AN AUTOMATED CYLINDRICAL NEAR-FIELD MEASUREMENT AND ANALYSIS SYSTEM FOR RADOME CHARACTERIZATION

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ABSTRACT

The David Florida Laboratory (DFL) was contacted by the Canadian Department of National Defense (DND) to develop an accurate, reliable, more cost effective method of characterizing existing nose cone mounted radomes for the radar systems aboard aircraft such as CF-18. Traditionally, these measurements have been performed in a far-field (FF) [1] range using conventional positioning and measurement systems and specialized instruments such as a null seeker. Recently, the use of near field methods has been incorporated in radome measurement practices [2]. This paper describes one such adaptation of a cylindrical near-field facility (CNF) for radome measurements.

Keywords: Cylindrical Near-Field, Material Measurement, Data Acquisition, Measurement Errors, Radome Measurements

1.0 Introduction

In order to qualify a radome, it must be evaluated to assure that it meets its intended electrical performance specifications. This involves measuring the differential change in a number of antenna parameters in the presence of the radome. Some of the parameters that need to be evaluated include transmission efficiency, beam-width, side lobe level change, beam deflection, beam deflection rate, beam unbalance, null depth, and return loss. The first part of this paper describes the adaptation of the CNF facility for radome measurements.

Measuring the electrical characteristics of a radome has traditionally been performed using FF measurement techniques, and consequently the specifications used to determine the radome's performance are written for these FF techniques. The second part of the paper explains the characterization parameters of interest; as well as, the process in which they were implemented.

Radome measurements become very involved due to the fact that the antenna within the radome is not static. This implies that the measurement process must be able to control the movement of additional axes and handle the large volume of data. The next part of this paper describes the data acquisition and analysis steps that were implemented for this project.

The remainder of this paper expands on the optimization of the data acquisition and processing process. This includes the selection of the measurement parameters for the varying antenna configurations, and the number of data analysis iterations that are needed to accurately describe the radome's performance.

2.0 CNF Adapation

In order to fully characterize the radome to its specifications, it is preferable to utilize an antenna that has the same characteristics in pattern, gain, and side lobes as the actual radar antenna. The antenna used is a radar monopulse antenna that has multiple modes of operation. The modes of interest consist of the main Sum Beam and the two Difference beams. The Sum beam is the main lobe or sum pattern of the antenna, and the Difference beams consist of an Azimuth and Elevation Difference beams. The difference beams produce a null along the axes of the above beams.

During normal operation, the antenna within the radome rotates in a broad angular range in azimuth and elevation. The angular limits used, were 670 Degrees in the azimuth plane and 630 Degrees in the elevation plane. If all of the requirements are combined with all the combination of the angular extremities of the specification, there are approximately 250 CNF tests that must be performed. With the large number of CNF tests being measured at three frequencies and three modes of antenna operation, produces an extremely large amount of data that must be collected and processed to obtain the radome's performance

The major modification that must be made is the design, fabrication, and installation of a structure that supports the radome and the positioning system for the antenna. The radome itself is almost two meters long and has a mass of close to 50 kilograms as seen in Figure 1. The antenna positioning system with the antenna adds another 20 kilograms.

Figure 1

For radome characterization, one must compare the radome measurements against free-space baseline measurements. If the support structure is not rigid enough, then the deflection of the structure with the addition of the radome will skew the results. That means that the support structure must be sufficiently strong to minimize the deflection for the radome measurements. For this support structure, a fixture was constructed of 19mm thick aluminum sheet stock with support struts added for rigidity. (Figure 2.)

The positioning system used to position the antenna within the radome was designed to locate the antenna in the same coordinates as in the aircraft. The positioning system consists of two micro-step stepper motors that are connected to ultra-low backlash gear heads. The combination of the low backlash gears and micro stepping of the drive motors allows the positioning system to achieve very accurate and repeatable positioning. Stepper motors were selected, as they allow direct integration with the positioning system of the CNF range.

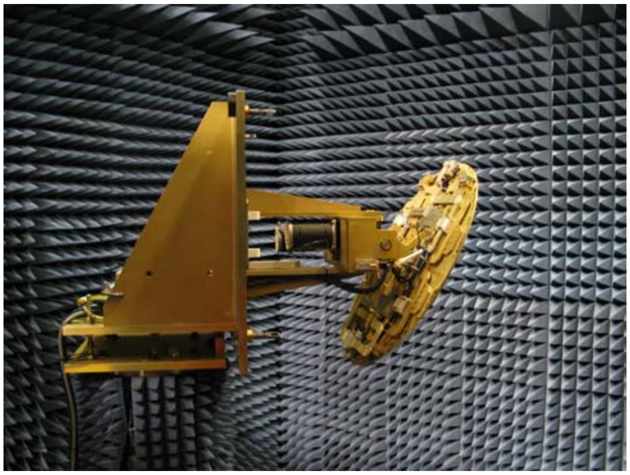

Figure 2

Beam deflection is one of the most important parameters in the characterization of the radome. As the radome is part of a radar system, angular determination of a target is key. If the radome deflects the beams too much, then the accuracy of the system is jeopardized. The specification indicates that the beam deflection by the radome cannot exceed approximately 0.25 Degrees. Therefore the positioning system must be able to repeat the positioning of the antenna to fractions of the specified value. With a rigid structure and a precision drive system, it was confirmed that the positioning system was able to locate the antenna to within 60.005 Degrees.

Since the antenna had multiple modes available, control of the antenna modes via software was essential to the functionality of the system. A module was designed to control the antenna via parallel port. The module reads the address specified by the software interface, and switches the antenna's mode of operation to the specified state. When the antenna switches from the Sum beam to the Difference beams, the RF port on the antenna changes as well. The design of the module handles this situation by controlling a pin diode switch. The addition of the pin diode switch and the fast response of the antenna components themselves, allows measurement of all beams at multiple frequencies simultaneously.

3.0 Radome Characterization Parameters

To fully characterize a radome, there are many parameters that must be calculated. In the FF case, this usually requires several different measurements to be performed. Each of these measurements is vary labour intensive and subject to more human error. With the adapted CNF system, one can identify each parameter in a single CNF measurement. This enables the user to perform one set of automated measurements, process the data and retrieve all the pertinent information. In order to identify the radomes performance, one must compare it to something. In this instance, a freespace measurement is performed on the AUT only and this data processed to the FF. This becomes the baseline for which the radome is compared.

The specifications for this task requires the following entities to be quantified: transmission efficiency, beam-width change, side lobe level change, beam deflection, beam deflection rate, beam unbalance, null depth change.

Transmission efficiency is calculated by obtaining the computed maximum FF amplitude of the sum beam for each CNF measurement. This value is then converted to a linear value and compared to the baseline. The result is given in percent. The beamwidth change is the change of the 3 dB BW through the peak of the sum beam. The HCUT and VCUT changes are made. The side lobe level change is determined by comparing the SLL changes of the HCUT and VCUT through the peak of the sum beam and the null of the difference beam. Measuring the change in the nulls azimuth and elevation position in presence of the radome identifies the beam deflection and beam deflection rate. The beam unbalance is established by comparing the peak levels of the first main lobe on either side of the null for the difference beams. The null depth change is simply the change in the null depth in presence of the radome.

4.0 The Automation Process

In order to have a practical system to qualify a large number of radomes, the system must be automated to reduce the amount of human involvement and error. Several scripts were created that enable the system to perform >90% of the tasks required automatically without operator intervention.

In order to accommodate future requirements and the irregular angular spacing of the AUT within the radome around the tip, the data acquisition script uses a file which it reads to identify what angles to position the antenna and what antenna parameters to measure. The acquisition process reads the parameter file, positions the AUT within the radome, sets up the CNF scan, measures the data, stores the data, and repeats until all the scans are completed. The entire measurement process takes just over 40 hours with the current hardware. It should be noted, that a new higher speed receiver system has been procured which will reduce the measurement time considerably.

The data acquisition script is a fairly simple process that utilizes the ability of the systems software to allow the user to control its processes through scripts. The data processing component of the script package is what allows the system to become a practical method of characterizing radomes.

Since the measurement process is a near-field technique, the first script takes the sampled NF data and converts it to the FF. Depending on the angular position of the AUT, the script identifies what parameters, if not all, need to be characterized and processes the data accordingly to provide the subsequent scripts with the proper information. Some examples include whether or not the beam deflection is required, side lobe levels, and where the AUT points. The output of the NFFF script produces an ASCII file that contains all the information extracted from the processed data (FF peak, 3 dB BW, null location etc.). It also produces files that contain an ASCII copy of HCUTs and VCUTs for the SLL processing. This process produces over 700 files for subsequent processing. This process takes just over two hours.

The next step in the processing sequence is the actual comparison of the AUT with and without the radome present. It should be noted that the script allows the user the ability to compare two freespace measurements for system verification. This script is the backbone of the process. It takes the 700 plus files for the freespace measurement and 700 plus files for the radome measurement and performs the comparison. The evaluation process compares the change of the radomes characteristics to the freespace and then these results to the specification. This process produces over 25 files that contain data for plotting and ASCII printable files that list any results that are out of spec. This process is completed in just a couple of minutes.

The side lobe level comparison process is carried out by an independent script as it takes longer to perform, and may not be necessary for each comparison. This process becomes demanding, as all side lobes in a region of 635.0 Degrees of the main lobe must be evaluated. The script takes the freespace cut data from the NFFF script and finds all of the side lobe peaks by comparing the slope of the data points in the cut from point to point. The script takes the peaks of the freespace side lobes and adds a value, which represents the spec limit, and then converts these peak values to a data "cut". This "cut" data is then subtracted from radome cut. Any results that are greater than zero, indicates a failure. These failures are listed in an ASCII printable file and a plot is produced showing the freespace cut, the spec cut, the radome cut, and the radome minus spec result. An example of the output is shown in Figure 3.

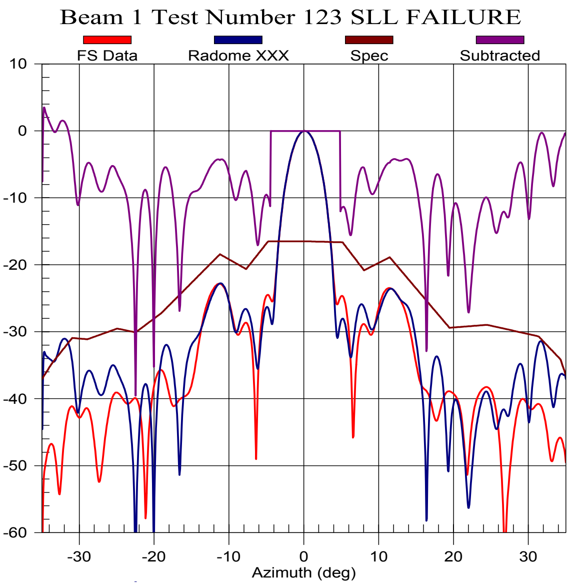

Figure 3

The final step in the data processing scripts is to plot all the required information. The requirements indicated that any results that deviate from the specification be provided in the ASCII files mentioned above, and that most data is presented in contour plots. The plotting script takes the information calculated in the comparison script and produces and prints contour plots of the test data. Figure 4 shows an example of the transmission efficiency contour plot.

5.0 Data Verification and Measurement Optimization

Before the final test results can be delivered, the data must be assessed to ensure that it is valid. Since the project did not allow the time or resources for a full error analysis, the data was verified to ensure its accuracy.

The transmission efficiency is one parameter that is measured for each AUT test position. In order to determine if the hardware and software identify this entity properly, the following measurements were performed on the system. Firstly, a script was created that measured the AUT at ten different test positions within the test angles and then repeated the process five times. The data was processed and all data sets were compared. The results showed that all of the FF peak values fell within a 60.06 dB range. These results gave us the confidence that the hardware had adequate repeatability for this task.

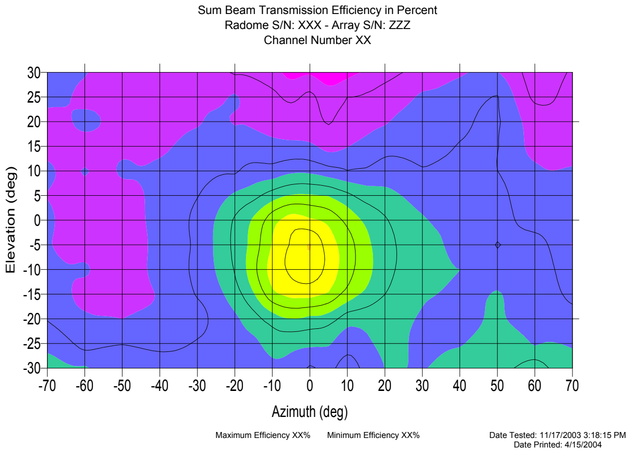

Figure 4

The next step was to ensure that the software would properly identify a change in the FF peak value. This was confirmed by installing a 1 dB attenuator in the transmit loop of the system. Then the AUT was measured using the script for the repeatability check. The data was analyzed and the results indicated that the change was found within the range seen in the repeatability check.

From these results, it was concluded that a repeatability of 60.06 dB was adequate for the measurements being made. With the repeatability within this range, the system was able to then identify the transmission efficiency to within 60.9%.

Since the radomes being characterized are used for radar on military aircraft, beam deflection due to the presence of the radome becomes a significant factor. The pass/fail criterion for this entity becomes a very small angular deflection, less than 0.25 degrees. The hardware and software have to be extremely accurate and repeatable. The antenna used for these measurements is the radar monopulse antenna used in the aircraft that the radomes belong. With this antenna, the difference beams were used for the beam deflection measurements as they produce well-defined nulls along the azimuth and elevation axes. The same antenna is used for the freespace and radome tests and is not removed between the two measurements. Therefore, the positioning system and the software become the two main error sources in this measurement.

In order to qualify this portion of the system, the same tests were performed as in the transmission efficiency validation except that the two difference beams were measured. Initially when these tests were performed it was discovered that there was a problem in the null positions, as well as, the patterns of the respective beams. A timing issue in switching the beams of the AUT and the receiver system caused this. After the timing issue was resolved and the tests repeated, the results indicated that the nulls could be clearly identified and located to within 60.02 degrees. This ensured enough accuracy for the specification. The second part of this assessment entailed skewing the AUT a known amount and repeating the measurements at the ten positions. The data was processed and was within the 60.005 degrees found previously.

The remaining test parameters were verified using the aforementioned processes and yielded acceptable results. As these parameters use the same hardware and software, the repeatability and accuracies are similar to the transmission efficiency and beam deflection tests.

The final check performed was the NF measurement optimization. Saving a couple of minutes per scan could reduce the total test time by hours. Thus the entire measurement sequence was scrutinized to shave as much time from the measurement as possible. From the measurements made to verify the test parameters, the system timing was optimized to ensure accurate results. Thus the only major time saving would be found in the truncation of the measurement cylinder. Changing the Maximum Radial Extent (MRE) of the measurement can significantly reduce the measurement time, but it can greatly influence the transformed FF data.

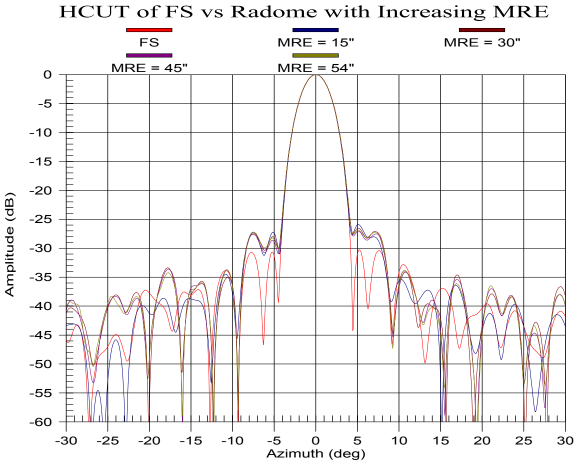

Figure 5

A series of measurements were made that varied the MR E for four values. These MRE values were a value the encompassed only the AUT, twice the AUT size, the majority of a radome and AUT, and all of the Radome and the AUT, refer to figure 5. It was found the MRE that was twice the size of the AUT provided ample NF sampling to accurately identify the transmission efficiency. Reducing the MRE resulted in poor accuracy in determining side lobes and beam deflection. It was determined that if the entire radome is not enclosed in the measurements MRE, that the output pattern is greatly affected by this truncation. It was proved that the attenuation of the signal in the presence of the radome is not affected by the truncation of the MRE.

Since the transmission efficiency could be measured at a reduced MRE without affecting the accuracy of the results, over 20 hours of test time was reduced from the entire measurement process.

7. Summary

In order to fully utilize an existing test facility, the DFL has successfully adapted its CNF test facility to perform radome characterization.

By using NF techniques the process for radome characterization can be performed in an indoor test facility where the entire test environment can be precisely controlled. The results obtained by the measurements performed thus far have given the DFL's clients accurate performance characteristics of its radomes.

The implementation of data acquisition and processing software enables radomes to be measured, analyzed, and reports generated in a repeatable, timely fashion. The current system permits a radome to be measured and returned to the client within 72 hours of delivery. This compares to two weeks using former methods.

8. References

[1] PS Radomes 1.0/10/03, MI Techologies 4500 River Green Parkway, Suite 200 Duluth, GA, 30096

[2] Dixon, W.C., Van Rensburg, D.J., Evaluation of Radome Performance from Cylindrical Near-Field Measurements; 2003 AMTA Symposium Southern California.