Forum for Electromagnetic Research Methods and Application Technologies (FERMAT)

Demonstration of Low-cost Ultra-wideband Planar Phased Array Having Multioctave bandwidth, Wide scan, and High efficiency

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Abstract — A planar phased array operating over 2-12 GHz with wide scan 60° off broadside and high-efficiency has been successfully designed and tested with a 16×16-element array prototype fabricated with low-cost standard commercial production processes. The measured performance is slightly better than that simulated based on the array factor and a moment-method solution for unit-cell in infinite array. The excellent and robust measured performance of the prototype sampled throughout its entire space-frequency domain is the first full-fledged demonstration of the viability of the planar phased array with multioctave bandwidth and wide-angle scan, which has been overshadowed by skepticism and controversies since its debut around 2000.

Index Terms — Antenna arrays, broadband antennas, phased arrays, ultra-wideband antenna arrays, conformal arrays.

I. Introduction

Since around 2000, research in ultra-wideband planar arrays with multioctave bandwidth and wide scan angles has been highly active, accentuated by a flurry of publications and patent applications [1]-[9]. Unfortunately, their supporting data in publications so far in the open literature are weak and incomplete (except for those with element radiators of the flared-notch type, which suffer from high cost and deficiencies in performance, weight and thickness).

Ultra-wideband planar arrays are highly complex and costly, and their design concepts are often riddled with enigma and controversies. As a result, even though driven by strong market needs and well-funded, breadboards and prototypes reported in the open literature were fairly small, generally no more than 8×8 elements, and some had only one feed—or none. Array tests (and thus their breadboards) often went only as far as the simple and limited Scan Element Gain (pattern) method (with only a center element actively fed). These are obviously indirect and incomplete test methods.

Today, some of these design concepts have fizzled out, and the field overall is overshadowed by skepticism and controversies—and rightfully so [1]. This paper reports a successful and fairly complete demonstration with a prototype array having 16×16 elements.

II. Design of the Array Prototype

The design goals of this prototype planar phased array are a continuous multioctave bandwidth of 2-12 GHz, linear polarization, low VSWR, high efficiency, and wide scan angle up to 60° off broadside. To achieve these ambitious goals timely, the design must not use magnetic material, metamaterial, or material of special dielectric property; any of these techniques would add development risks.

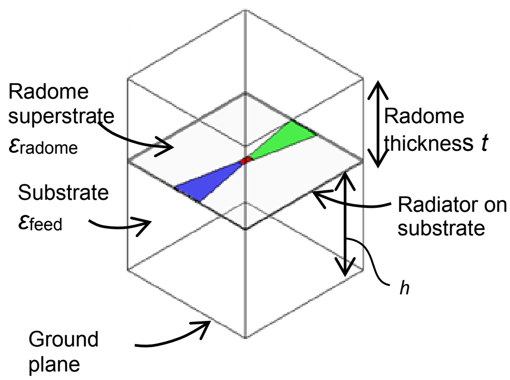
Fig. 1 shows the array element design in a square unit-cell configuration of an infinite periodic array, which is also used in numerical modeling by a moment-method solution using commercial software. Scan radiation patterns are calculated using the unit-cell pattern and the array factor. For linear polarization and wide bandwidth, the radiator chosen is a planar bowtie dipole etched on a thin Teflon substrate having a relative permittivity ε_{r1} with low loss tangent.

To suppress grating lobes, the length *l* and width *w* of the unit cell are chosen to be smaller than $\lambda_h/2$, where λ_h is the free-space wavelength at the highest operating frequency; *l* = *w* = 12.5 mm were chosen. The radiator on substrate is spaced

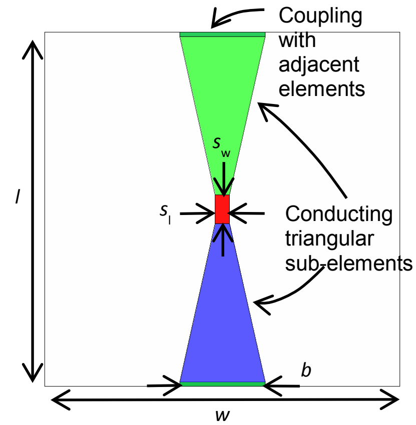
*This paper had been submitted in December 2014 to IEEE International Microwave Symposium without author info and any content of this footnote, according to IMS2015 submission guidelines, to ensure fair double-blank review. It was rejected and is submitted to FERMAT on December 12, 2015. (Author identity, biosketch, acknowledgment, etc. are added for this submission.) 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.

above a conducting ground plane by h, where $h<\lambda_h/2$. The feed structure between the array radiator and the conducting ground plane is a transmission line, which connects to the impedance matching circuit inside a closed region below the ground plane. The superstrate layer above the radiator serves as a radome, which is very thin.

Fig. 2 shows a photograph of the prototype, which has 16×16 (or 256) elements, fabricated with low-cost standard commercial production processes. It is 1.14-inch thick, comprising the unit cell region in Fig. 1, the region containing the matching circuits below the unit cell, and a 90-mil-thick aluminum mounting plate with 256 press-fit SMA connectors.



(a) perspective view



(b) exploded top view

Fig. 1. Unit cell of the planar array with planar bowtie radiator.

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.

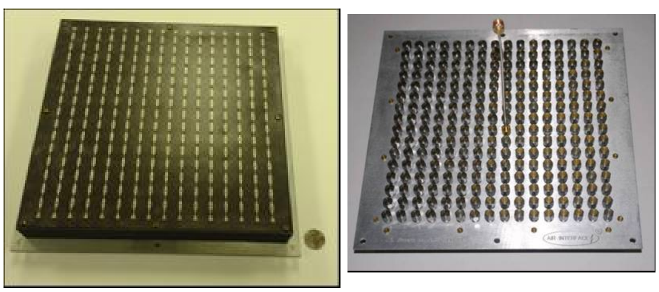


Fig. 2. Photograph of the prototype array (front and back views).

III. Test Setup

Fig. 3 shows the fully assembled array under far-field tests in an anechoic chamber. As can be seen, on the mounting platform of the pedestal, there are three True-Time-Delay (TTD) BSN banks behind the array panel of Fig. 2. The BSN is a corporate feed network consisting of 8-1 and 2-1 power dividers/combiners connected with semirigid cables, which could be integrated into the array panel as discussed earlier.

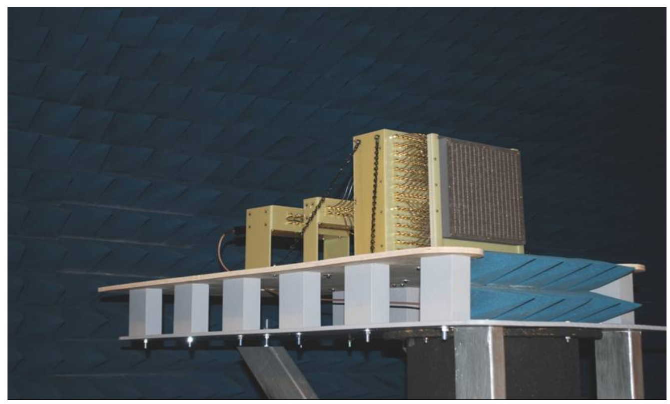


Fig. 3. Far-field measurement of the prototype array with banks of BSN in anechoic chamber.

IV. Measured Performance

Fig. 4 displays measured SWR for the array with BSN set at 0° scan (broadside). The results are very good; yet it is noted that additional analysis and evaluation on the data are needed to obtain an accurate interpretation. It is also noted that, in systems application, impedance matching is often integrated into the feed network that includes the BSN, T/R module, etc., not in a corporate feed configuration.

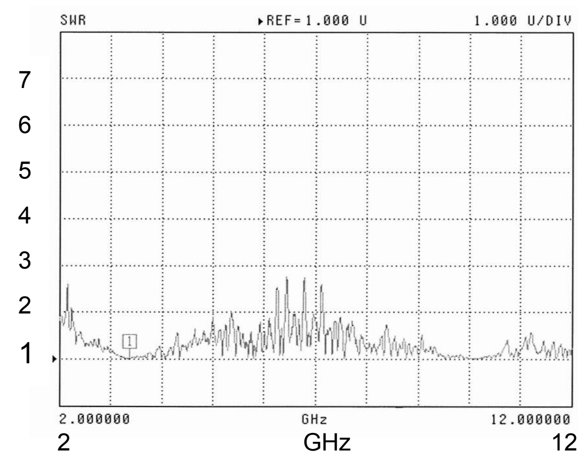


Fig. 4. Measured SWR for array with 0° scan.

It is also worth noting that, for a large array antenna, impedance matching is a much simpler engineering problem than optimizing radiation patterns. Failures in radiation patterns can be very difficult and expensive to fix—due to the large number of parameters and dimensions involved in optimizing pattern performance over multioctave bandwidths. Mathematically speaking, for a planar phased array, impedance matching per se can be formulated as a simple scalar Fourier transform of scalar parameters; yet the radiation pattern is a vector Fourier transform of vectors and tensors. For the latter problem, analysis is already a very difficult problem very cumbersome to manipulate, not to say synthesis over multioctave bandwidths and large scan angles.

In this research, far-field radiation patterns for principal polarization over 2-12 GHz, at 0.25 GHz intervals, are taken in an anechoic chamber, with BSN steering the array's main beam to scan angles of 0° (broadside), -30°, -45°, and -60° (or + angles by reversing the feed arrangements), in E and H planes. The measured data are surprisingly good, very close to the ideal cases in textbooks based on classical antenna theory, as exhibited in beam widths, sidelobes, etc.

Fig. 5 shows measured H-plane patterns at 2 and 12 GHz, respectively, for scan angles at -45° and -60°. These patterns are displayed together with computer simulation patterns. **These are the worst cases in the measured data; data at other frequencies or scan angles are much better. Naturally and fundamentally, array performance generally deteriorates with increase of scan angle and deviation from the center of the operating frequency range.**

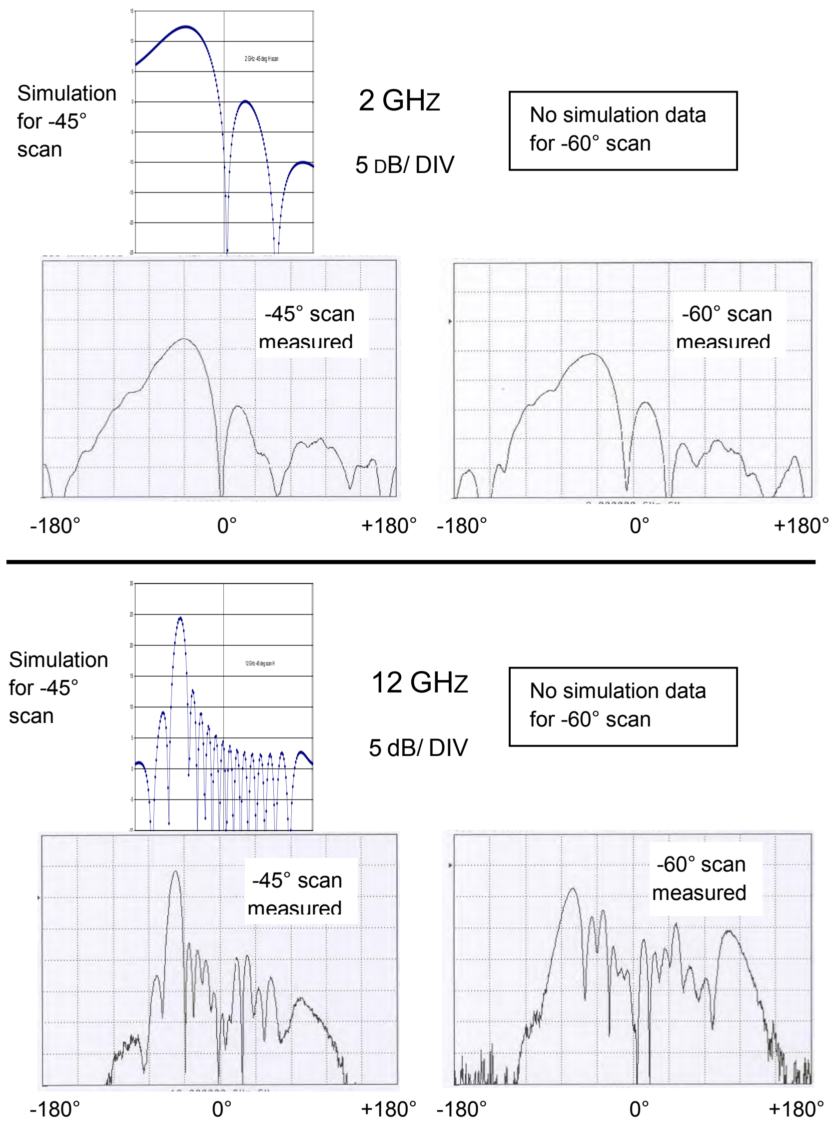


Fig. 5. Comparison of measured and simulated radiation patterns of prototype array for -45° and -60° scan at 2 GHz and 12 GHz.

Note that there is no simulation data for -60° scan; simulation for scan beyond 45° was halted early on because the simulated performance was poor. It is also worth noting that the measured patterns generally have lower 1st, 2nd, and 3rd side lobes. The better measured performances result from the fact that the edge effects are inherent in the physical model, while the numerical model ignores the edge effects of the array and assumes a uniform distribution.

Additionally, the commercial software used in modeling the unit-cell of a planar infinite array likely has limitations rooted in its approximations embedded in the algorithms, particularly those computing the fields or equivalent currents. The computer used in the simulation is also likely inadequate for large scan angles at higher frequencies, which require more basis functions and higher numerical precision in order to minimize numerical round-off errors.

V. Conclusion

Ultra-wideband planar phased array covering 2-12 GHz and wide-angle scan to 60° off broadside has been demonstrated to be a viable approach by a 16×16-element array prototype fabricated with low-cost standard commercial production processes. The tests, using true-Time-Delay beamsteering networks, show excellent and robust array performance in a fairly complete and full-fledged manner that meets the sampling criteria for the entire space-frequency domain of the array.

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Since 1991 he has been Chief Scientist and President of Wang Electro-Opto Corporation (WEO). From 1975 to January 1995, he was on the faculty of the Georgia Institute of Technology, Atlanta, Georgia. Prior to his tenure at Georgia Tech, he had seven years of industrial experience in the design of various antennas and phased arrays. At Georgia Tech his research was in the area of antennas, microwaves, and electromagnetic theory. A focus of his research was the computation of a variety of three-dimensional electromagnetic problems using digital computers by the method of moments. His current fields of interest are broadband/multiband low-profile conformable antennas, smart antennas, software-defined arrays, ultrawideband phased array antenna systems, multifunction and diversity antenna systems employing modern microwave and lightwave technologies, digital beam forming, as well as wireless telecommunications.

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