A New Planar Multioctave Broadband Traveling-Wave Beam-Scan Array Antenna

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Abstract - **This paper presents a new approach for broadband planar phased array antenna, in which the array elements are traveling-wave antennas comprised of planar 2-dimensional frequency-independent antennas closely spaced above a conducting ground plane. Adjacent array elements are strongly coupled or directly connected. The present approach has the potential to achieve 10:1 bandwidth for wide-angle beam scan.**

I. INTRODUCTION

Broadband planar arrays have become increasingly more important for both military and commercial applications. The broadband requirement is driven by the proliferation of wireless systems and the need for high speed. The planar form is desirable for both transport and installation on platforms, and lends itself to low weight and low-cost production.

Early ultra-wideband planar array designs mostly employed 3-dimensional (3-D) element antennas, such as flared slots and horns. However, arrays of 3-D elements have a large dimension perpendicular to the plane of the array, leading to high production cost and large weight and thickness. To overcome these operational and transport shortcomings, major research efforts have recently been carried out on using planar 2-dimensional (2-D) elements such as patches, slots, etc., for broadband beam-scan arrays.

This paper reviews the state-of-the-art for planar broadband beam-scan arrays using 2-D elements, and presents a new approach based on the traveling-wave (TW) antenna concept, which potentially has performance advantages over other existing approaches.

II. STATE OF THE ART OF BROADBAND PLANAR PHASED ARRAYS OF 2-D ELEMENTS

Although the possibility of a broadband planar beam-scan array using 2-D radiating structure had been envisioned by Wheeler four decades ago by way of a conceptual Current Sheet Antenna (CSA) [1], its design remained elusive until recently. Hansen [2] showed in 1999 that a planar phased array using planar dipoles, without a ground plane, exhibits easy-to-match active resistance and fairly stable element gain pattern, over a wide range of scan angles and bandwidth (over 5:1). Although the reactance remains to be matched, the difficulty is only in matching with the frequency since the reactance changes very little over a modest scan angle. He noted, however, the array failed to work when a ground plane is added to change the array's bidirectional radiation to unidirectional.

Since then, significant progresses have been reported in this area, following either the CSA [3-8] or the Fragmented Aperture Array (FAA) [9-12] approach. The CSA claims a 10:1 bandwidth, and the FA claims an operating bandwidth even wider. However, as observed by Thors et al [12], design guidelines and results are often scant, particularly in dealing with the ground plane problem. This is particularly true in the case of the FA approach, for which Thors et al [12] only managed to achieve a bandwidth of 2.23:1.

A review of the state of the art of these planar phased arrays of 2-D planar elements with ultra-wideband performance reveals that the following critical issues are either ignored or only vaguely addressed:

1. the necessary ground plane,
2. the feed network.

III. ULTRA-WIDEBAND PLANAR TW ARRAYS

A planar TW array lying parallel to the *x-y* plane is depicted in Figure 1 by its cross-sectional view. The periodicity of the TW array elements is implicit, generally in the *x* and *y* axes. The array is preferably thin, and sometimes flexible and conformable to a surface that may not be strictly flat. To deal with the grating lobe problem in a phased array, it is necessary that the spacing *S* between centers of adjacent array elements be less than $\lambda_H/2$, where λ_H is the free-space wavelength at the highest operating frequency. Consequently, a phased array of ultrawide bandwidth is a densely packed array, particularly at upper bound frequencies. A rigorous treatment on the planar array for radiation and scattering problems can be found in [13].

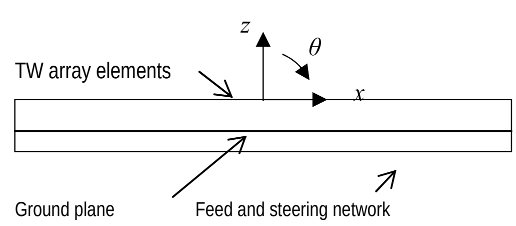

Figure 1: *Cross-sectional view of a planar array.*

The planar array is comprised of planar 2-D frequency–independent (FI) TW antenna elements positioned parallel to a conducting ground plane spaced less than $0.5\lambda_H$ between them. Adjacent antenna elements are arranged to be tightly coupled together or connected with each other.

FI planar antennas, such as the planar spiral antenna, the sinuous antenna, the log-periodic (LP) antenna, with truncation techniques to reduce them to practical finite sizes, represented a major progress for planar antennas made in the 1960s. Yet without a ground plane, these planar FI antennas typically employed a cavity on one side filled with lossy materials to absorb the undesired radiation on the other side of the bidirectional antenna.

The invention of the SMM (Spiral-Mode Microstrip) antenna [14-17] enabled the addition of a ground plane to FI planar antennas to suppress bidirectional radiation, which is essential to practical applications. The work in ensuing years gave rise to TW antennas and arrays having instantaneous bandwidth of up to 10:1 or more [e.g., 18].

To use the FI TW antenna as array elements, there are two design issues. First, it is preferable that the radiation takes place within the array element unit cell; particularly at upper frequencies. Second, there is a concern that residual power not efficiently radiated in an element could be absorbed in adjacent elements via coupling mechanism between them. The second issue could be serious at low frequencies where adjacent elements are closely spaced electrically.

With regard to the first issue, the design faces the fundamental gain-bandwidth limitation for an antenna constrained by its electrical size, which is known as the Chu limitation. Recently, it is shown by this author that there are shortcomings in the Chu limitation, in particular when applied to conformal TW antennas mounted on a platform [19], in which case octaval bandwidth of 10:1 or more could be achieved for self-complementary (SC) TW antennas [14].

With regard to the second issue, it was discovered six decades ago that antennas closely spaced less than 0.1λ, where λ is the operating wavelength, can radiate efficiently. This important phenomenon was first discovered by Brown [20] for parasitic arrays, and later by Kraus [21] for two out-of-phase antenna elements, and finally by Wheeler [1] for planar array effectively of infinitesimal elements and spacings.

Therefore, the foundation for the inherent broad bandwidth of closely spaced elements in the planar array was discovered many years ago, from Brown (1937) to Kraus (1940) to Wheeler (1965). Notably, they all observed that there is a potentially large bandwidth in a planar sheet of array elements, particularly those with an SC feature. Nevertheless, to realize a practical array, they have to add the necessary ground plane and to achieve the amplitude and phase distribution in the aperture current for the beam scan.

IV. Some empirical results of Planar TW arrays

Several models were designed, fabricated and tested. Figure 2 shows one of them based on LP dipole elements. Each array cell of the array is square (*abcd*) in shape, consisting of two LP dipoles, as shown in Figure 3. Only the center element is fed via a broadband balun across a pair of feed terminals. Each of the other 24 LP dipoles has a 100-ohm chip resistor load. All the 25 orthogonal LP dipoles have their feed terminals floating (open-circuit with no connection to other element or device).

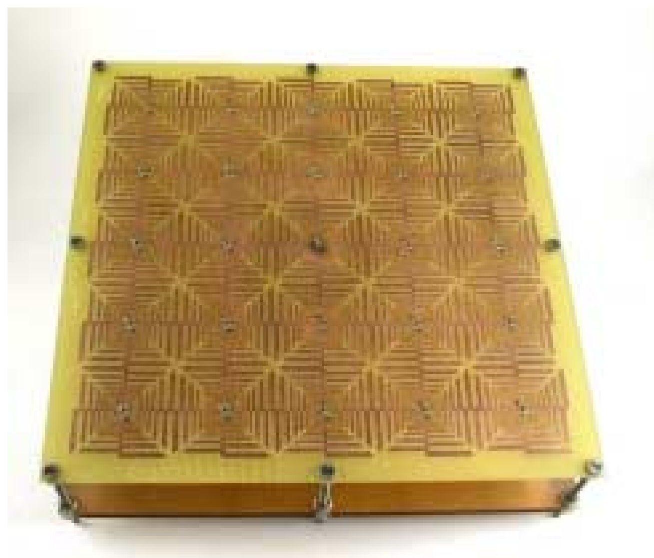

Figure 2: *A planar array based on LP dipole elements.*

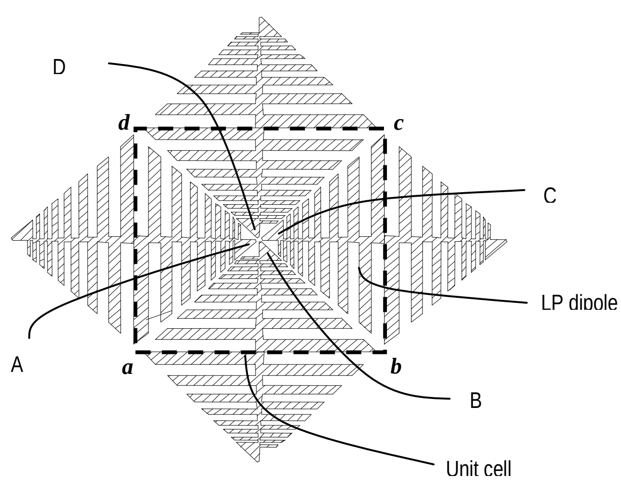

Figure 3: *Unit cell of the planar array in Fig. 2.*

As shown in Figure 3, there are four feed lines at the center of each element. Dual polarization or circular polarization can be achieved by feeding these four terminals (A, B, C, D) with proper phasing. However, in this model only one polarization (AC or BD) for each cell (*abcd*) is fed; therefore, the array has only a linear polarization.

The model was developed to measure the active element gain pattern of the array, which is an efficient and low-cost approach to assess the potential performance of a planar beam-steering phased array.

Figure 4 shows measured SWR of the 5×5-element array of Figure 2. As can be seen, the impedance match is fairly good since this research effort is in its infant stage, relatively new and small. There are several optimization techniques that can be applied to improve the impedance match.

The active element gain patterns, which take account of the mutual coupling and beam scan of a planar array, were measured. The active element gain pattern reveals the scan property of the element antenna, including both impedance matching and radiation pattern. The array gain pattern is then obtained from the active element gain pattern and the array factor.

Figure 5 shows the broadside array gain, in dBi, based on the measured active element gain pattern, of the 5×5-element array of Figure 2. The array gain is displayed in comparison with the theoretical gain limit for the aperture area of the array, given by $4\pi A/\lambda^2$, where A is the area of the array aperture.

As can be seen, the poor SWR around 2.2-2.8 GHz and 4-4.5 GHz in Figure 4 is reasonably consistent with the lowered gain in Figure 5, considering the early stage of the research. The discrepancies were probably due to fabrication errors, including the reactance of the chip resistors loading the passive array elements.

Another breadboard planar array model empirically studied, showing broadband potential, was a 113-element array shown in Figure 6. Since this model is not sufficiently self-complementary, further improvements are expected by using models of the sinuous type, as well as by optimizing the design. The 5×5-element array discussed earlier is not fully SC either. The choice of these planar FI structures not perfectly SC was largely due to the easiness in fabrication of these geometries which are formed solely by straight lines.

Thus, measurements on the impedance and active gain pattern of the two models indicate that this array has a potential of 10:1 bandwidth.

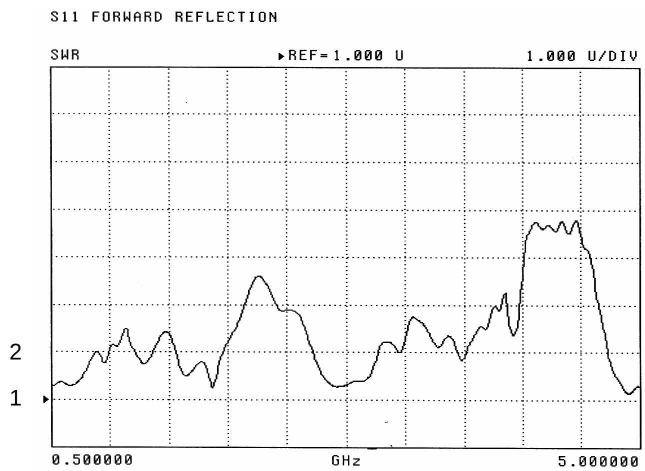

Figure 4: *Measured SWR of the 5×5-element array of Figure 2.*

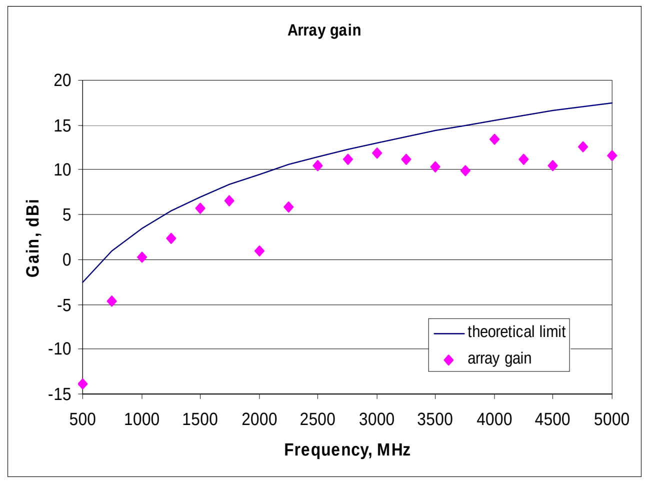

Figure 5: *Antenna gain of the 5×5-element array of Figure 2.*

Figure 6: *A planar array with 113 elements.*

V. Use of Dielectric or Magneto-Dielectric Substrates/Superstrates for Specific Performance Enhancement

The planar array's impedance property as well as radiation properties, such as broadening of the scan angle, can also be improved by employing layers of dielectric or magneto-dielectric substrates of various permittivity or permeability (between array elements and ground plane) and superstrates (above array elements).

Indeed, such techniques have been envisioned in TW element antennas per se. Specifically, magnetic substrates can be used for size reduction of planar TW antennas [22], and dielectric or magneto-dielectric substrates can be used to implement slow-wave antennas for miniaturization [23].

VI. Conclusions

A technique for planar broadband beam-steering phased array antenna has been conceived. Experimental data showed that it has the potential of achieving a bandwidth of approximately 10:1.

VII. References

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