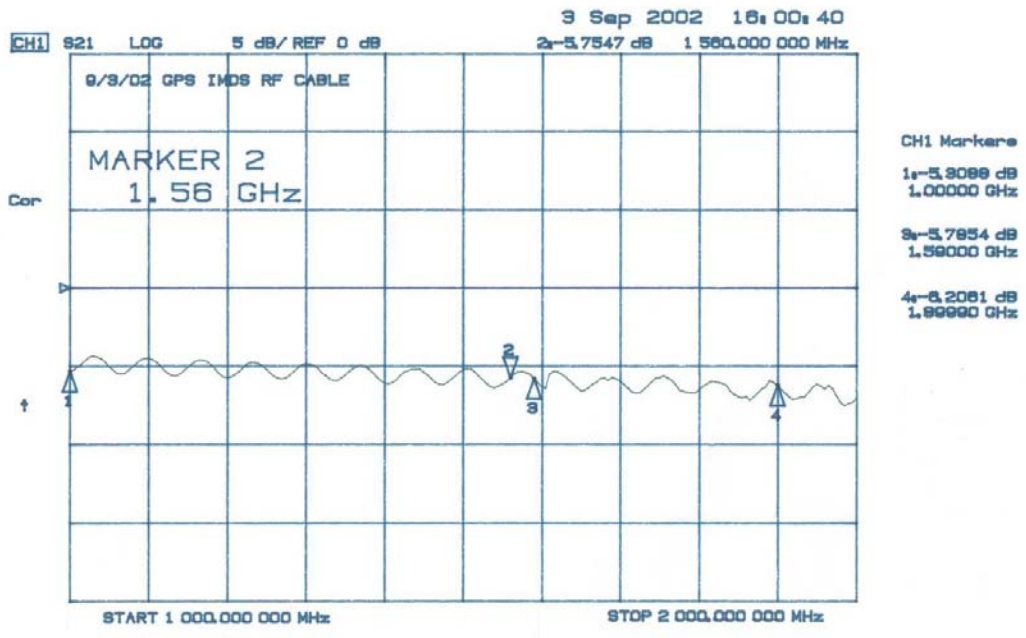
A4 L-Band 35 ft. RG-393 Cable (TX Cable for interferer)

Figure A4: L-Band Plot of Insertion Loss of 35 ft. RG-393 TX Cable



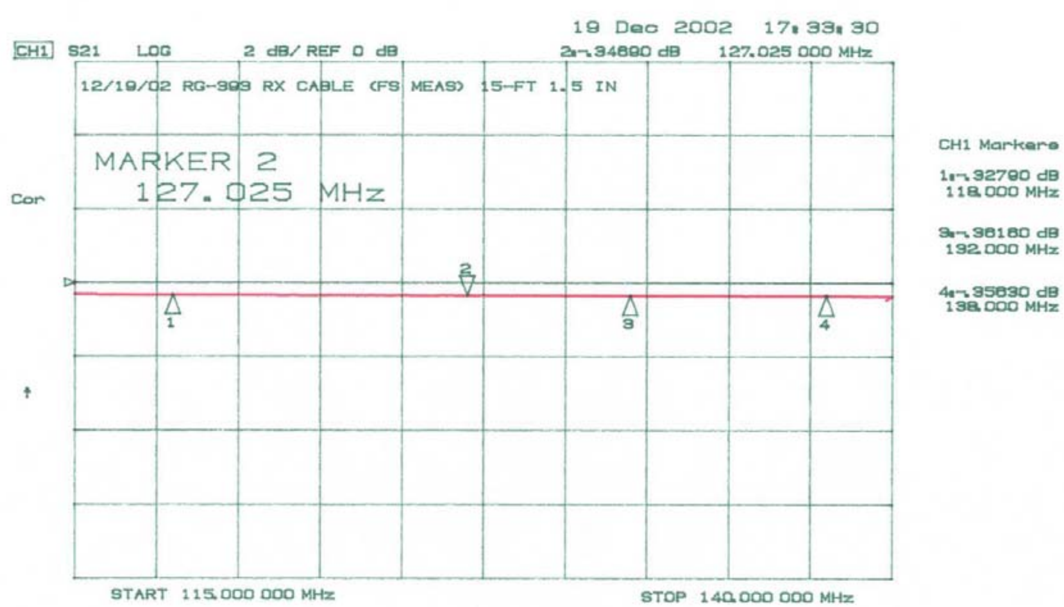
A5 L-Band 74 ft. Cubic RF Cable (Cubic Array to DF Processor)

Figure A5: L-Band Plot of Insertion Loss of 74 ft. Cubic RF Cable



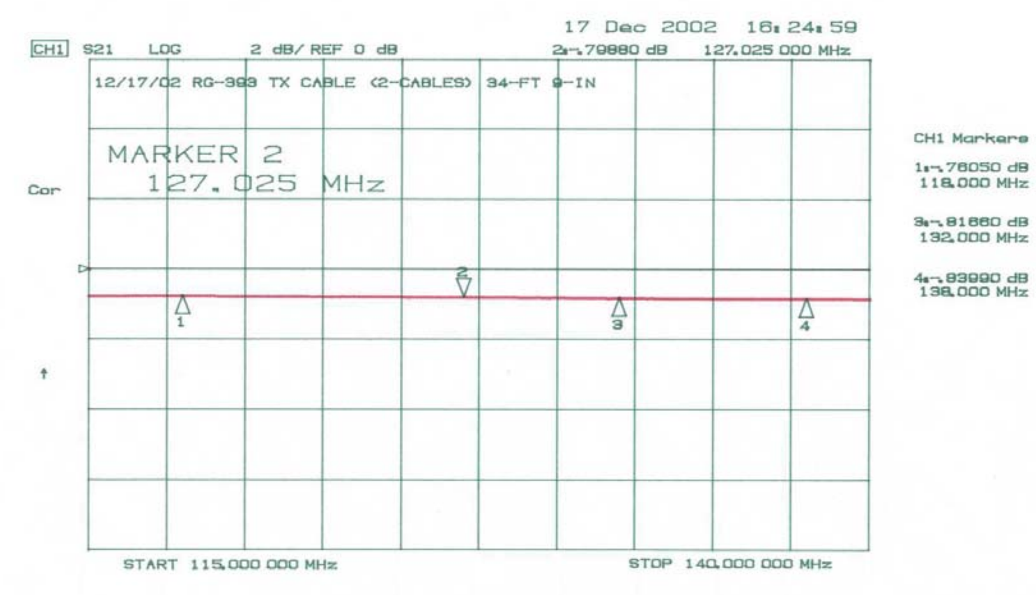
A6 VHF-Band 15 ft. RG-393 Cable (RX cable for VHF Field Strength Measurements)

Figure A6: VHF-Band Plot of Insertion Loss of 15 ft. RG-393 Cable



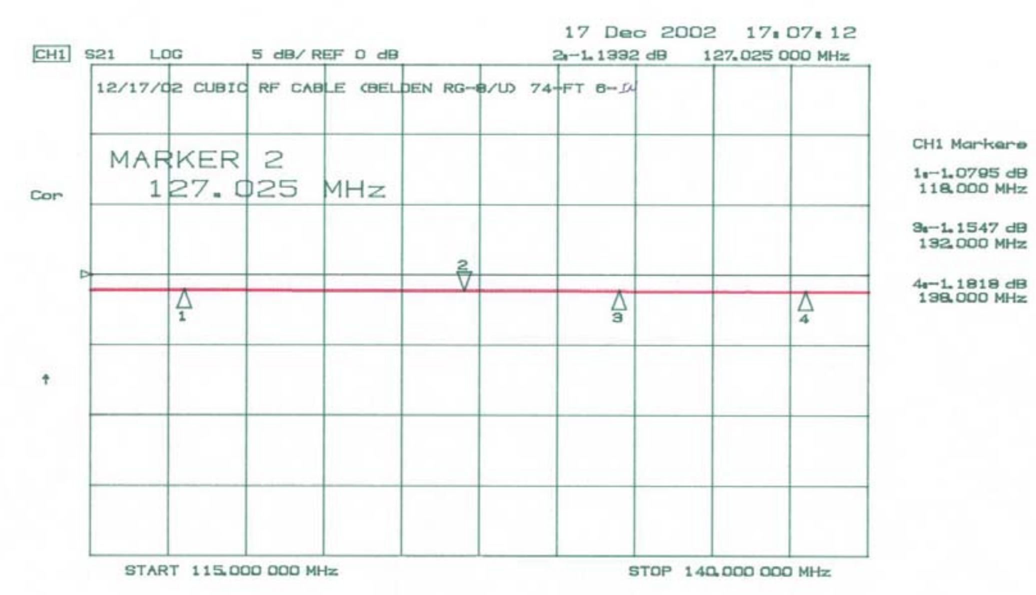
A7 VHF-Band 35 ft. RG-393 Cable (VHF TX Cable for interferer)

Figure A7: VHF-Band Plot of Insertion Loss of 35 ft. RG-393 TX Cable



A8 VHF-Band 74 ft. Cubic RF Cable (Cubic Array to DF Processor)

Figure A8: VHF-Band Plot of Insertion Loss of 74 ft. Cubic RF Cable

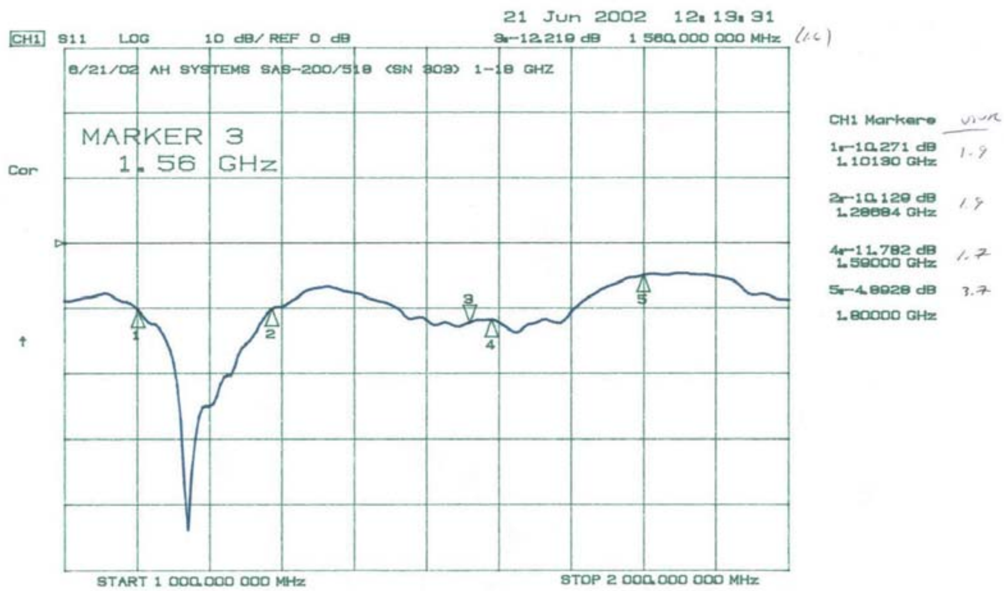


Appendix B: VSWR Measurements on Test Antennas

The return loss for all four-test antennas was measured on the 8753ES Network Analyzer, and the plots are shown below in Sections B1 through B4.

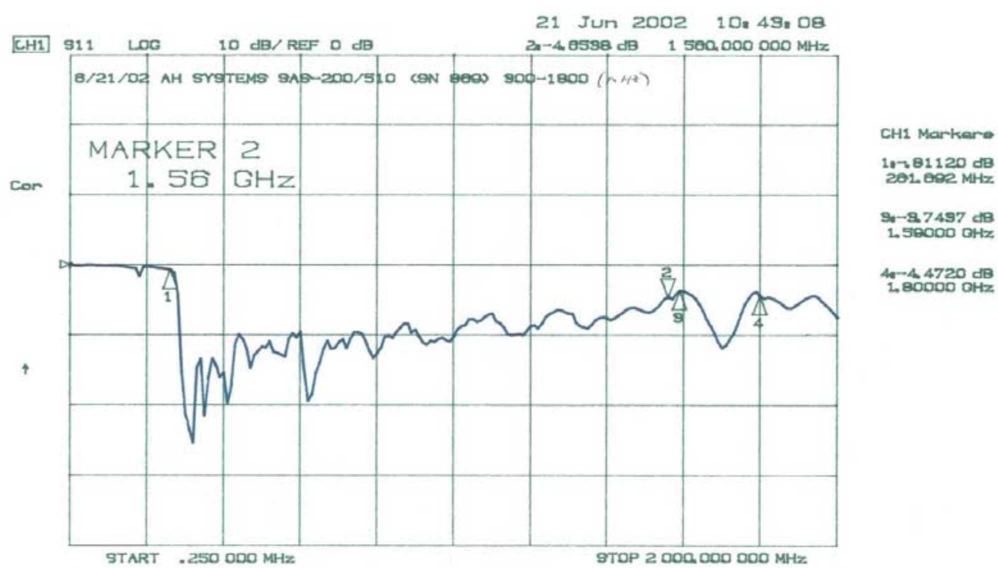
B1 AH Systems (Model SAS-200/518; SN 303) LP Antenna (L-Band interferer)

Figure B1: Plot of Return Loss vs. Frequency for AH Systems LP SAS-200/518



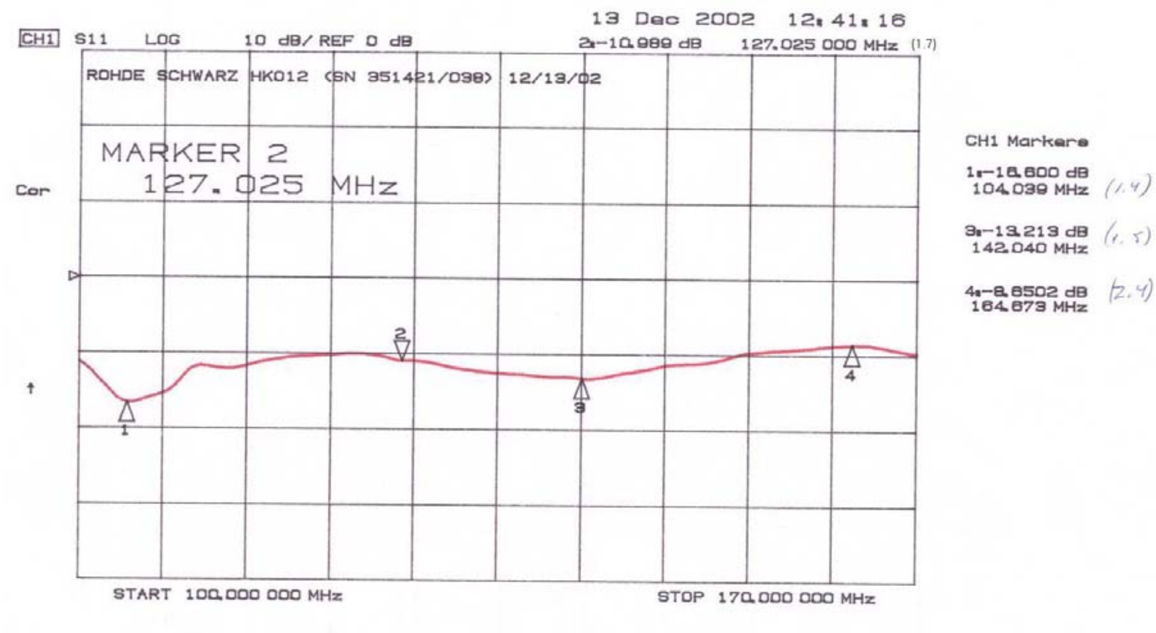
B2 AH Systems (Model SAS-200/510; SN 869) LP Antenna (Field Strength measurements)

Figure B2: Plot of Return Loss vs. Frequency for AH Systems LP SAS-200/510



B3 Rohde & Schwarz (Model HK-012; SN 351421) Coaxial Dipole (VHF-Band interferer)

Figure B3: Plot of Return Loss vs. Frequency for Rohde & Schwarz Coaxial Dipole HK-012



B4 AH Systems (Model SAS-200/530; SN 562) Biconical Antenna (Field Strength measurements)

Figure B4: Plot of Return Loss vs. Frequency for AH Systems Biconical SAS-200/530