An All-Electronically-Scanned Antenna Measurement Technique for Rapid Performance Characterization by Using a Circular Array of Reflection Surfaces

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***Abstract*— This paper presents an all-electronically scanned antenna pattern measurement technique (AESAP) based on the distinct feature of controllable reflection angle of the reflection surface (RS). The purpose of AESAP is to provide a rapid, cost-effective test system for fast development, pre-qualification, or pass/fail determination in the production line. The RSs with different reflection angles are arranged in a circular arch. The antenna under test (AUT) is located at the center of the arch, while another beamforming phased array, used as the source, is placed above the AUT. Therefore, any forms of mechanical rotation on the antenna under test (AUT) and/or the source antenna are not required. The calibration issue associated with this new structure is also investigated to suppress the multiple reflections and inter-surface coupling effects. A 28 GHz AESAP is implemented to verify the proposed technique. The measured gain patterns of standard horns, used as the AUTs, agree very well with those measured by the standard antenna measurement system.**

***Keywords*—mmWave; reflectarray; antenna measurement system; rapid measurement; all-electronically scanned antenna pattern measurement technique (AESAP).**

I. INTRODUCTION

A rapid antenna performance characterization is of more demand for the timely development of an antenna. However, most antenna characterization systems nowadays use mechanical rotation to change the relative angle of the antenna under test (AUT) to the source horn such that two- or three-dimensional radiation patterns can be obtained [1-3]. Therefore, the overall measurement time takes tens of minutes to hours due to limited step-motor rotational speed. The long antenna characterization time becomes a bottleneck for design and manufacturing. Therefore, shortening the measurement time becomes crucial.

A multi-probe antenna test station was introduced by [4], which is composed of a probe array and a Styrofoam column, both equipped with rotational motors. The probe array consists of 15 equally-spaced probes, mounted along the circular structure. The probe array is used to sample the field radiated by the AUT, and a radiation pattern on a full elevation cut can be obtained by mechanically rotating over 25°, instead of 360°. It takes 30 seconds for a two-dimensional radiation pattern [5]. Furthermore, since the AUT is mounted on top of the Styrofoam column, a three-dimensional radiation pattern can be obtained in a few minutes by rotating the Styrofoam column over a full 360°.

In this article, an all-electronically scanned antenna pattern measurement technique (AESAP) without any mechanical motors is proposed for the purposes of rapid development, pre-qualification, or pass/fail determination in the production line.

II. PRINCIPLE OF ALL ELECTRONICAL SCANNING

A. Description

The configuration of the proposed AESAP is illustrated in Fig.1, which is composed of an array of reflection surfaces (RSs) arranged along a circular arch, and a beamforming front-end (BFE) with a 4×4 antenna array [6] as the transmit source. The AUT is located at the center of the arch, and the BFE is placed above the AUT with a separation larger than 20 wavelengths.

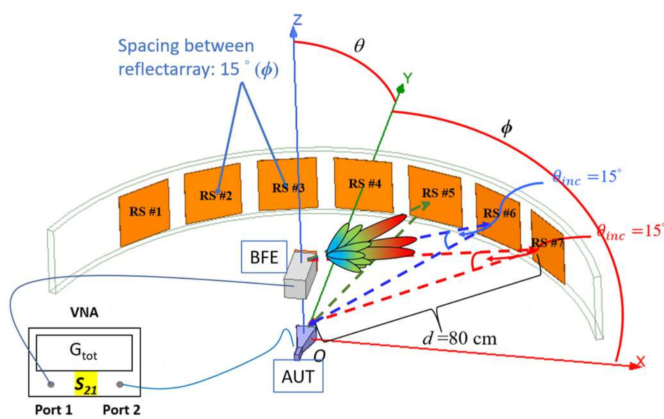

Fig. 1. Configuration of the proposed AESAP.

In conventional motor-based test systems, the motors are used to rotate the AUT or the source horn to generate numerous incident waves with different desired incident angle to the AUT. To avoid using these motors, the RSs and the BFE are integrated to provide plane waves with different incident angles to the AUT as follows.

The beam #m is transmitted from the BFE to precisely illuminate the whole panel of RS #m. Then the RS #m reflects this beam power toward the AUT with a specifically desired azimuthal angle. This establishes a source-AUT path, which is equivalent to the line-of-sight path between the source and the AUT in the conventional motor-based test system. Similarly, once the total M beams are sequentially generated from the BFE, the M source-to-AUT paths with desired different azimuthal angles are formed. From the S_{21} scattering parameter dictated by the vector network analyser, the radiation patterns on the azimuthal plane is completed.

Note that the system can also be used for characterizing Tx-mode AUT by switching the BFE from transmit operation to receive one and utilizing the Tx-mode calibration reference.

B. Mathematical Formulation

In order to correctly obtain the radiation pattern of the AUT, the signal, emitted from the BFE, propagating through the entire array of RSs, and received by the AUT, must be formulated. Suppose N is the total number of beam states available from the BFE, and M is the total number of RSs. By sequentially scanning the total N beams, the gain pattern associated with the AUT can be expressed as

$$g_{AUT} \cdot \Gamma \cdot {G_T}^{\mathrm{T}} = g_{tot} \tag{1}$$

where $g_{AUT} \in \mathbb{C}^{1\times M}$ is the AUT pattern, $\Gamma \in \mathbb{C}^{M\times M}$ is the inter-surface coupling matrix of this system, $G_T \in \mathbb{C}^{N\times M}$ is the matrix of the gain pattern of the source BFE, $g_{tot} \in \mathbb{C}^{1\times N}$ is the S_{21} parameter measured by the vector network analyzer.

For convenience, M out of the N beam states are selected for this design, thereby resulting $g_{tot} \in \mathbb{C}^{1\times M}$. In addition, the finite beamwidth and unavoidable sidelobes of beam #m, pointing at RS #m, may interact with the rest of the M-1 RSs. This will generate the non-diagonal entries of the Γ matrix. The main purpose of the pattern measurement is extracted g_{AUT} pattern from (1).

C. Calibration Methodology

The calibration methodology must be developed to eliminate the multiple reflections, inter-surface coupling, and so on. In other words, in order to obtain the actual AUT pattern g_{AUT} in (1), another set of BFE is placed at the AUT to be used as a calibration reference, such as Rx mode of BBox. Therefore, Eq. (1) becomes as

$$G_R \cdot \Gamma \cdot {G_T}^{\mathrm{T}} = G_{tot} \tag{2}$$

where $G_R \in \mathbb{C}^{M\times M}$ is the radiation gain pattern matrix of the reference BFE. Once the matrices G_{T} and G_{R} are both measured in the anechoic chamber as shown in Fig. 2, the matrix Γ can then be estimated by taking the matrix inversion of (2).

Next, the AUT is placed at the AESAP for measurement. After sequentially scanning M beam states of the source BFE, the g_{tot} matrix is obtained from the scattering parameters by vector network analyzer. That is, the radiation field pattern of the AUT is obtained as below:

$$g_{AUT} = g_{tot}\left(\Gamma \cdot {G_T}^{\mathrm{T}}\right)^{-1} \tag{3}$$

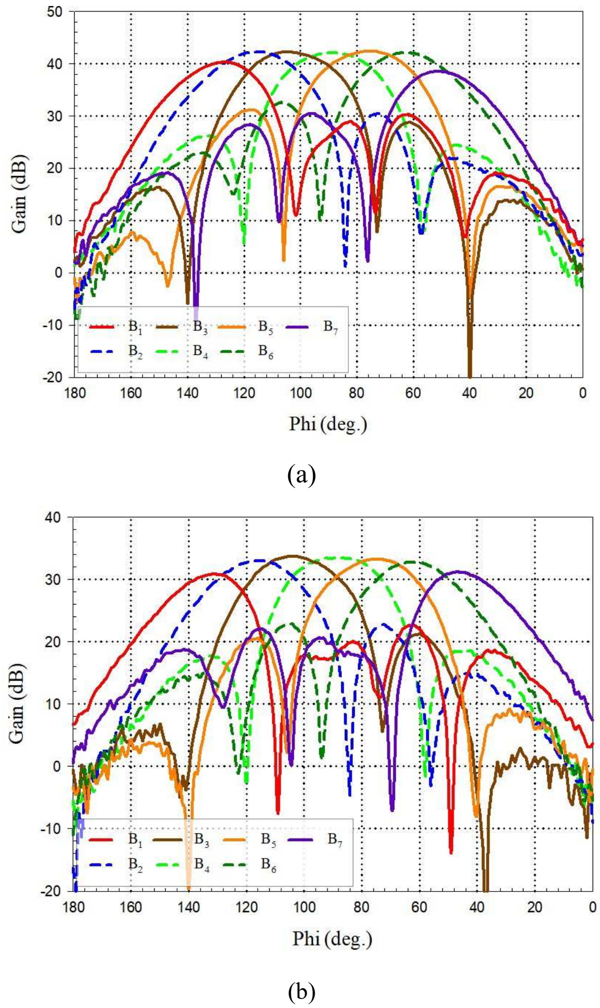

Fig. 2. (a) Tx- and (b) Rx-mode measured radiation patterns of the adopted BBox for calibration T/Rx matrix. *(N = M = 7)*

III. Implementation

A. Configuration

In this work, in order to validate the proposed approach, a 28 GHz AESAP is implemented with $N = M = 7$, where the seven RSs are installed at φ = 45º, 60º, 75º, 90º, 105º, 120º, 135º, respectively. The source BFE is installed at (0, 0, 21.44) cm of the AESAP with the beam patterns. The antenna-under-test (AUT) is located at the origin (0, 0, 0). The seven RSs are installed on the circumference of a circle with a radius of 80 cm and the center of (0, 0, 0) cm lying on the *xy*-plane. The separation angle between the RSs is θ_{inc}=15º, providing a θ_{step}=15º angle resolution.

B. Reflection Surface Realization

The RS is designed based on [7,8] by controlling the sizes of the unit cells for fulfilling the required reflection phase distribution thus achieving the demanded spatial response. The reflection phase $\psi_R(x_i, y_i)$ for the i^{th} element is calculated as.

$$\psi_R(x_i, y_i) = k_0[d_i - (x_i cos\varphi_b + y_i sin\varphi_b)sin\theta_b]. \quad (4)$$

where k_0 is the wavenumber at the center frequency, d_i is the distance from the phase center of the source BFE to the i^{th} cell.

The implemented RS with 15.6 cm × 15.6 cm and the measured radiation patterns are shown in Fig. 3. A relative sharp beam with 25 dB gain at θ_b = 90º can be observed. Fig. 4 presents the photograph of the implemented AESAP.

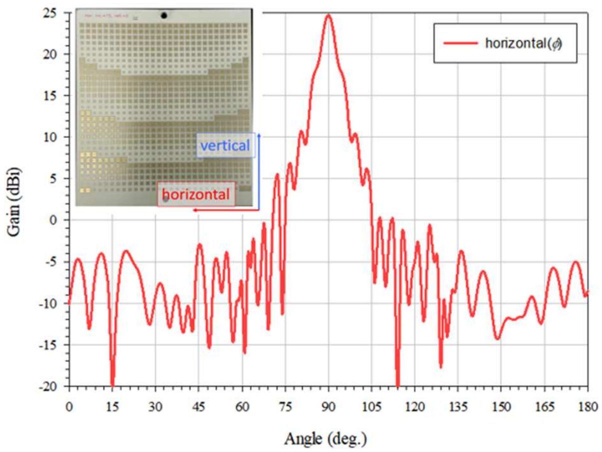

Fig. 3. Radiation pattern of the reflectarray antenna.

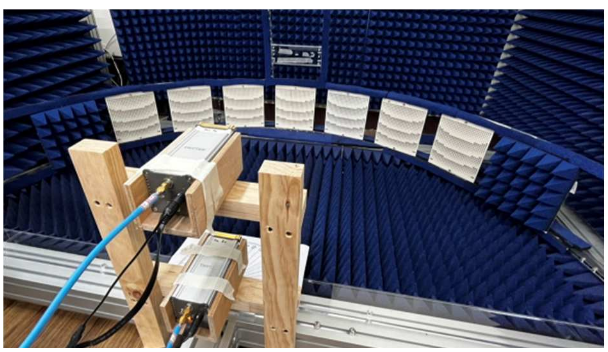

Fig. 4. Photograph of the AESAP system (this is the calibration stage, and the two BBoxs are set to Tx mode and Rx mode, respectively)

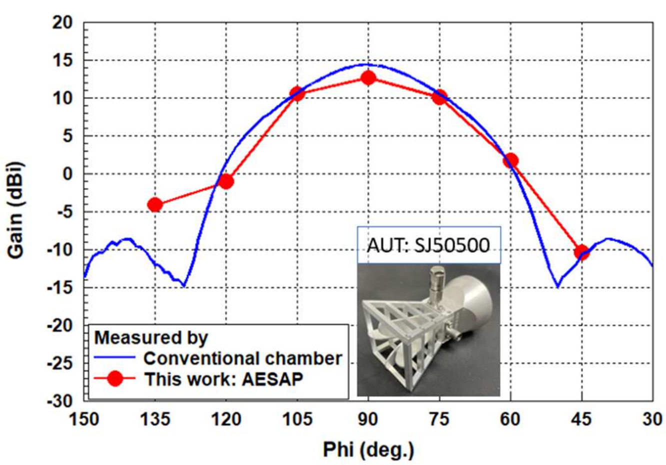

Fig. 5. Measurement result of SJ-50500 by conventional chamber and the AESAP system.

IV. Measurement Results and Discussion

A. *Measurement Results from the AESAP*

Based on the aforementioned measurement procedure and calibration step, a standard horn, A-INFO SJ-50500, is used as the AUT.

The gain pattern at the azimuthal cut of the AUT is measured and shown in Fig. 5, where the measurement time is less than 3 seconds. The results measured by the conventional anechoic chamber are also plotted in Fig. 5 for comparison. Both measurement results show the average gain discrepancy is 2 dB, and the maximum gain deviation is 7.8 dB at -45º.

B. Gain Error Contributed from the Source BFE

It is found that the cause of the gain deviation of 7.8 dB is the beam shape deterioration of the source BFE when its beam is steered to a large angle away from the normal direction. As observed from Fig. 2(a), the two exterior beams (i.e. B_1 and B_7) do not precisely point to the centers of two marginal RSs (RS #1, RS #7). As a result, when measuring the gain at 135º of the AUT, a lot of power is received not from RS #1 but from RS #2.

In order to verify this statement, the source BFE is replaced by a standard horn antenna WavePro SG34. The measured patterns of the AUT both by the AESAP and by the anechoic chamber are shown in Fig. 6. The maximal gain error is reduced to 2.9 dB at 45º, and the average gain error is reduced to 1.8 dB.

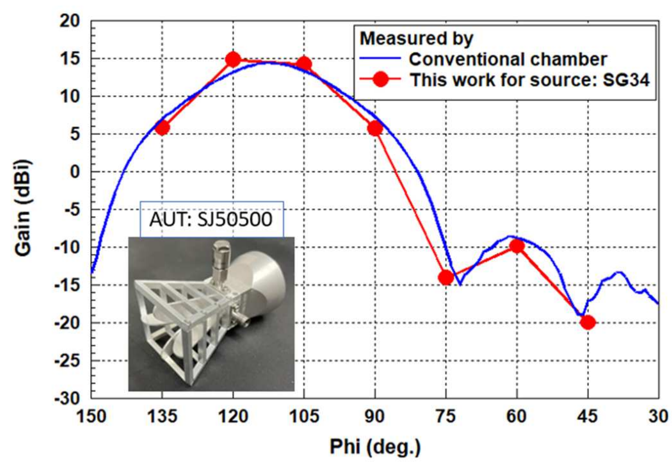

Fig. 6. Improve measurement results by using SG34 to be a source.

V. Conclusion

A novel millimetre-wave all-electronically scanned antenna pattern measurement system (AESAP) is proposed for the purposes of rapid development, pre-qualification, or pass/fail determination in the production line. An array of seven RSs and a 28 GHz beamforming front-end are integrated to measure the radiation pattern of the AUST with no need of any mechanical rotation. The calibration method associated with this new structure is also developed to eliminate the multiple reflection and inter-surface coupling effects.

The measured radiation patterns are compared with those from the standard antenna characterization chamber. Both radiation patterns agree very well within 2 dB gain discrepancy. For a two-dimensional radiation cut, our developed AESAP takes less than 3 seconds, which a significantly shorter than 30 seconds taken by the standard characterization system.

ACKNOWLEDGMENT

This work was supported by the National Science and Technology Council of Taiwan under Grants 111-2218-E-194 -004 -, and TMYTEK for supporting mmWave equipment. We would like to thank the National Center for High-performance Computing and Taiwan Semiconductor Research Institute (TSRI) under the National Applied Research Laboratories (NARLabs) for supporting computational resources and simulation software.

REFERENCES

[1] T. Matsui, "30-1000 MHz field strength standard developed in anechoic chamber," *IEEE Trans. Instrumentation and Measurement*, vol. 41, no. 6. pp. 997-1000, December, 1992.

[2] B. K. Chung and H. T. Chuah, "Design and construction of a multipurpose wideband anechoic chamber," *IEEE Antennas Propag. Mag.*, vol. 45, no. 6, pp. 41–47, Dec. 2003.

[3] V. Rodriguez, "Basic rules for indoor anechoic chamber design," *IEEE Antennas Propag. Mag.*, vol. 58, no. 6, pp. 82–93, Dec. 2016.

[4] L. Duchesne, P. Garreau, N. Robic, A. Gandois, P. O. Iversen and G. Barone, "Compact multi-probe antenna test station for rapid testing of antennas and wireless terminals," in *2004 IEE Antenna Measurements and SAR*, AMS, pp. 101-105, Loughborough, UK, 2004.

[5] T. A. Laitinen, J. Ollikainen, C. Icheln, and P. Vainikainen, "Rapid spherical 3-D field measurement system for mobile terminal antennas," in *Proc. IEEE IMTC*, May 20–22, 2003, pp. 968–972.

[6] BBox™ 5GmmWave NR Beamforming Development Tool [Online]. Available: https://tmytek.com/products/beamformers/bbox

[7] P. Nayeri, F. Yang, and A. Z. Elsherbeni, *Reflectarray Antennas: Theory, Designs, and Applications*. Hoboken, NJ, USA: Wiley, 2018.

[8] P. Nayeri, A. Z. Elsherbeni, and F. Yang, "Radiation analysis approaches for reflectarray antennas," *IEEE Antennas Propagat. Mag.*, vol. 55, no. 1, pp. 127–134, Feb. 2013.