# Empirical and Theoretical Characterization of Multioctave Planar Phased Arrays


Johnson J. H. Wang
Wang Electro-Opto Corporation (WEO)
Marietta, Georgia 30067, USA
jjhwang@weo.com



***Abstract*—Theoretical and empirical characterizations of Multioctave Planar Phased Arrays (MPPA) are highly difficult, complex and costly; rooted in MPPA's complexity and its huge data and metrics that encompass large spatial and frequency domains. This paper presents theoretical and empirical characterizations as applied to an MPPA called Traveling-Wave Antenna Array (TWAA). The physical model has 16×16 elements, fed with True-Time Delay (TTD) corporate feeds for wide-angle scan up to 60° off broadside over 2-12 GHz. Excellent agreements between theoretical and empirical data were observed except for angles beyond 45°. Merits and limitations of classical and numerical analysis approaches are discussed.**


## I. Introduction

Research in Multioctave Planar Phased Arrays (MPPA) claiming to have multioctave bandwidth and wide-angle scan has been increasingly active since 1980s [1]-[5]. Unfortunately, except for those of flared-notch elements, their characterization has been mostly indirect and/or incomplete, generally stopped at the stage of numerical simulation of an infinite planar array and/or measured Scan Element Gain (SEG) patterns of a rather small empirical model (8×8 elements or fewer). This common practice is to circumvent the high costs inherent in the research on MPPA, which is complex and burdened with huge data and metrics that encompass large spatial and frequency domains. Not too well known are the technical difficulties and costs in modeling the array's feed region and for large scan angles. This paper discusses the techniques for theoretical and empirical characterization as applied to a thin MPPA called Traveling-Wave Antenna (TWA) Array, or TWAA [5]-[6].

## II. TWA Array (TWAA)

Fig. 1 shows a 2-12 GHz TWAA with 16×16 (256) elements, which was fabricated by standard commercial production processes. The design concept from a unit-cell perspective has been discussed in [5]. The array is 1.14-inch thick, with planar closely-coupled bowtie dipoles as element radiators. The array is comprised of an RF unit-cell region, a matching circuit below the unit cell, and a 90-mil-thick aluminum mounting plate with 256 press-fit SMA connectors.

To suppress grating lobes, the length and width of the unit cell are chosen to be $\lambda_h/2$, where $\lambda_h$ is the free-space wavelength at the highest operating frequency. The array radiator is fed by a transmission line which connects to the impedance matching circuit contained inside a closed region below the ground plane. For systems integration, there is room more than 0.5 inch in thickness below the ground plane (out of the 1.14-inch thickness) that can be used to accommodate T/R modules, BSN (Beam Steering Network), etc.

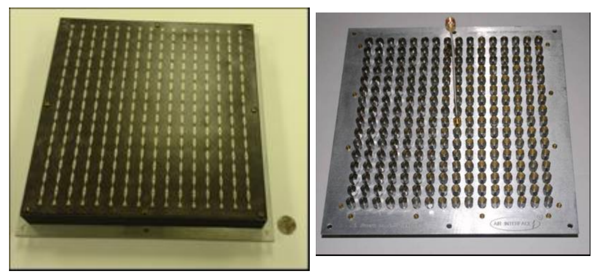

Fig. 1. Photograph of the TWAA in front and back views.

## III. Empirical and Theoretical Characterization

For empirical characterization, measurements of far-field radiation performance on a sufficiently large array are most direct and credible, and were adopted here. Since there were few, if any, BSNs that can cover the 2-12 GHz bandwidth needed, a True-Time-Delay (TTD) BSN corporate feed network had to be developed in-house. Discrete TTD lines for beams at 0º, ±30º, ±45º, and ±60º were made of phase-matched semirigid coaxial cables in combination of stages of broadband power dividers that are reciprocal for both transmit and receive.

E and H-plane radiation patterns over 0º-360º for principal polarizations, covering 2-12 GHz at 0.25 GHz intervals, were measured in WEO anechoic chamber for array beam scan at 0º, ±30º, ±45º, and ±60º. Thus the data sampled are fairly dense throughout the large spatial and frequency domains. Fig. 2 shows an example comparing computed and measured patterns for scans to -45° and -60° off broadside at 5 GHz. The computed patterns were generated at Electro-Science Laboratory (ESL) of The Ohio State University (OSU), fairly independently. The simulated patterns were obtained by multiplying the array factor and the Scan Element Gain (SEG) patterns of an infinite array, as suggested by the author, with a moment-method solution using commercial software.

In light of the controversies [3], the author also dictated that the simulation be in the transmit mode and with special attention to the numerical modeling of the feed mechanism and

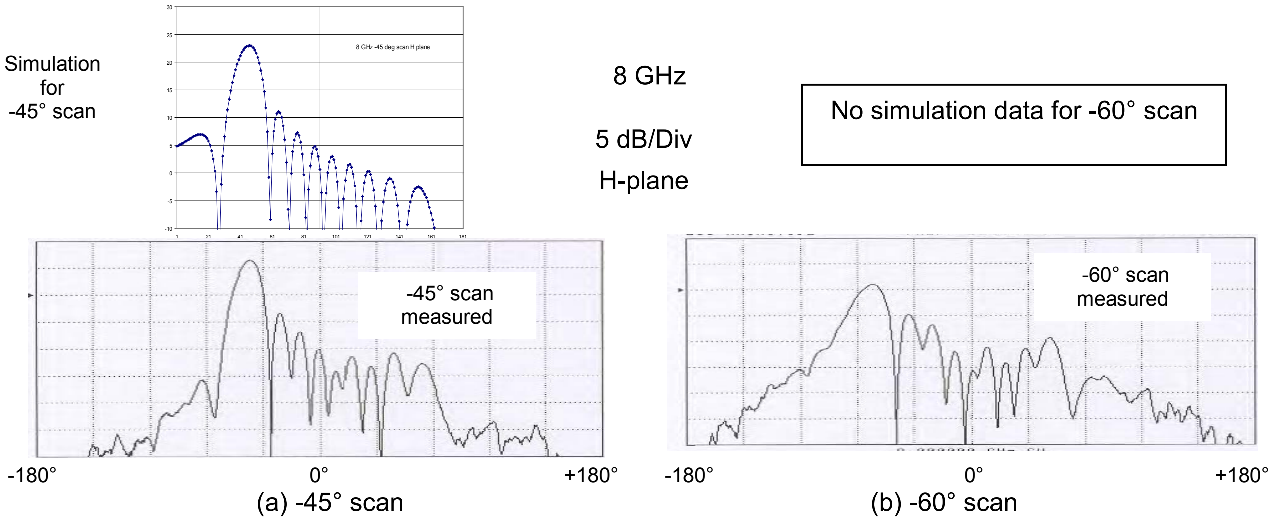


Fig. 2. Comparison of measured and simulated radiation patterns for wide scan to -45° and -60°.

the equivalent source. Note that the computed patterns do not have the -60º-scan case yet; this is a very challenging case due to the large scan angle. Also, the computed patterns cover only a half space, -90º to +90º, due to limitations of the infinite array model. On the other hand, the measured data have 60º-scan cases and cover the full 360º appropriate for a finite array. In practice, a planar array panel needs full 360º property for assembling to a full array or installation on a small platform.

## IV. Discussions and Conclusions

The measurements were conducted before the simulation data were obtained. As this was believed to be the first full-fledged characterization in the controversial field of MPPA [3]—except for those of flared notch type—the tests began with some sense of uncertainties and apprehension. It was a relief when the first measured patterns looked like ideal theoretical patterns based on classical array theory. That the measured patterns are close to, and sometimes better than, the simulated performance can be partially attributed to TWAA's robust performance, which had been observed in a simulation study of manufacturing tolerance on array active impedance conducted earlier. The following are additional explanations.

The infinite-array unit-cell analysis has inherent deficiencies arising from ignoring the edge effects in a real-world array, which is always finite. Also, in numerical analysis it is increasingly more difficult and expensive to achieve relative convergence as the main array beam is steered away from broadside. Thus worthy simulation data for the case of ±60º have not yet been generated.

Approximations in the algorithms of commercial software such as those for computing fields or equivalent currents speed up computing but also degrade the accuracy of the numerical model. Round-off errors arising from large computations with limited CPU RAM further aggravate the problem, as discussed in [7].

In conclusion, excellent agreements were observed between theoretical and empirical data, except for numerical modeling for wide-angle scan beyond 45°. Overall, both classical theory and numeric analysis are useful in characterizing MPPA.

These limitations and usefulness for numerical modeling of MPPA will be further discussed.

## Acknowledgement

The material in this paper is based on work supported by the Naval Sea Systems Command under Contract No. N00024-13-C-4526. The author is grateful for the technical support of the Ohio State University ESL team, since 2007, led by Dr. John Volakis.

## References

[1] B. A. Munk, Finite Antenna Arrays and FSS, Hoboken, N.J.: J. Wiley & Sons, 2003.

[2] J. J. Lee, "Ultra-Wideband Arrays," in Antenna Engineering Handbook, 4th ed. by J. L. Volakis, New York: McGraw-Hill, 2007, Chapter 24.

[3] R. C. Hansen, Phased Array Antennas, 2nd ed., Hoboken, N.J.: Wiley, 2009, pp. 233, 465-477.

[4] W. F. Moulder, K. Sertel, and J. L. Volakis, "Superstrate-enhanced ultrawideband tightly coupled array with resistive FSS," IEEE Trans. Antennas and Prop., Vol. 60, No. 9, pp. 4166-4172, September 2012.

[5] J. J. H. Wang, "Traveling-Wave Antenna (TWA) Array as a Thin Multioctave Planar Phased Array (MPPA)," 2013 IEEE International Symposium on Phased Array Systems & Technology, Boston, MA, pp. 207-213, October 2013.

[6] J. J. H. Wang, "Demonstration of Low-cost Ultra-wideband Planar Phased Array Having Multioctave bandwidth, Wide scan, and High efficiency," unpublished.

[7] J. J. H. Wang, Generalized Moment Methods in Electromagnetics—Formulation and Computer Solution of Integral Equations, Wiley, New York, 1991; Chapter 10, "Planar phased arrays and periodic structures," and Chapter 12, "Computer-Related Considerations."