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System Design and Implementation of Multiprobe Planar Near Field Antenna Measurements

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Abstract. This article presents practical implementation of a novel multiprobe planar near-field range (PNFR) measurement system, utilizing a simplified mechanical setup with seven antipodal Vivaldi antennas serving as probes. The proposed system retains the design simplicity of existing configurations while enhancing measurement efficiency by reducing testing time. The antipodal Vivaldi antennas, known for their broadband capabilities, ensure precise and wideband near-field measurements. The developed setup is experimentally validated on a representative antenna under test (AUT) in the X-band frequency range, demonstrating its practical effectiveness and robustness in real-world applications. The results confirm the system's ability to deliver high-resolution measurements, consistent with numerical simulations, thereby affirming its viability for advanced antenna testing and characterization.

Keywords: multiprobe planar near field antenna measurements, microstrip patch antenna characterization, antipodal Vivaldi antenna, planar near field antenna range, PNFR, multiprobe PNFR measurements

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1. Introduction

The increasing demand for antennas operating at higher frequencies has led to a proportional rise in the measurement distance of far-fields. This challenge is primarily attributed to the extensive open-space environments required for far-field testing, which are difficult to replicate within laboratory settings. To address these limitations, near-field antenna measurement techniques were introduced. These methods involve capturing the electromagnetic field of the antenna under test (AUT) in its near-field region and reconstructing the far-field radiation pattern using spatial Fast Fourier Transform (FFT) [1].

Initially, three primary near-field measurement approaches were proposed: spherical, cylindrical, and planar, each distinguished by its geometrical configuration and computational methodology [2]. However, spherical and cylindrical techniques, despite their theoretical benefits, often demand complex mathematical transformations and complex mechanical systems, resulting in limited adoption [3]. Conversely, planar near-field measurements have gained popularity due to their simpler mathematical framework and mechanical implementation. This method involves scanning a measurement probe across the near-field surface of the AUT to extract the far-field components. However, the reliance on precise mechanical movement of the probe introduces significant drawbacks, including increased complexity and slower measurement times which are key constraints in modern testing and metrology.

This article presents the implementation of a novel multiprobe rectangular planar near-field range (PNFR) measurement system designed to enhance measurement efficiency and reduce mechanical complexity. By employing a multiprobe approach, the proposed setup aims to accelerate test durations and streamline the overall mechanical structure, potentially lowering the total cost of testing. While near-field measurements are inherently more complex both physically and mathematically compared to traditional far-field methods, their ability to operate at smaller distances within controlled environments offers significant advantages. These include improved measurement precision, enhanced security, and better electromagnetic control, all contributing to higher throughput and reliability in testing.

In this study, the PNFR measurement system integrates an antipodal Vivaldi antenna (AVA) as the near-field probe. A custom mechanical holder for static probe placement was fabricated using 3D printing technologies and designed in AutoDesk Fusion 360. Prior simulations of the system were conducted in the Altair FEKO environment, and near-field to far-field transformations were performed using MATLAB [4].

2. Experimental setup

As depicted in Fig.1, the experimental setup for the plane rectangular near-field antenna measurement system incorporates a National Instruments PXIe-1095 chassis equipped with a PXIe-5842 vector signal transceiver (VST) [5]. The PXIe-5842 operates across a frequency range of 30 MHz to 26.5 GHz and includes network analysis capabilities, making it well-suited for near-field S-parameter measurements. Its compact physical dimensions further contribute to the overall simplicity of the system. For this experiment, a PXI-2596 dual 6x1 switch [6] was employed to sequentially capture S_{21} measurements for each probe. However, the switch can be omitted and replaced with additional VSTs, enabling fully synchronized and simultaneous measurements through the precise synchronization techniques described in prior work [7]. To minimize the influence of external interference on the measurement setup, a shielded enclosure providing over $90dB$ of isolation was utilized.

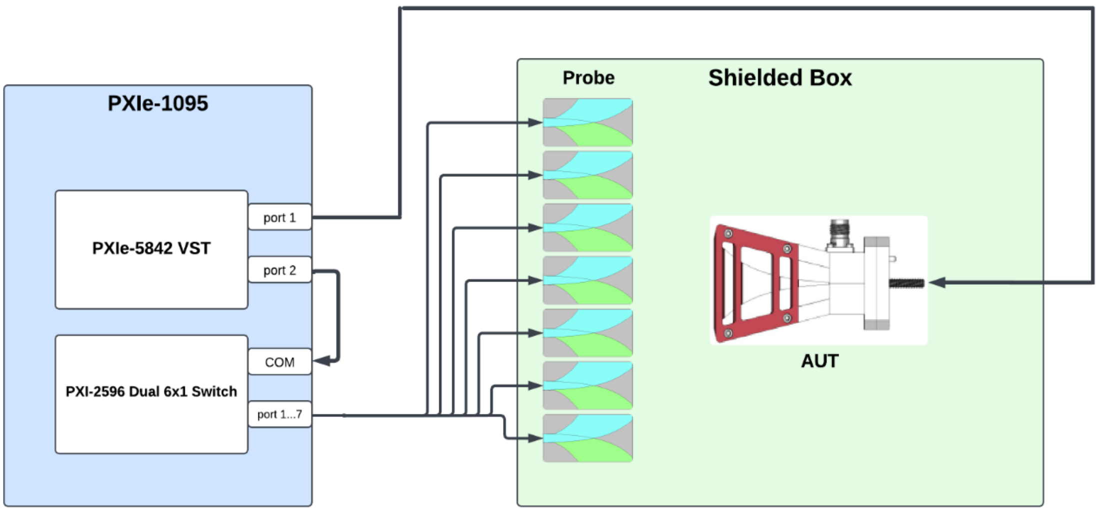


Fig. 1. Block diagram of PNFR measurement system.

Since one of the critical aspects of a PNFR measurement system is the requirement for a wideband capability to accommodate a broad range of frequencies, AVA-based near-field probes have been designed which are offering wideband operation with high gain. The compact size of these antennas, attributed to their dielectric-based substrates, makes them well-suited for integration within the PNFR lattice. Furthermore, AVA antennas provide excellent return loss characteristics and minimal signal distortion, ensuring reliable and accurate measurement performance. Seven units of AVAs have been designed (as illustrated in Fig.2) and fabricated in order to take signal measurements in the near-field of AUT.

The AVA is fabricated at $f_{min} = 10\ GHz$ on $\varepsilon_r = 4.6$ substrate with $h = 1\ mm$ height. Based on [4] the structural parameters of AVA are: $W = 1.25\ cm$, $L = 2.4\ cm$, $W_f = 2.3\ mm$, given that the line with $50\ \Omega$ impedance is estimated. Antenna scattering characteristics are measured using National Instruments PXIe-5633 Vector Network Analyzer. Fig.3 shows reflection coefficient of fabricated AVA. Because of its wideband capabilities, the antenna can be used at full 9-11GHz frequency range. At 10GHz frequency, reflection coefficient is $S_{11} \approx -24\ dB$.

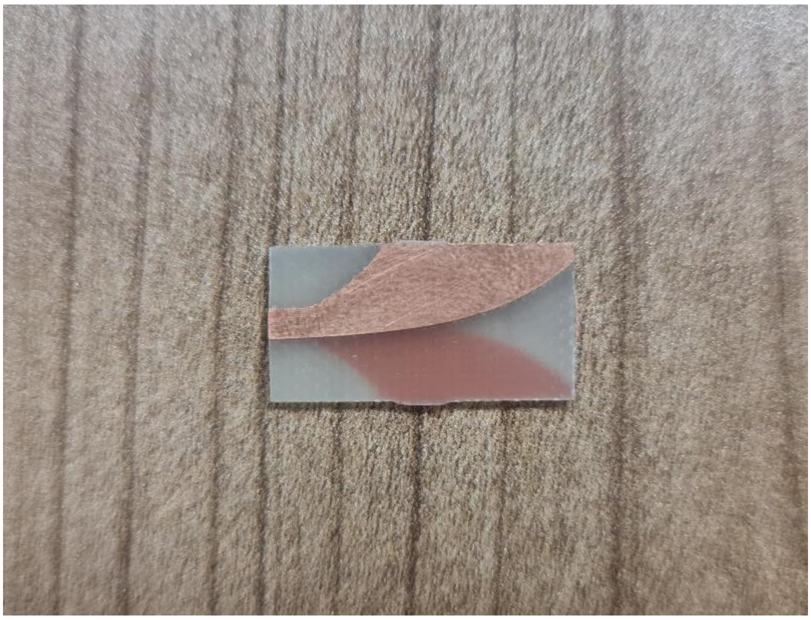


Fig. 2. Fabricated antipodal Vivaldi antenna without source connector.

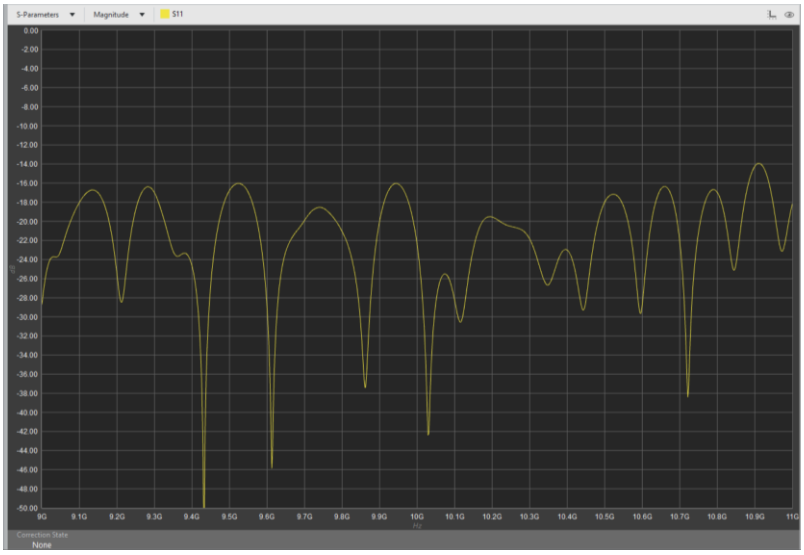


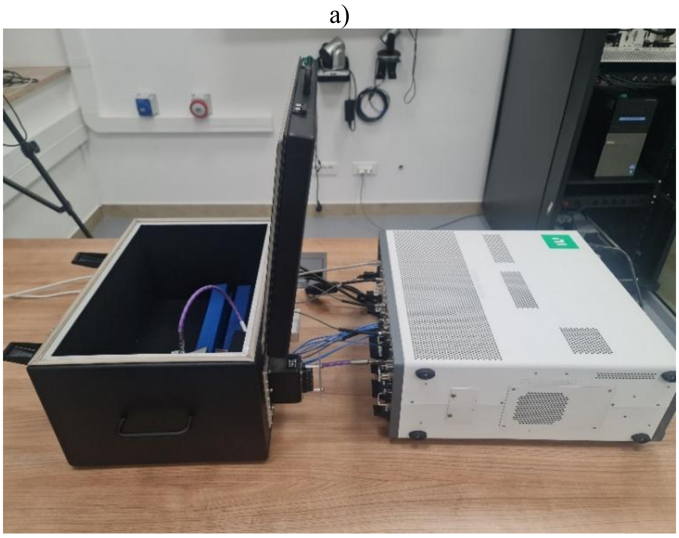
Fig. 3. Fabricated antipodal Vivaldi antenna's reflection coefficient.

The antenna under test (AUT) in this study is the DRH50 double-ridged horn antenna (see Fig.4) from RFSpin, chosen for its wideband performance and low VSWR characteristics [8]. At a frequency of 10 GHz, the reflection coefficient achieves a VSWR of approximately 1.05, demonstrating its suitability for precise and reliable measurements.

AUT and Probes are placed $1cm$ far from each other order to suffice near field criteria for horn antenna ($R_{AUT-ff} \approx 2.7cm$). The complete actual view of implemented measurement setup is presented in Fig.5a and 5b.

Fig. 4. Double-ridged horn antenna for PNFR system validation.

a)



b)

Fig. 5. a) Actual view of AUT with AVA probes. b) Actual view of PNFR measurement system.

3. Results and discussions

The rectangular PNFR measurement system is researched for $f_{op} = 10\ GHz$ (X-band) operating frequency range and implemented. Seven AVAs were fabricated and integrated into a custom 3D-printed mechanical holder. A comparative analysis of AUT's radiation pattern is conducted using near-field to far-field (NF-FF) reconstruction [8].

As illustrated in Fig. 6a, the measurement setup employs a 7-element AVA probe array, with each probe spaced $10\ mm$ apart. This satisfies the sampling point criteria [9], as the operating wavelength at $\lambda_{op}/2 = 14.98\ mm > 10\ mm$. The AUT is positioned at the center of the AVA probe line, where the electric field (E) is assumed to be maximal. To measure both X and Y polarized fields, the AUT is rotated during the measurement process, and the resulting and E_x and E_y field data are presented in Fig.6.

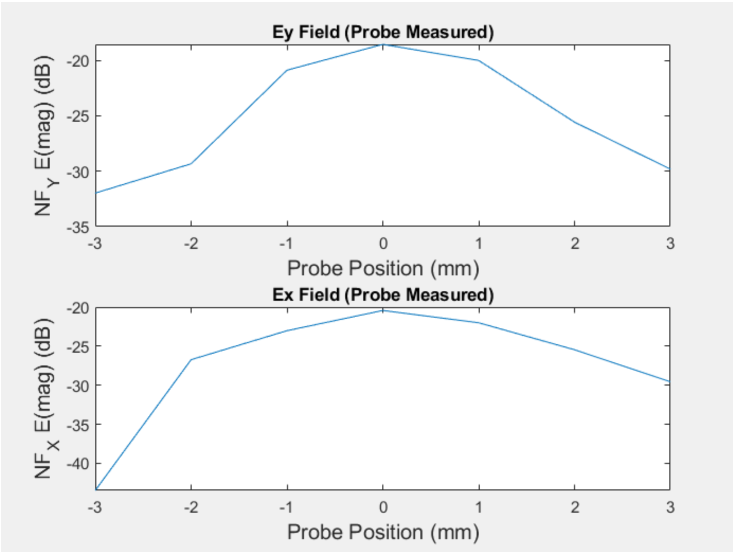


Fig. 6. E_x and E_y fields - Probe measured.

NF-FF conversion was performed based on the method outlined in [4], and interpolated plane wave spectrum for X and Y-axes are calculated [1] to achieve far-field reconstruction. The reconstructed far-field radiation pattern of double-ridged horn antenna is shown in Fig.7.

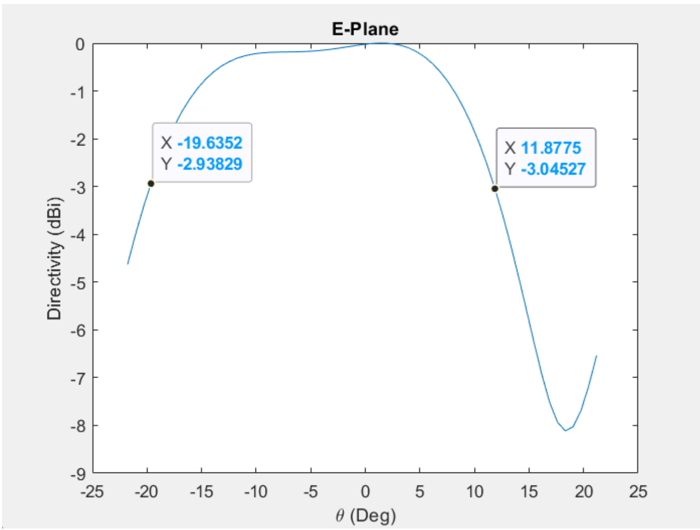


Fig. 7. Reconstructed E electric field in θ plane.

The reconstructed radiation pattern reveals a beamwidth of the AUT of approximately $2\theta_{0.5} \approx 30^{\circ}$ which aligns closely with the vendor-provided specifications for the horn antenna [8].

4. Conclusions

The practical implementation of the novel rectangular PNFR measurement system was conducted. Seven AVA units were fabricated and positioned using a 3D-printed mechanical holder. The fabricated AVAs demonstrated good VSWR performance over a wide frequency range, ensuring the system's suitability for broader frequency coverage. The radiation pattern in the θ plane was reconstructed, and the 3 dB beamwidth which is $2\theta_{0.5} \approx 30^{\circ}$ was compared with the specifications provided by the AUT's vendor. The close alignment between the reconstructed beamwidth and the vendor's specifications confirms the validity of the measurement system. Overall, the results obtained from the PNFR system, along with the test times required for sampling points, demonstrate the system's effectiveness and robustness of the measurement system. The setup is well-suited for modern accurate antenna characterization applications, particularly in scenarios where measurement space and speed are critical.

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