Advancing Spherical Near-Field Probe Technology: Design and Validation of High Precision Wideband 3dB/180° Couplers

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***Abstract*— A desirable feature of probes for Spherical Near Field (SNF) measurements is the absence of radiated higher order spherical modes in the pattern [1]. This implies that the probe pattern can be fully described by a linear interpolation of its principal plane patterns leading to a significant simplification in the NF/FF transformation when probe pattern compensation is included. Probes with such properties are inherently narrow band. Although probe correction algorithm for NF/FF transformation with any probe pattern are available [2], there is a need for probes approximating first-order performance across a large bandwidth. Traditional first-order probes rely on geometrically symmetric Ortho-Mode Junctions (OMJ) and externally balanced feeding. Such probes utilize couplers that ensure equal amplitude and opposite phase of the balanced feeding scheme [4]. This paper introduces the design and validation of a novel 3dB/180° coupler, based on the natural anti-symmetric properties of the electric field within the coupler to achieve quasi-perfect amplitude and opposite phase distribution. To realize these properties, an architecture based on slot coupling is selected. The coupler concept is suitable for various frequencies and has been realized at UHF to Ku-band, as a stand-alone cased component. The paper includes experimental data specifically at L/S-band, showcasing outstanding coupler performance concerning matching, balance, and isolation, aligning well with full-wave electromagnetic predictions. Furthermore, the study assesses measured probe design improvements due to enhanced coupler accuracy on a 1.4-4.2GHz SNF probe design [1].**

I. Introduction

Hybrid couplers that provide equal amplitude and opposite phase distribution at their output ports (3dB/180° couplers) are crucial in antenna applications where precision feeding is required. This is particularly true for dual-polarized probes in SNF measurement systems. To achieve high-quality radiation patterns with excellent symmetry, low cross-polarization, and reduced higher-order azimuthal modes in the radiated pattern, these probes necessitate external balanced feeding circuits. This approach prevents the excitation of high-order modes in the Ortho-Mode Junction (OMJ), especially when wideband operation is essential. Overmoding in the OMJ can deteriorate probe pattern characteristics and increase radiated higher-order azimuthal modes. Precision mechanical manufacturing can ensure excellent accuracy in the radiating parts of these probes, eliminating the excitation of high-order modes.

The quality of the radiation pattern is directly linked to the precision of the components generating balanced feeding. Amplitude and phase errors in these components can induce high-order mode excitation, leading to radiation pattern degradation. Most commercially available couplers lack inherent anti-symmetric distribution over frequency. The proposed concept in this paper leverages the natural anti-symmetric properties of the electric field within the component. This is achieved through the anti-symmetric geometrical structure of the selected coupling technique, providing quasi-ideal amplitude and opposite phase distribution. The chosen coupling technique is based on slot coupling. The designed coupler covering the nominal 1.4-4.2 GHz frequency band has been manufactured, tested and integrated in a high precision SNF measurement probe, SP1400 as shown in Figure 1.

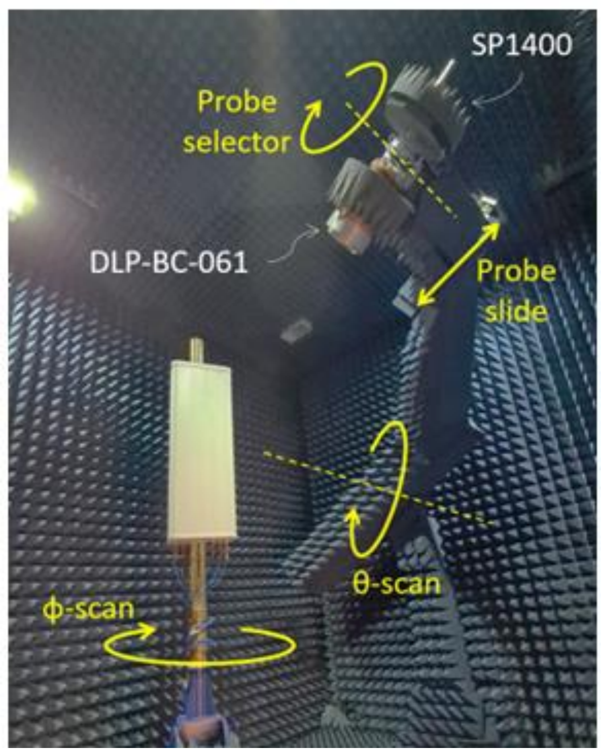

Figure 1. Final SP1400 probe covering the full 1.4-4.2GHz frequency range in a gantry arm SNF system.

II. Coupler Concept and Architecture

The proposed 3dB/180° coupler architecture is suitable for implementation in the microwave frequency range, typically from UHF to Ku-band. The core of the coupler is a double dielectric layer printed circuit board. This printed circuit technology offers a simple and compact solution, well-suited for slot coupling techniques. The coupler's architecture comprises three copper layers: a central ground plane with etched slots, a lower layer containing input microstrip lines, and an upper layer containing output microstrip lines. The electric field from the input lines is transferred through the slots to the output lines. A 180° phase inversion is achieved by reversing the direction of one output line compared to the other, while preserving equal amplitude distribution. Additionally, a multiple section Wilkinson divider is employed for better isolation between the outputs. The printed circuit, manufactured in RO4350B [5] and silver plated for improved conductivity is shown in Figure 2.

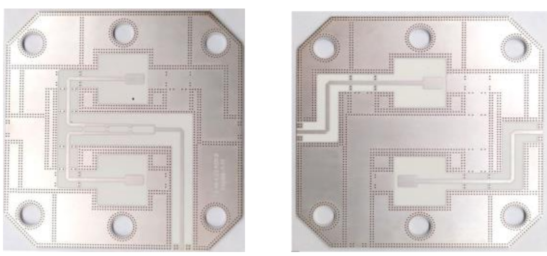

Figure 2. Final layout of 3dB/180° coupler: lower face (left) and top face (right).

III. Coupler Manufacturing and Validation

The coupler is manufactured in several units as cased three-port devices with connectorized RF interfaces. Precision-milled aluminum clamshells enclose the assembly, resulting in a compact structure suitable for integration with spherical near field probes. The measured output amplitude and phase balance shown in Figure 3 shows deviations of less than 0.02dB, 0.5° over the operational bandwidth of 1.4-4.2GHz. The average input reflection coefficient is -20 dB is excellent. The isolation between output ports is -25 dB, while transmission losses remain around 0.8dB. The measured performances confirm very good manufacturing repeatability.

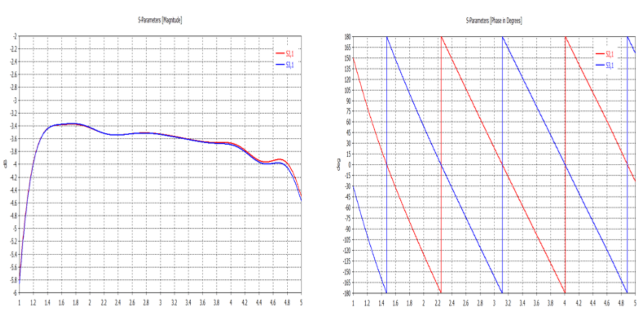

Figure 3. Measured output amplitude (left) and phase (right) of the realised coupler. Measured maximum deviation: 0.02 dB and 0.5°.

IV. Coupler Implemented with SNF Probe

The coupler has been validated as stand-alone component confirming the excellent amplitude and phase balance. It has been integrated with a near-field dual-polarized probe, SP1400 covering 1.4-4.2GHz. The measured spherical mode content of the new probe is illustrated in Figure 4. The measurements confirm the SP1400 equipped with the newly designed couplers maintains excellent first-order behavior, with higher order modes below a -35dB threshold.

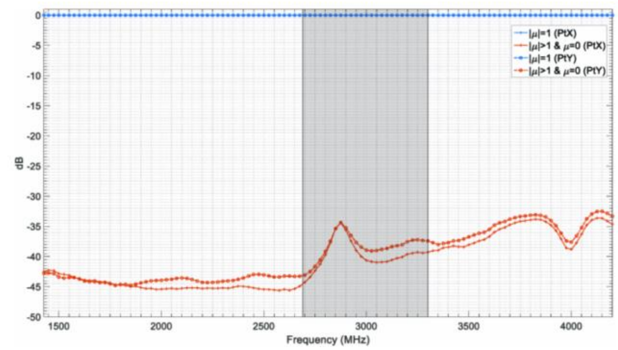

Figure 4. Measured modal content of SP1400 with new coupler. Fondamantal vs higher order modal content in the radiation pattern.

V. Conclusion

The paper concludes with the presentation of a novel 3dB/180° coupler design based on slot coupling, exhibiting quasi-ideal amplitude and opposite phase distribution. The coupler's excellent performance is validated through experimental data, and its integration into a SNF measurement probe showcases its impact on measurement accuracy. The design's innovative approach leverages the natural anti-symmetric properties of the electric field, making it a promising solution for enhancing the capabilities of SNF measurement systems.

References

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