VALIDATION TESTING OF THE PLANAR NEAR-FIELD RANGE FACILITY AT SPAR AEROSPACE LIMITED

W. Keith Dishman and Sidney J. Manning

ABSTRACT

A series of measurement were made to validate the performance of a Planar Near-Field (PNF) Antenna Test Range located at the Satellite and Aerospace Systems Division of Spar Aerospace Limited. These measurements were made as a part of a contract to provide Spar with a Model 2095 Microwave Measurement System with planar near-field software options and related instrumentation and hardware.

The range validation consisted of a series of self-tests and far-field pattern comparison tests using a planar array antenna provided by Spar that had been independently calibrated at another range facility.

This paper describes the range validation tests and presents some of the results. Comparisons of far-field patterns measured on the validation antenna at both the Spar PNF facility and another antenna range are presented.

Keywords: Planar Near-Field, Near-Field Scanning, Range Validation

1. INTRODUCTION

The Spar planar near-field facility is designed for high accuracy measurements of large aperture synthetic aperture radar (SAR) antennas such as the Canadian RADARSAT SAR satellite antenna. The facility includes a planar scanner with a 5 meter by 18 meter coverage area, a two-axis laser interferometer for accurate X-Y positioning of a dual-ported linear probe antenna, a Scientific-Atlanta Model 2095 Microwave Measurement System for fully automated data acquisition, and planar near-field analysis software based upon the theory and procedures devised and implemented by the National Institute of Standards and Technology (NIST). A more complete description of the Spar facility instrumentation and software may be found in reference [1].

A series of measurements to validate the performance of the near-field facility were carried out. These tests were designed to measure the system level performance of the facility.

Tests of individual system components such as the planar scanner, RF probe, and RF instrumentation were conducted prior to the tests discussed in this paper.

The validation testing consisted of both self-testing and comparison testing [2] using a validation antenna provided by Spar. The validation antenna was a breadboard panel equivalent to a 1/8 segment of the RADARSAT SAR antenna. The beamforming network was configured to steer the antenna beam in a fixed direction. Table 1 summarizes the performance characteristics of the validation antenna. The validation antenna's pattern and gain had been previously measured at an independent high accuracy measurement facility in Europe and these data were used during the validation process for comparison.

Table 1
Validation Antenna Characteristics

Parameter	Value
Antenna Type	Slotted waveguide array
Size	1.5 m x 1.9 m
Polarization	Horizontal
Nominal Gain	35 dBi
Beam Peak Location	4.8° azimuth -11.7° elevation

2. RANGE VALIDATION PLAN

The validation test plan was designed to verify a number of system performance specifications and to provide Spar with guidelines for designing the test methodology for the full scale RADARSAT antenna. The following tests were included in the range validation procedure:

1. RF Signal Leakage
2. Crosstalk
3. RF Path Error Correction
4. Scan Area Determination
5. Probe Travel Speed
6. Frequency/Beam Multiplexing
7. Measurement Repeatability
8. Probe Alignment Repeatability
9. Probe/AUT Separation Variation
10. Range Reflectivity Levels

Each of these tests will be described and some of the results will be presented in section 4.

3. SYSTEM CALIBRATIONS

Various calibrations and alignments were performed prior to the start of the validation testing. These included the following:

Probe Calibration. The RF probe was calibrated by NIST during November 1991. The results of the calibration were the plane-wave receiving coefficients as a function of theta and phi, $s_{02}(\theta\phi)$, at five frequencies and the complex reflection coefficient for each probe port at 5 MHz steps.

Probe Alignment. The probe coordinate system was aligned to the scan plane coordinate system by rotating the probe about its x and y axes until it was aligned within 1 second of arc relative to the best-fit scan plane (previously established by Spar). The probe was then rotated about its z axis until a precision bubble level incorporated into the probe assembly read level.

Channel Balance. The purpose of the channel balance is to measure the difference in amplitude and phase between the two orthogonal ports of the probe including the probe, interconnecting RF cables, and the polarization multiplexing switch unit. These measurements were made at discrete frequencies and stored in a look-up table in the analysis computer.

Scanner Error Map. Three scanner error maps defining the Δx, Δy, and Δz probe position errors were supplied by Spar corresponding to three different z-axis positions of the probe assembly.

Validation Antenna Alignment. The validation antenna was mounted in four different positions in the near-field range during the validation testing (see section 4). At each position, Spar personnel aligned the antenna to the scan plans using a dial indicator. The accuracy of the alignment for each position was less than 0.002°.

Reflection Coefficients. The S-A 2095 PNF software requires reflection coefficient measurements at each of the measurement interfaces (AUT interface, probe ports, source interface, receive interface, etc.) in order to accurately compute the antenna gain. These measurements were performed by Spar using a vector network analyzer.

4. VALIDATION TEST RESULTS

4.1 RF Signal Leakage

The RF leakage test is a measurement of the signal detected when either the RF probe or the AUT is replaced with a matched termination and a normal scan is made over the measurement plans. Figure 1 shows a horizontal scan through the maximum near-field level. Three traces are plotted, one with the normal configuration, one with the source port terminated, and one with both receive ports terminated. The typical leakage signals are less than -80 dB relative to the desired signal level.

4.2 Crosstalk

The crosstalk test is a measurement of the signal level appearing in one receiver channel when a signal is injected into the other channel. This test was performed by terminating the horizontal polarization channel at the probe interface and injecting a signal directly into the vertical polarization channel at a level approximately equal to the maximum received level during a scan. The signal crosstalk was less than -70 dB across the 5.25 to 5.35 GHz operating range.

4.3 RF Path Error Correction

The near-field measurement system at Spar included a new technique for correcting the measured signal for amplitude and phase errors introduced by the motion of the RF cables and rotary joints during the scanning process. This technique, which Scientific-Atlanta has applied for a patent on, utilizes measurements of multiple RF paths to generate correction terms during data post processing. The details of this technique are described elsewhere in these proceedings.

In order to verify the technique, small amplitude and phase variations (approximately 1 dB and 15°) were introduced into the RF signal path during a scan. The scan was then repeated without introducing the variations and the two scans were compared both before and after applying the data correction process to determine the residual error. The residual errors were loss than 0.02 dB and 0.20° for all measurement cases examined.

4.4 Scan Area Determination

The purpose of the scan area determination test is to find the minimum scan area size for acceptable AUT measurements. A data acquisition is performed over a large area centered on the AUT aperture and the far-field pattern is computed. The data set is then truncated in software and a new far-field pattern computed. This is repeated for successively smaller data sets and the resulting patterns are compared to determine the minimum acceptable scan area for the particular aperture size and probe/AUT separation being considered.

The initial data acquisition was performed over a 4.8m by 7m area centered on the 1.48m x 1.9m AUT aperture. The probe-to-AUT separation was 40 cm (7 wavelengths @ 5.3 GHz). This represents an area ratio of 11.95. The data sets were truncated in both dimensions in equal percentage steps down to an area ratio of 1.56. The desired far-field angular coverage region was ±70° in elevation and ±65° in azimuth. It was found that the far-field patterns began to slightly deteriorate when the scan area was less than the limits found by applying the truncation rule [3] given by

$$\theta_s = \arctan\left(\frac{L - a}{2d}\right) \tag{1}$$

where L is the scan dimension, a is the aperture dimension, d is the probe/AUT separation distance, and θ_s is the desired maximum far-field coverage angle. The scan limits corresponding to (1) represent an area ratio of 4.73. Figure 2 is a plot of the peak gain versus scan area size and the scan area ratio predicted by the truncation rule corresponds to the beginning of slight oscillations in the gain value. The effects on the far out sidelobes and crosspol were more pronounced and the scan limits selected for the remaining validation tests corresponded to a ratio of slightly greater than 6.

4.5 Probe Travel Speed

The probe travel speed test consists of a series of frequency multiplexed near-field measurements repeated for different probe scan velocities. The far-field patterns are then compared to determine the effects of probe velocity on the far-field parameters including gain, boresight error, sidelobe level, and crosspol level. Measurements were made at five frequencies for scan speeds of 5, 10, and 15 cm/sec. No detectable degradation of the far-field patterns was observed at any of the speeds. A speed of 1 0 cm/sec was selected for all subsequent validation tests.

4.6 Frequency/Beam Multiplexing

The frequency/beam multiplexing test is a verification of the frequency and beam switching capabilities of the system. The RADARSAT AUT is capable of switching between four different beam steering configurations under the control of the Model 2095 Measurement System. For this test, three different data acquisitions were conducted with different combinations of frequencies and beam steering commands. The first acquisition consisted of 25 frequencies and 1 beam with the range configured to transmit through the AUT. The second acquisition consisted of 10 frequencies and 4 beams, for a total of

40 combinations. The third acquisition was the same as the first except that the range was configured to transmit through the probe antenna. These data sets were transformed to the far-field and the resulting patterns were compared to verify that the multiplexing did not effect the measured data.

4.7 Measurement Repeatability

This measurement consists of repeating the same data acquisition several times under nearly identical conditions. Three acquisitions were made, each at a different time of the day. The maximum temperature variation in the anechoic chamber during these tests was 0.2°C. All scans were made at five multiplexed frequencies.

The results of the far-field pattern analyses for 5.30 GHz are shown in Table 2. Only minor variations were observed in the gain, sidelobe, and crosspol parameters. No variations were observed in the pointing angle of the beam peak. Similar results were obtained at the other four frequencies.

Table 2
Measurement Repeatability Test Results

Scan No.	Gain (dBi)	Max. SLL (dB)		Max. XPOL (dB)	
		AZ	EL	AZ	EL
1	34.931	-12.998	-18.848	-22.974	-23.406
2	34.930	-13.012	-18.848	-22.983	-23.396
3	34.923	-12.993	-18.848	-22.956	-23.316
Delta	0.008	0.019	0.000	0.027	0.090

4.8 Probe Alignment Repeatability

In this test a multiplexed data set was acquired and then the probe assembly was removed from its mount. The probe was reinstalled and aligned, and the date acquisition was repeated. The date sets were analyzed and the far-field patterns compared. The pattern differences for all parameters were within the measurement repeatability variations observed previously.

4.9 Probe/AUT Separation Variation

The effect of the probe-to-AUT separation distance was measured with this test. Five multiplexed data acquisitions were made on scan planes spaced approximately 1/8 wavelength apart. Each data set was transformed to the far-field and the patterns compared. Table 3 shows the variation in peak gain at three frequencies. Minimal variation is observed at 5.30 GHz which corresponds to the center frequency of the AUT, while larger variations occur at the frequencies that correspond to the AUT band edges.

Table 3
Peak Gain Vs Separation Distance

Probe-AUT Distance (mm)	Peak Gain (dBi)		
	5.275 GHz	5.300 GHz	5.325 GHz
400	35.106	34.969	34.973
393	35.059	34.954	34.874
386	35.001	34.924	34.941
379	34.999	34.909	34.803
372	35.053	34.944	34.701
Average	35.044	34.940	34.822
Variation	0.107	0.060	0.240

The radiation patterns showed significant variation only in a few specific areas of the far out sidelobes. This is illustrated in Figure 3 which is an overlay plot of three patterns at 5.30 GHz corresponding to different separation distances, plus a plot of the average of these three patterns. Additional testing revealed that these variations were being caused by extraneous signals being reflected off of the side port RF connector on the probe antenna. This port was located slightly in front of the absorber panel and included several right angle carriers that could cause reflections.

4.10 Range Reflectivity Levels

The range reflectivity levels were examined by repeating a set of near-field scans with the AUT located at four different positions within the 5m by 18m scan area. At each position, multifrequency measurements were made at three different probe-to-AUT separation distances and the results averaged to remove any multiple reflection effects between the probe and the AUT. The resulting four averaged far-field patterns were compared to determine if reflections from the range walls or other fixed structures were above acceptable levels.

Table 4 summarizes the results at 5.30 GHz. The peak gain values were not compared because different lengths of uncalibrated waveguide were used to interface the validation AUT to the RF subsystem at each new range position. No variation was observed in the position of the main beam peak.

Table 4
Range Reflectivity Test Results

Pos.	Max. SLL (dB)		Max. XPOL (dB)	
	AZ	EL	AZ	EL
1	-12.99	-18.93	-23.55	-23.81
2	-13.02	-18.95	-23.55	-23.85
3	-13.07	-18.91	-23.01	-23.40
4	-13.01	-18.93	-23.18	-23.47
Delta	0.08	0.04	0.54	0.45

An examination of the far sidelobes showed that the level of reflection attributable to the range was less than -55 dB in all cases.

5. RANGE COMPARISON

As a final verification of the Spar planar near-field measurement facility, a set of far-field patterns measured during the range validation were compared to a set of patterns measured on a different range facility. Figures 4 and 5 show the comparison between the azimuth and elevation plane cuts at 5.30 GHz. In general, the agreement is excellent, with the only significant difference occurring in the -50°, + 65° regions of the azimuth plane pattern. The sidelobe variation in these regions are due to the multiple reflections off the probe side port connector as discussed previously. It was found that by averaging two patterns obtained on scan planes spaced 1/4 wavelength apart that excellent agreement could be obtained at all pattern angles. Similar agreement was obtained for the crosspol patterns. The peak gain values obtained on the two ranges were within 0.10 dB.

6. CONCLUSIONS

The results of a range validation program conducted on the Spar planar near-field range have been presented. The range has met all the required performance specifications, exhibiting excellent accuracy and repeatability. Comparisons with data measured on another antenna range have shown very good agreement, strengthening the argument that the Spar PNF facility is a state-of-the-art range with excellent performance.

7. REFERENCES

[1] J.H. Pape and O.M. Caldwell, “Measurement System Performance Considerations for Planar Near-Field Scanning Applications”, in *Proc. 1991 Antenna Measurement Techniques Association Meeting*, Boulder, CO, October 1991, pp. 5-25-5-32.

[2] E.B. Joy, “Near-Field Range Qualification Methodology”, *IEEE Trans. Antennas Propagat.*, vol. AP-36, no. 6, pp. 836-844, June 1988.

[3] A.C. Nowell, “Planar Near-Field Measurements”, NBS Lecture Notes. June 1985.

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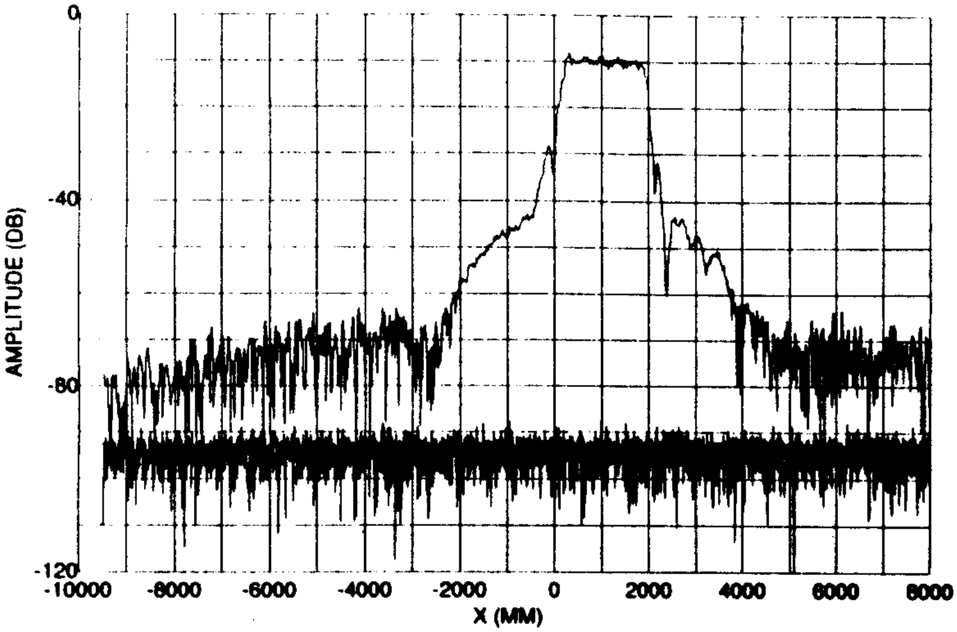

Figure 1. Typical RF signal leakage levels, horizontal scan at 5.30 GHz.

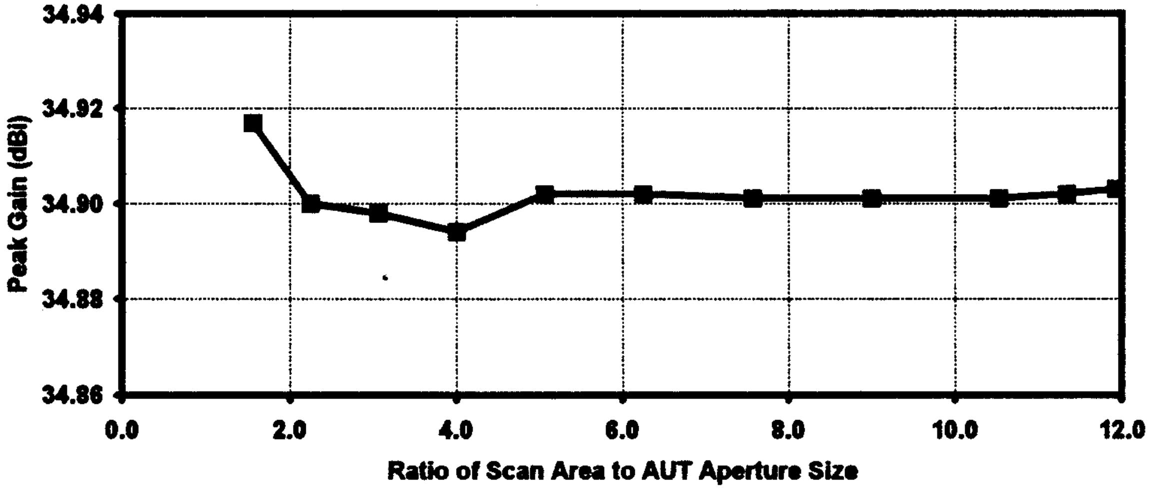

Figure 2. Peak gain at 5.30 GHz versus ratio of scan area to AUT aperture size.

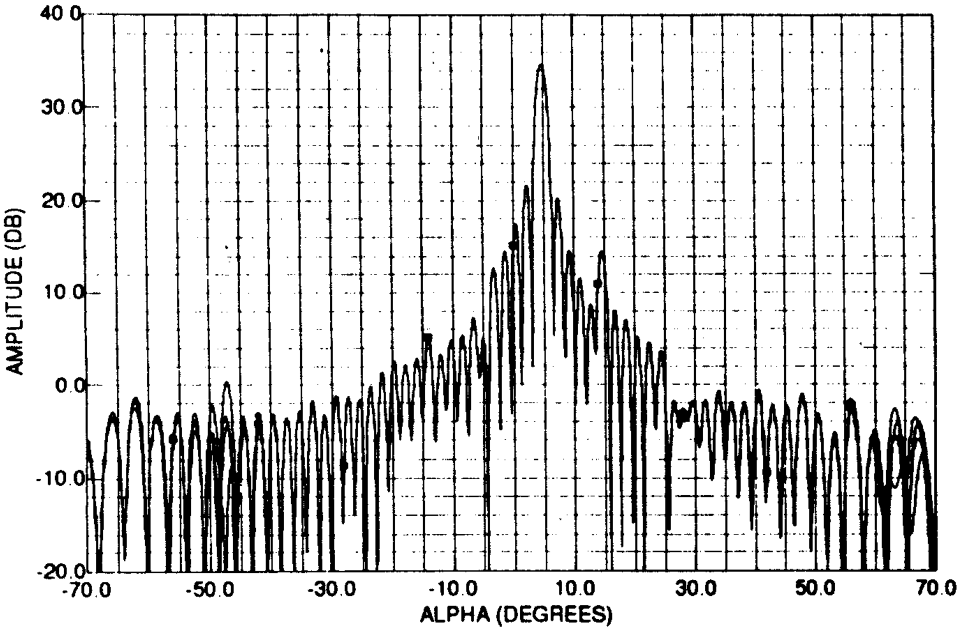

Figure 3. Overlay plot of azimuth plane patterns for 1/8 scan plane spacings.

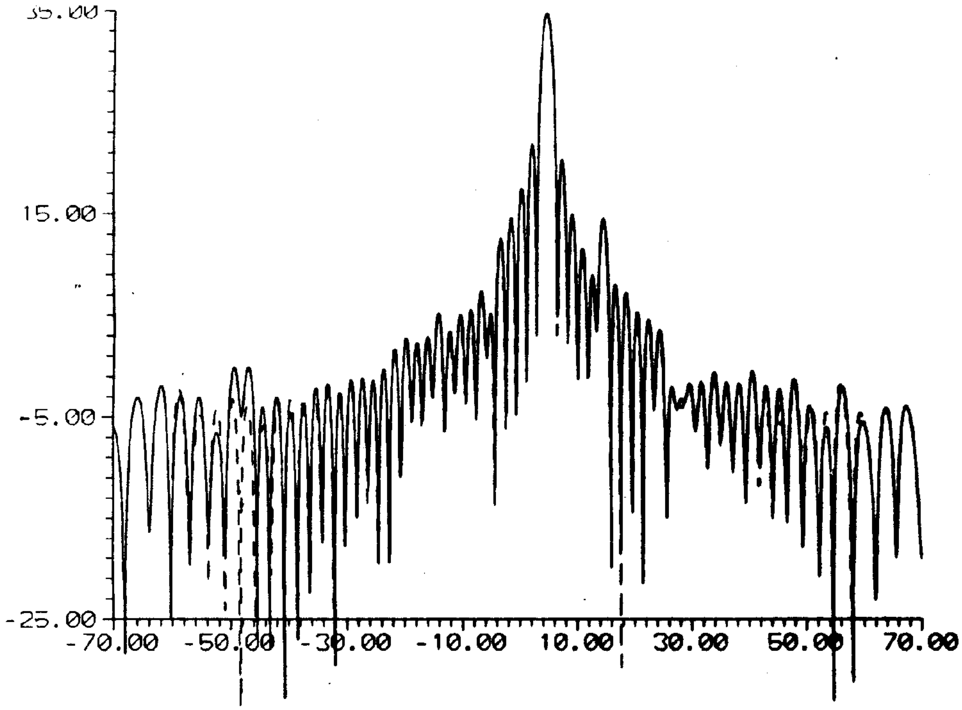

Figure 4. Comparison between azimuth plane patterns at 5.30 GHx measured at the Spar PNF range (Solid line) and a second range (dashed line).

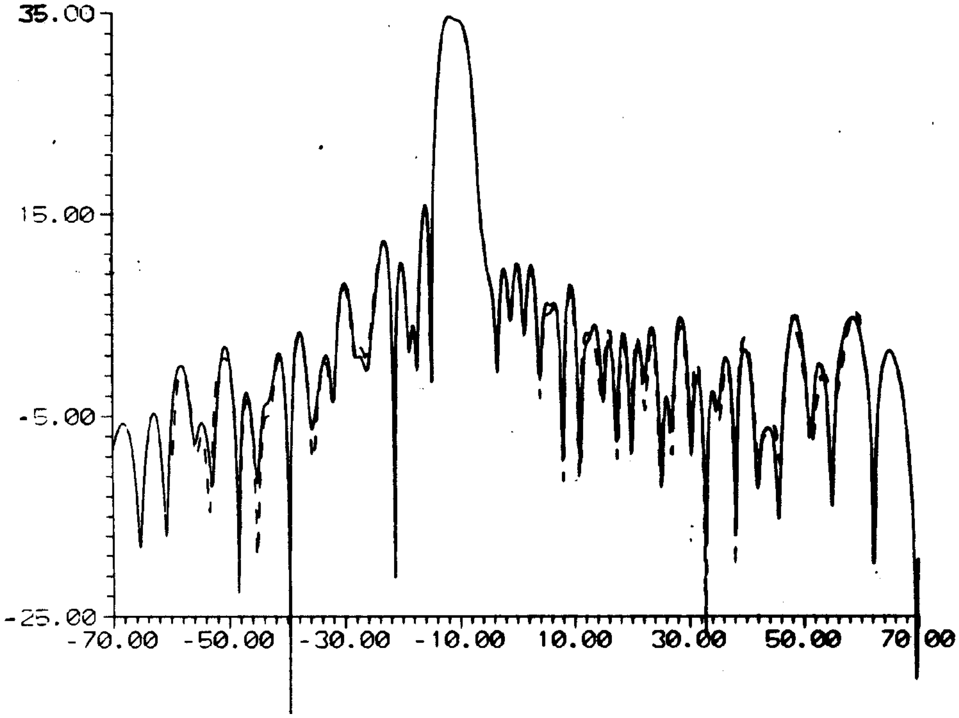

Figure 5. Comparison between elevation plane patterns at 5.30 GHz measured at the Spar PNF range (solid line) and a second range (dashed line).