A DUAL-PORTED PROBE FOR PLANAR NEAR-FIELD MEASUREMENTS

W. Keith Dishman, Doren W. Hess, and A. Renee Koster

ABSTRACT

A dual-linearly polarized probe developed for use in planar near-field antenna measurements is described. This probe is based upon Scientific-Atlanta's Series 31 Orthomode Feeds originally developed for spherical near-field testing. The unique features of this probe include dual-orthogonal linear ports, high polarization purity, excellent port-to-port isolation, an integrated coordinate system reference, APC-7 connectors, and a thin-wall horn aperture to minimize probe-AUT interactions. The probe was calibrated at the National Institute of Standards and Technology (NIST) and the calibration data consisting of the probe's complete plane-wave spectrum receiving characteristic $s'_{02}(\mathbf{K})$ were imported directly into the Model 2095/PNF Microwave Measurement System. This paper describes the dual-ported probe and its application in a planar near-field range.

Keywords: Planar Near-Field, Near-Field Scanning, Near-Field Probe Antenna

1. INTRODUCTION

Planar near-field testing of antennas requires the acquisition of two orthogonally polarized signals. The use of a dual-polarized probe to acquire both sets of data in a single scan reduces the time required for data acquisition by a factor of two as compared to the traditional single ported probe approach and eliminates the need for a probe rotation mechanism [1]. When combined with a high speed multi-frequency automatic measurement system, dual-ported planar near-field probes enable maximum utilization of a measurement facility.

The desirable properties of a dual-polarized planar near-field probe include the following:

- High polarization purity
- Good port-to-port isolation
- Integrated coordinate system reference
- Low scattering aperture

- Repeatable RF interface
- Convenient mounting interface

Several of these features are already available in the Series 31 Orthomode Feeds. The Series 31 feeds were originally developed for spherical near-field measurements [2] but have also been used for feeding compact ranges and parabolic reflector antennas.

Using the Series 31 feed design as a baseline, a dual-polarized C-band probe for planar near-field measurements was designed having the desirable properties listed above. The probe was calibrated by NIST and the calibration data were imported into the Model 2095/PNF Microwave Measurement System.

2. PROBE DESCRIPTION

The probe antenna is shown in Figure 1 and consists of an air-filled circular waveguide propagating orthogonal TE_{11} modes. Two coaxial ports are provided, one at the rear of the probe (Port 1) and the other on the side of the probe (Port 2). The side port is visible in Figure 1. The TE_{11} modes are excited by an integral broadband orthomode transducer that utilizes two different types of coaxial-to-circular waveguide transitions. The rear port uses a coaxial-to-WR137 rectangular waveguide transition followed by a rectangular-to-circular tapered waveguide transition. The side port has a unique coaxial-to-finline transition [3] that tapers to circular waveguide. The coaxial connectors are APC-7 type and were selected because they provide a repeatable, easily-defined reference plane for the measurement of the reflection coefficient.

The probe was required to radiate fields with high axial ratios (greater than 35 dB). The axial ratio of the probe is highly dependent on the roundness of the circular waveguide [4] and therefore the manufacture of the probe had to be done using precise methods. Electroform construction was chosen to ensure high dimensional accuracy and to eliminate electrical contact problems at the finline-to-circular waveguide transition. The main body of the probe including the finline transition and the rectangular-to-circular waveguide transition was fabricated from copper using electroform techniques.

A limitation of all near-field scanning measurements is set by the suppression level of the multiple pass standing wave within the measurement configuration. For cases where the antenna under test is modest in electrical size, it is practical to reduce the standing wave by increasing the distance between the aperture of the probe horn and the structure of the test antenna. Very often in this case a separation distance of 10 to 20 wavelengths will suppress the second pass signal to a level of -40 dB. It has been found however, when testing electrically large antennas, that 10 wavelengths of separation might correspond to a second pass signal suppressed by only 25 dB for open-ended rectangular waveguide probe horns.

While there are many possible methods of dealing with this problem, the two most common are to use multiple scan averaging and to minimize the size of the probe aperture. The multiple scan averaging technique is an ad-hoc practical approach in which measurements are made on several scan planes separated by 1/8 wavelength and then to average the resulting far-field patterns. This approach is very successful and is a user selectable option in the Model 2095/PNF Near-Field Measurement System. Minimizing the size of the probe aperture reduces the scattering cross section of the aperture structure. Reduced height rectangular waveguide has been successfully utilized for single linearly polarized probes. For dual-polarized probes, dielectrically loaded square or round waveguide has been used, but this approach typically worsens the mismatch at the probe aperture and requires careful control of the dielectric material to ensure clean and symmetric probe patterns.

The approach taken for this probe is to select a circular waveguide diameter that operates sufficiently above cutoff to be well matched but no higher. This minimizes the size of the aperture and the associated backscatter wave amplitude. The specific frequency of operation for the probe is from 5.25 to 5.35 GHz. For a circular waveguide diameter of 1.65-inches, the lower operating frequency is 1.25 times the TE_{11} mode cutoff, and the upper operating frequency is 0.78 times the TE_{21} mode cutoff and 0.98 times the TM_{01} mode cutoff. The nominal waveguide wall thickness of 0.125 inches tapers to just 0.040 inches at the aperture to further minimize the scattering cross section.

A mounting structure with adjustments for roll, pitch, yaw, and coarse z-translation is attached to the probe to create the probe assembly shown in Figure 1. The probe is designed to mount to a z-axis translation table that provides fine resolution adjustments. The electroformed probe body includes an integral mounting flange to enable the probe to be mounted without distorting the circular waveguide. Also shown in Figure 1 is a precision bubble level that is used to set the vertical reference when aligning the probe coordinate system y-axis to the coordinate system of the near-field range or of the calibration range. A spindle target mirror insert that precisely fits inside the aperture of the probe is used to optically define the z-axis direction. A precision fit is obtained by utilizing a piece of the electroforming mandrel for the insert.

An absorber panel is included as part of the probe assembly to shield the mounting structure and the scanner probe carriage. The panel mounts to a flange on the probe mount and its position is fixed relative to the probe aperture. The panel is approximately 20 by 30 inches and consists of 8-inch pyramidal absorber with an aluminum backing plate.

The performance specifications for the near-field probe are summarized in Table 1.

Table 1
Probe Performance Specifications

Characteristic	Specification
Structure Type	Round waveguide
Polarization	Dual linear
Axial Ratio	>35 dB
Isolation, Port-to-Port	>40 dB
Gain	7 to 9 dBi, nominal
VSWR	2.0:1, maximum
RF Connector Type	APC-7

3. PROBE CALIBRATION

The probe assembly was calibrated at the U.S. National Institute of Standards and Technology during the month of November, 1991. The calibration consisted of determining the plane-wave receiving coefficients as a function of theta and phi, $s'_{02}(\theta,\phi)$, at five frequencies for each probe port. The calibration methods and coordinate system definitions are described in [5]. In addition to the plane-wave receiving coefficients, swept gain and reflection coefficient measurements were performed.

The coordinate system of the probe was defined by the bubble level and spindle mirror described above. This enabled the probe assembly to be installed in the near-field range in the same orientation used for calibration. The rectangular absorber panel was included with the probe assembly during the calibration process.

The results of the on-axis calibration measurements are given in Tables 2 and 3 along with the measurement errors reported by NIST. Figures 2, 3, and 4 show the swept frequency measurements of gain and return loss measured by NIST and the port-to-port isolation measured by Scientific-Atlanta. The nominal 0.4 dB gain difference between the two ports is due to the greater insertion losses of the finline-to-coaxial transition used for the side port.

The amplitude and phase of the relative radiation patterns of the probe for two orthogonal polarizations were measured by NIST and used in conjunction with the on-axis measurements to compute the absolute plane-wave receiving coefficients required for performing probe correction of the measured near-field data. The relative patterns were measured over the forward hemisphere of the probe on a grid equally spaced in θ and ϕ. The orthogonal vector components used are the θ and ϕ components as defined in [5]. The resultant probe receiving coefficients, $s'_{02\phi}(\theta,\phi)$ and $s'_{02\theta}(\theta,\phi)$, were recorded in ASCII format on floppy discs. A standard format was developed in conjunction with NIST that enabled the data files to be imported directly into the Scientific-Atlanta Model 2095/PNF Microwave Measurement System.

Figure 5 shows a typical receiving coefficient pattern cut. The cross-polarization level on-axis does not correspond to the measured axial ratio because of the non-zero tilt angle of its polarization ellipse. The power gain of the probe is related to its receiving coefficient by [6]

$$G(\theta,\phi) = \frac{4\pi\eta_0 k^2 \,|\, s_{02}(\theta,\phi)\,|^2}{y_0\,(\,1 - |\,\Gamma_p\,|^2\,)}$$

where $k = \frac{2\pi}{\lambda}$ with λ being the wavelength in centimeters, Γ_p is the probe port reflection coefficient, and $\mathbf{y}_0$ and η_0 are admittance factors which are taken as being equal [5]: $\mathbf{y}_0 = \eta_0$.

4. SUMMARY

A dual-linearly polarized probe with excellent polarization purity and isolation has been designed, fabricated, and calibrated for use in a planar near-field measurement facility. The basic design was based upon an existing standard product design, the Series 31 Orthomode Feeds. The probe incorporated a low scattering aperture design, an integral mounting structure, and coordinate system alignment features. Calibration data in the form of the absolute plane-wave receiving coefficients were computed and formatted for direct importation into the near-field measurement system software.

5. REFERENCES

[1] F.H. Larson and J.E. Hanson, “A Dual-Polarized Probe System for Near-Field Measurements”, *Proc. 1979 IEEE AP-S Int. Symp.*, vol. 2, pp. 557-560.

[2] J.R. Jones and D.P. Hardin, “A Dual-Ported, Dual-Polarized Spherical Near-Field Probe”, *Proc. 1983 Antenna Measurements Techniques Association Meeting*, Oct. 1983, pp. 21-1 to 21-14.

[3] “Series 31 Orthomode Feeds”, Scientific-Atlanta Data Sheet, March 1984.

[4] E. Lier and K. Bergh, “Cross-Polarization in Perturbed Circular Cylindrical Waveguides”, *Microwave Journal*, pp. 193-195, February 1986.

[5] A.G. Repjar, A.C. Newell, and M.H. Francis, “Accurate Determination of Planar Near-Field Correction Parameters for Linearly Polarized Probes”, *IEEE Trans. Antennas Propagat.*, vol AP-36, no. 6, pp. 855-868, June 1988.

[6] A.C. Newell, “Planar Near-Field Measurements”, lecture notes for NBS Short Course, June 1985.

ACKNOWLEDGEMENTS

We would like to thank Mitch Blalock of Scientific-Atlanta for designing the probe mounting structure and Katie McReynolds of NIST for performing the probe calibration measurements.

Table 2
On-Axis NIST Calibration Results of Port 1

					Reflection Coefficient	
Frequency (GHz)	Power Gain (dB)	Axial Ratio (dB)	Sense of Polarization	Tilt Angle (degrees)	Amplitude	Phase (degrees)
5.250	8.00	73	Left	-1.4	0.043	-144.0
5.275	8.01	60	Left	-1.4	0.082	-97.9
5.300	7.98	67	Left	-1.4	0.148	-125.0
5.325	8.09	56	Left	-1.4	0.192	-158.5
5.350	8.11	73	Left	-1.2	0.203	165.8
Est. Error	±0.11	±5		±0.4°		

Table 3
On-Axis NIST Calibration Results of Port 2

					Reflection Coefficient	
Frequency (GHz)	Power Gain (dB)	Axial Ratio (dB)	Sense of Polarization	Tilt Angle (degrees)	Amplitude	Phase (degrees)
5.250	7.60	58	Left	88.7	0.016	-114.8
5.275	7.65	67	Left	88.8	0.075	-107.7
5.300	7.63	81	Right	88.8	0.124	-118.8
5.325	7.72	64	Left	88.8	0.164	-130.8
5.350	7.79	69	Right	88.9	0.195	143.9
Est. Error	±0.11	±5		±0.4°		

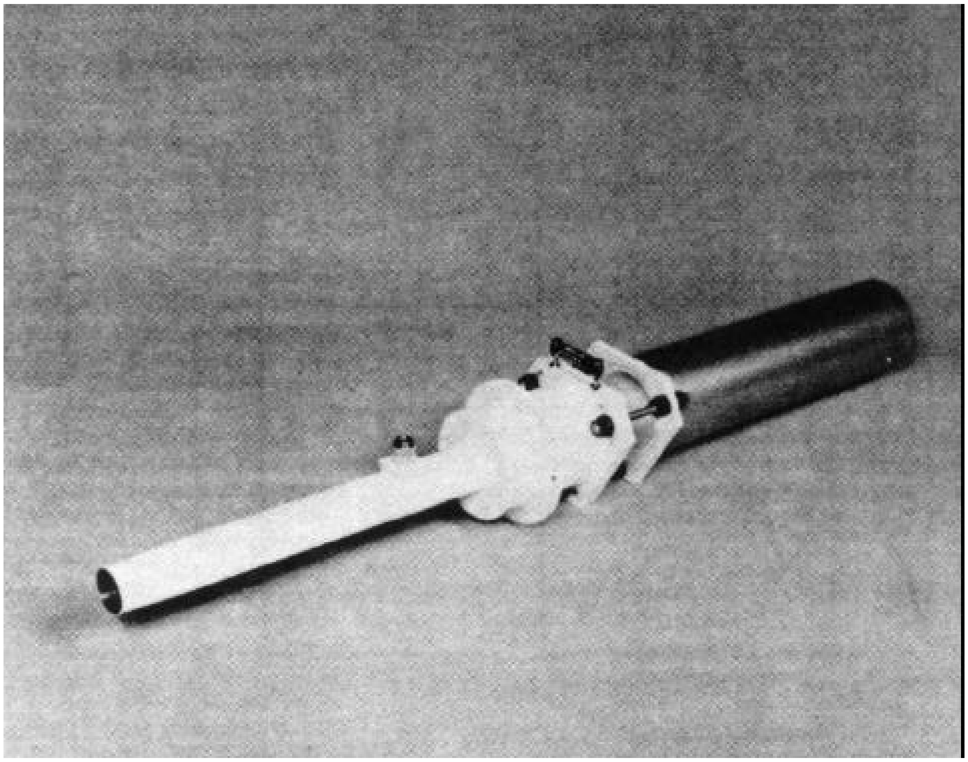

Figure 1. Dual-Ported Probe Assembly

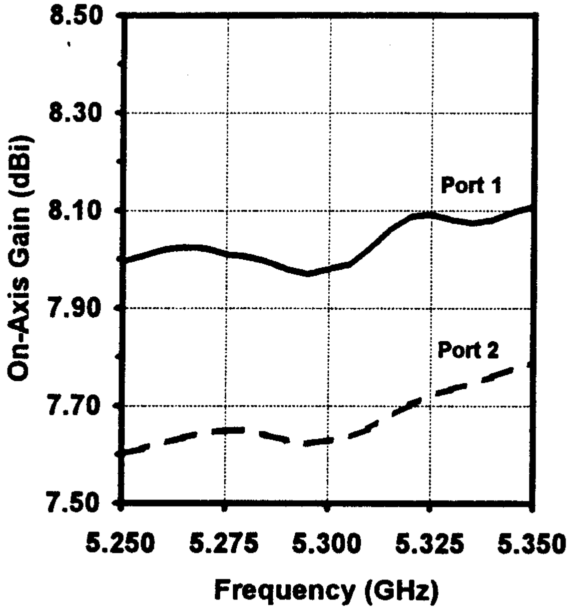

Figure 2. Swept Frequency Power Gain

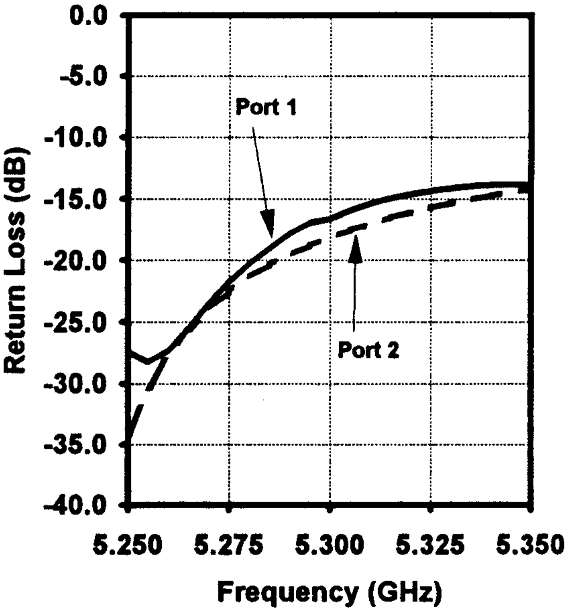

Figure 3. Swept Frequency Return Loss

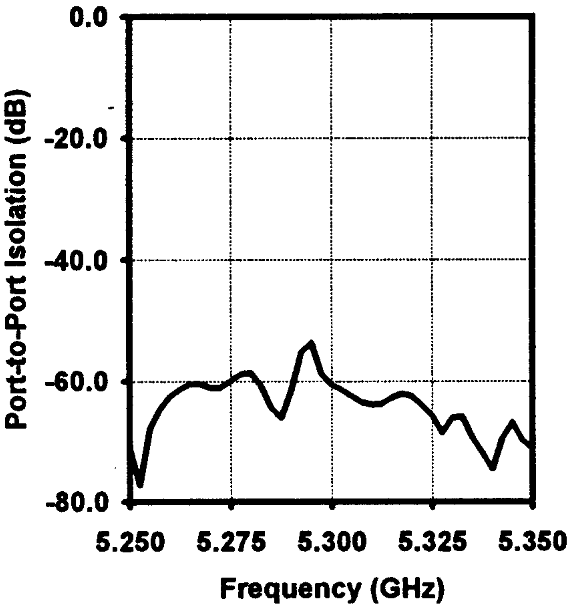

Figure 4. Swept Frequency Isolation

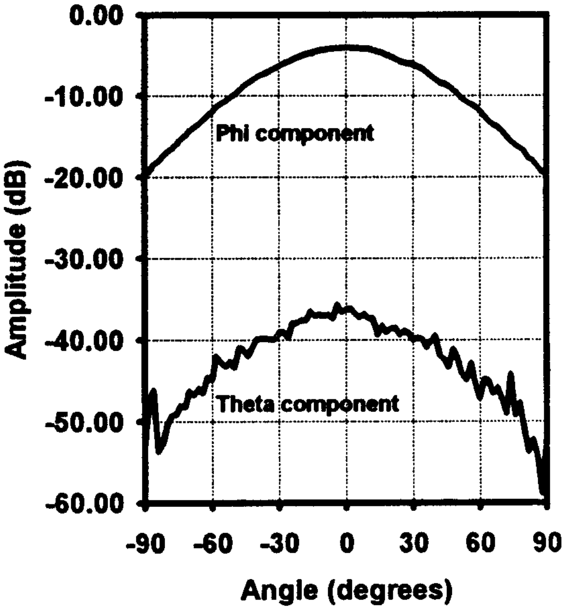

Figure 5. Typical Plane-Wave Receiving Coefficient s'(θ,ϕ), E-plane, 5.30 GHz