IMPLEMENTATION OF A SMALL PLANAR NEAR-FIELD SYSTEM

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ABSTRACT

This paper describes a novel planar near-field measurement system designed to test a beam-steered flat face phased array antenna. This system is unique in its ability to measure multiple beams during a single scan of the aperture. The system utilizes a very fast planar scanner with six foot by six foot of travel combined with fast beam-steering commands to significantly reduce the test time of multiple-beam phased array antennas. These features combined with software based on algorithms developed by the National Institute of Standards and Technology provide state of the art measurements of planar phased array antennas.

KEYWORDS: Planar Near-Field Measurements, Planar Scanner

1.0 INTRODUCTION

Phased array antennas are increasingly being used in modern radar and communication systems. The multiple beams of these antennas pose an interesting test problem. Since a single antenna may have a thousand different beams, measuring a significant subset of these beams in a reasonable amount of time becomes a challenging test problem. This paper describes a small planar near-field system designed to quickly and accurately characterize multiple beams during a single scan of the aperture plane.

2.0 THE MEASUREMENT PROBLEM

The planar near-field system was specifically designed to test a beam-steered flat face phased-array antenna approximately three feet in diameter. Pattern measurements were required for each of the antenna's multiple beams at multiple frequencies. Typically the number of different beams characterized exceed 100, and the number of different frequencies employed be less than 10. The test frequency range extended from 4 GHz to 44 GHz.

Element diagnostics and the ability to run a single scan "quick look" were required. The PNF software needed to possess an array of graphical presentation choices along with analysis programs like antenna gain. The new PNF system had to use the Hewlett-Packard 8510B network analyzer and 8341A signal source already on site.

3.0 OUTLINE OF SOLUTION

The delivered planar near-field system includes a planar scanner with a scan plane of six feet by six feet. The system uses the existing instrumentation along with a digital position controller and an 80486-based PC. A block diagram of the system is shown in Figure 1.

The system software uses transformation and correction algorithms from the National Institute of Standards and Technology (NIST). It also features a full compliment of plot software including gray scale three-dimensional plots.

4.0 APPROACH

Design considerations focused on the requirement to test beam-steered flat face phased arrays. Measurement efficiency and accuracy were paramount in the design.

4.1 Scanner

The first design consideration for the scanner was its practical use at 44 GHz. At this frequency the wavelength is only 6.8 mm so any error in the planarity of the scanner will introduce considerable phase errors into the measurement. Fundamentally, the absolute accuracy of the position of the probe antenna is very important in near-field measurements. This fact was established in extensive research done at the National Institute of Standards and Technology (NIST), an acknowledged world leader in near-field scanning techniques. Although probe position correction algorithms are available, none are universally accepted.

The approach is to make every effort to start with accurate probe position information. The delivered PNF scanner provides excellent uncorrected probe position accuracy. Scanner accuracy is ±0.00008 inches (2μm) RMS along both the x and y axis. Accuracy along the z axis is better than ±0.001 inches (25.4 μm) RMS. The planarity of the x-y scan plane is ±0.005 inch (127μm) RMS.

The scanner is of the moving tower style and is shown in Figure 2. This design was chosen over the box-frame style for a number of reasons. Although there are manufacturing advantages, the primary motivation to select this style relates to system performance. The major advantages are outlined below:

1. The traveling tower presents fewer structural elements to shield with absorber and provides for a less cluttered aperture.

2. The structural load path is much more direct reducing the impact of changing loads.

3. Coordinated drive systems (top and bottom or left and right) are not required, increasing the reliability.

4. Alignment and calibration is greatly simplified since the adjustments need not be spread over large distances.

5. Thermal gradient effects are minimized since the bulk of the structure is at ground level, with no supporting elements located in the regions sensitive to temperature change.

Since the primary design goal of the planar scanner was the accuracy of the scan plane, all major elements of the design were carefully selected to promote this goal.

Another design goal of the entire system (including the scanner) was measurement time efficiency so the scanner was designed to run at a maximum rate of six inches per second along both the x and y axis.

4.2 Probe

Open-ended waveguide is used for the near-field probe. The open-ended waveguide is considerably less expensive than probes with dual-orthogonal ports. For greatest accuracy when performing near-field measurements, two orthogonal polarizations must be measured. [1] Open-ended waveguide requires two measurement scans and thus takes twice as much measurement time as with a dual-ported probe.

Further cost savings were realized because the probe was not calibrated by an organization (such as the National Institute of Standards and Technology) to provide information on probe radiation pattern and gain. Instead, two models were developed to approximate these parameters. The delivered software provides a model for open-ended waveguide radiation based on waveguide dimensions and frequency of operation. The software also provides an option to use a $\cos^n$ model where the user substitutes values for n to represent the probe pattern in the E- and H-planes. Measured data presented in Figure 3 shows that the patterns calculated using the first model are very accurate for pattern levels as low as -20 dB. [2] This accuracy is important since errors in the estimated probe gain and patterns will correspond to respective errors in the measured gain and sidelobe levels of the AUT.

4.3 Instrumentation

The Model 8510B and its companion signal source, the Model 8341A, from Hewlett Packard are used as the microwave measurement receiver and source for the PNF measurement system.

The most time efficient test would ideally include measuring each antenna beam over all of the required frequencies for each antenna channel during the scan. Although running multiple frequencies and multiple beams on-the-fly was an attractive solution, it was not practical to implement both features and achieve an acceptable measurement speed. The most efficient use of these instruments was determined to be a single frequency, single channel measurement of each antenna beam. This decision was based on the fact that the AUT possesses over 100 different beams so antenna beam control was considered a more important feature than multiple frequency control. Consequently, all data collection is accomplished on-the-fly using the network analyzer in a "cw" mode.

Position readout and servo control instrumentation is provided through a Aerotech Unidex 12 Position Controller which is fully integrated into the 2095 PNF Software. This controller has some application within the machine tool industry and is of an extremely robust design.

The controller directs the two DC servomotors used on the vertical and horizontal axes. It also controls two stepper motors: one for z-axis motion and the other for probe polarization. All axes parameters are within the control of the system controller, though only the x and y axes may be used actively for scan and step axes during data acquisition. The motion control is assured by both rate feedback through a tachometer in each motor and position feedback through optical glass scales on both the x and y axes. The resolution and accuracy of the encoder are excellent and provide for extremely tight motion control.

The system controller is a Compaq 80486-based, 33 MHz PC with an extended VGA monitor. This controller has several functions: 1) to control the programmable instrumentation for automated measurements, 2) to store the measurement data, 3) to analyze and process the data, and 4) to display the processed data.

Scientific-Atlanta's Data Acquisition Coprocessor (DAC) resides in the controller. Its purpose is to provide direct hardware control of the data acquisition process and to buffer data destined for the system controller. This permits much faster system operation than could be accomplished under software control alone. Use of the DAC ensures the highest possible overall data rates, commensurate with the speed of the associated instruments, while simultaneously allowing the possibility for multi-tasking operation of the system controller. The DAC controls the transmission and reception of trigger signals and buffers the acquired data.

4.4 Software

The installed system uses our Model 2095/PNF software which provides the capability to acquire planar near-field data, calibrate and correct the acquired data, transform the data to the far-field, and display the measured data and post-analysis results.

The 2095/PNF software takes advantage of the pre-emptive multi-tasking and multi-threading capabilities of the IBM OS/2 operating system. Multi-tasking refers to the ability to simultaneously execute multiple processes (or application programs). For example, data can be acquired while concurrently processing and displaying previously acquired data sets. Multi-threading is a similar capability which allows separate entities within a single process to execute independently while sharing the same program resources. The real time control process (RTC) uses this feature to efficiently handle the DAC, GPIB instruments, and data/message processing during data acquisition by separating these responsibilities into three threads.

4.4.1 Acquisition Software

The RTC DAC Acquisition thread is the most time critical and by definition possesses the highest priority among the three threads. After the DAC issues a trigger, this thread is activated. It reads the position data set from the DAC and pairs it with the amplitude/phase data set from the 8510. This acquired data is then sent to the Message/Data Queue.

The Message/Data Queue thread "takes" the data and is responsible for converting it from the 8510 internal data format to the standard I and Q format used in the NIST transformation algorithms.

The GPIB/SRQ thread services the IEEE instruments and monitors the bus for error messages that may interrupt the data acquisition. Thus, as the RTC code runs it is literally executing multiple processes simultaneously which contributes to the overall efficiency of the entire planar near-field system.

During a scan, the multiple beams of the phased array are controlled by the Data Acquisition Coprocessor (DAC) as it continues to direct the data collection process. A 16-bit parallel I/O bus is used to send command words to the beam-steering computer of the antenna-under-test (AUT). Thus, in sequence, the system is triggered by reaching a designated position increment. At each trigger, the amplitude/phase and position set is recorded and followed by an issued command from the DAC to change beam state. The system repeats this procedure until all beams are measured and before the next position increment is reached.

All 16 bit patterns are controlled by the operator who programs the beam sequence (during the test file setup) along with an optional delay, which allows time for beam settling, and strobe setup.

To insure that data is collected on a fixed grid, the system features sub-interval triggering. This feature can best be described with the help of a measurement example. A test might consist of measuring five different beams of the AUT at an increment of a half wavelength. Under this scenario, the planar near-field software will partition the increments so that each beam is measured at a sub-increment of 0.1 λ. The first beam will be measured at the initial increment followed by the second beam at 0.1 λ, the third beam at 0.2 λ, the fourth beam at 0.3 λ, and the fifth beam at 0.4 λ. This method allows the DAC time to reset the AUT to the first beam before the next half wavelength increment is reached and insures that all data is placed on a fixed grid. During the next scan (which will run in the opposite direction), this sequence is reversed so that the fifth beam is the first one measured, and the first beam is the last one measured. Figure 4 illustrates this idea.

The acquisition software possesses some other unique features. For one, it allows a single scan "quick look" which can be transformed for far-field inspection. The customer uses this feature to aid in testing antenna power dividers and aligning the array.

Another software feature is the timing calculator that gives the operator a test time estimate when a particular collection file is specified.

In addition to supporting data acquisition with a dual ported, dual polarized probe, the software supports the use of single-ported probes such as an open-ended waveguide. The software will merge the two polarization data files (collected using open-ended waveguide probes) into a single dual polarized file.

The software is capable of accepting probe calibration data from NIST, which affords the greatest measurement accuracy, or two analytic probe compensation models (outlined in paragraph 4.2).

4.4.2 Analysis Software

The delivered software features a wide variety of pre-transform correction and post-transform analysis. The near-field to far-field transformation (with probe correction) is based on NIST algorithms. The software package includes:

PNF Data Correction

PNF Transformation

PNF Output File Processing

Multiple Scan Averaging

RMS Sidelobe

Peak Gain

Sum Pattern Boresight and

Pattern Analysis

The PNF Data Correction analysis corrects for receiver amplitude nonlinearity, thermal drift of the planar scanner, channel imbalance of dual-ported probes, probe position errors, and range insertion loss.

The PNF transformation is essentially a two-dimensional Fourier transform of each polarization component. A probe pattern correction algorithm is applied to the transformed data.

After transformation, the Output File Processing can be applied to the data which is stored in k-space coordinates. This data is converted to angular coordinates for use in listings and display.

Multiple Scan Averaging can be used to reduce errors created by the standing wave signal between the probe and AUT. Any number of scans may be selected for averaging.

The RMS Sidelobe analysis is based upon a principal plane cut in θ and ϕ to produce an "average" RMS side-lobe level.

The Peak Gain analysis is based on the system's determination of the range insertion loss and the reflection coefficients of the probe and AUT. It is found using transformed far-field data.

The Sum Pattern Boresight analysis identifies the boresight angle of the far-field sum pattern. The analysis is conducted using the high-resolution data file in angular coordinates.

The Pattern analysis determines the beamwidth of the far-field pattern.

4.4.3 Presentation Software

The presentation software offers a wide variety of plot types including both two-dimensional (rectangular and polar) and three-dimensional (contour, colorfill, and isometric) representations in an off-line mode. A rectangular "real-time" confirmation plot is also available during data acquisition.

In addition, a 256-color rainbow or gray scale plot representation is also available for the off-line and real-time cases. For this plot type, either a continuous rainbow spectrum or shades of gray are used to represent amplitude or phase levels over a scan region. Real-time, simultaneous display of both the amplitude (gray scale) and phase (rainbow color scale) can be displayed during an acquisition. In the off-line mode, gray/rainbow scale plots may be copied to a laser printer in gray scale form. Special processing is also available for this plot type.

Histogram equalization can be selected to uniformly distribute the data levels among the available colors, allowing for greater perceived detail in the display. Differentiation can be used in conjunction with histogram equalization, or separately to highlight those areas of rapidly changing data levels.

A processing feature available for all phase plots is phase unwrapping which removes the cyclical nature of the phase data, and, in addition, extracts any linear phase characteristic (or phase tilt) from the data.

5.0 MEASUREMENT TIMING

A typical measurement using the delivered system might consist of measuring 15 beams at 10 GHz using $\lambda/2$ measurement increments. Using the entire scan plane length in both x and y, this measurement will take 81 minutes to measure and record 241,935 data points. A planar near-field system not possessing AUT beam control will repeat this same measurement 15 times (one scan per beam) in roughly 30 to 45 minutes per test. Thus, a comparison of 81 minutes to 7.5 hours (minimum test time) illustrates the efficiency of this planar near-field system.

6.0 SUMMARY

Implementing a planar near-field system to quickly and accurately characterize the multiple beams of a phased array antenna will present a number of challenges to the design engineer. Often the majority of the design effort will concentrate on the PNF software. This paper described a recently delivered system which employs an 8510B, a digital position controller, a 80486-based PC, and a planar scanner.

The system is used primarily for the evaluation of beam-steered flat face phased array antennas. The PNF system features multiple beam control of the phased array antenna along with sub-interval triggering which places the collected data on a fixed grid. With these unique features, the system is able to quickly accomplish the testing required for phased array antennas.

REFERENCES

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[2] A. D. Yaghjian, "Approximate Formulas for the Far Field and Gain of Open-Ended Rectangular Waveguide", IEEE Trans. Antennas Prop., vol AP-32, pp. 378-384, April 1984.

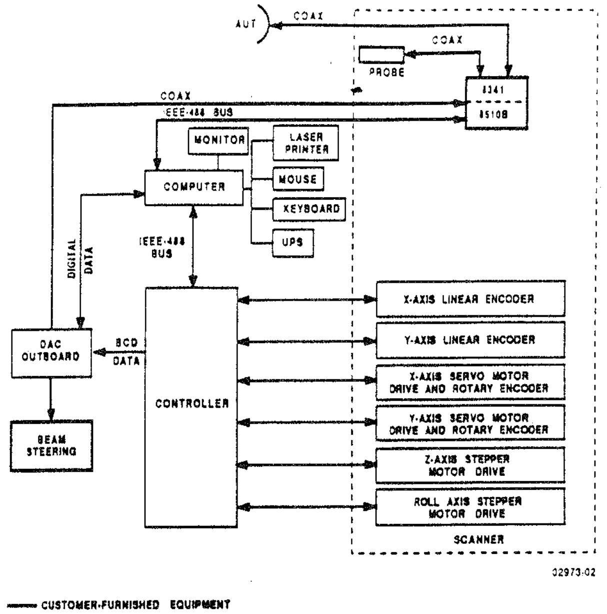

Figure 1. Block Diagram of Planar Near-Field System

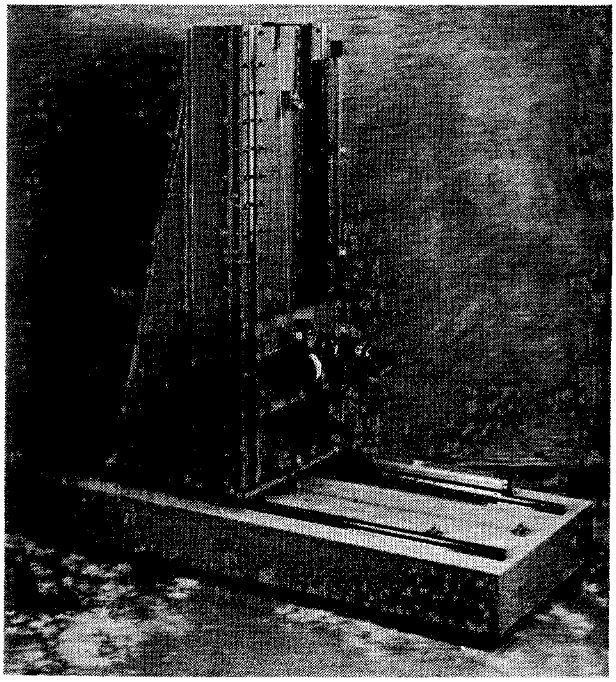

Figure 2. Planar Scanner

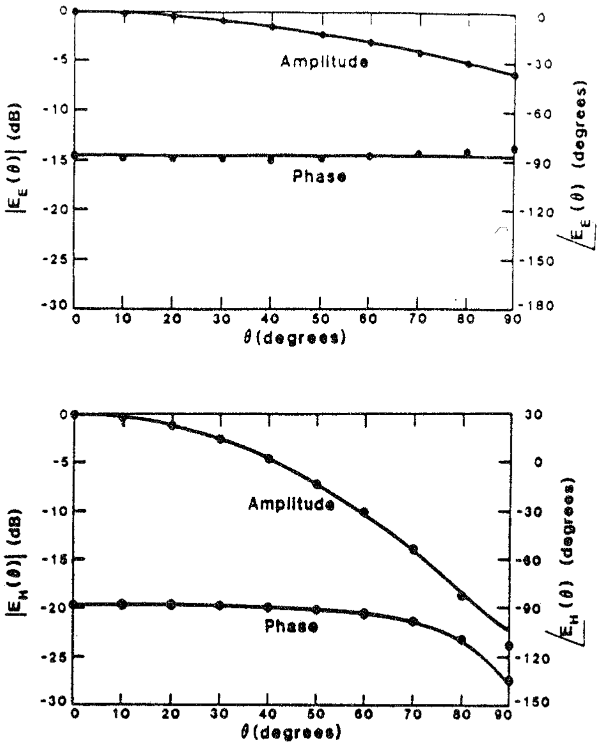

Figure 3. Amplitude and Phase of WR90 Waveguide at 9.32 GHz Using Open-Ended Waveguide (—) and Measured at NIST (....). Top: E-Plane. Bottom: H-Plane.

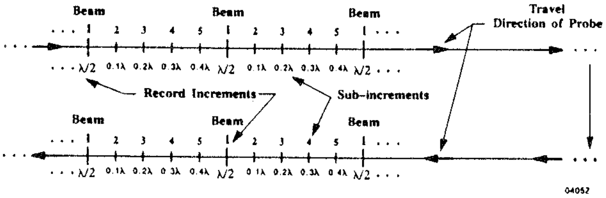

Figure 4. Illustration of Sub-Interval Triggering