Preface

THIS Special Issue on Conformal Arrays encompasses research and development that has been in progress for the past few years. Requirements for wide angle scanning and the need to eliminate radomes have led to this interest in conformal arrays, and some of the resulting work was reported at two conferences primarily devoted to this topic. These were held at the Naval Electronics Laboratory Center, San Diego, Calif., under the leadership of J. H. Provencher [1]–[4]. Recent efforts have been aimed in two major directions: 1) the implementation of experimental systems and prototypes and 2) the furtherance of research leading to a better understanding of beam steering, pattern synthesis, and mutual coupling.

The term conformal array has no unique definition. However, in most general terms it implies an array that is nonplanar. A more restricted but perhaps more exact definition postulates an array whose shape is dictated by the contours of a vehicle: the shape of the antenna is not at the disposal of the antenna designer. Thus one can visualize flush mounted arrays on aircraft, missiles, satellites, surface ships, and also fitted to the contours of the ground. The capability of electronically scanning the array is usually implied.

Since planar phased arrays have enjoyed a tremendous amount of research, development, and systems applications over the last two decades, many of the developments in conformal arrays have been extensions of the concepts for planar phased arrays. However, there are significant differences between planar and conformal arrays that make additional studies necessary. In the next few paragraphs the salient differences between planar and conformal arrays will be delineated.

Most developments on planar arrays have been concerned with arrays large in terms of wavelength, and for all practical purposes infinite in extent insofar as analysis of the behavior of the radiating elements is concerned. Thus each radiator has identical pattern and impedance properties. From this approximation, the "ideal" element concept has been formulated and applied; however, the infinite array approach does not apply to wide angle scanning or to scanning near endifre. Problems with "blind spots," surface waves and dielectric matching structures have been investigated. More importantly for the implementation of actual systems, feeding networks, phase shifters, their drivers, and scan controllers have been implemented. However, most applications involve one-of-a-kind ground based systems where weight, prime power, and even cost have been of secondary importance.

Conformal arrays, on the other hand, can take an infinite number of shapes depending on the particular surface that has to be fitted. Idealized shapes are usually employed to make analysis and initial design tractable; these include the cylinder, cone, ogive, sphere, and wedge. Wide angle scanning is required by many designs, for instance, hemispherical coverage from conical arrays and circumferential scanning from cylindrical arrays. For the most general case of wide angle scanning, beam steering for conformal arrays involves four significant differences from that in planar arrays.

1) Since the arrays are placed on curved bodies, not all the radiating elements contribute equally in the beam pointing direction. The noncontributing elements must be turned off for satisfactory pattern control and efficiency in gain.

2) The patterns of the elements point in different directions, thus the element pattern cannot be factored out from the array factor. Consequently, the usual synthesis techniques for planar arrays are not directly translatable to conformal arrays. There is no proven synthesis technique available for conformal arrays.

3) The radiating elements are in different environments. For instance, the radiators near the tip of a conical array are influenced by tip diffraction while those near the base of the cone are in an environment more akin to that for radiators on a cylinder. Because the surface is closed, the element patterns are influenced by the energy that is coupled around the back of the array.

4) Cross polarization is also a problem to conformal arrays. Since each radiator points in a different direction, the polarization vector from each radiator will not usually project in the same direction when viewed from the beam pointing direction. This characteristic is illustrated by three views of a conical array shown in Fig. 1. The slot radiators are located along generatrices and oriented to give linear polarization in the axial direction. With this orientation of the radiators, differing polarization would be radiated if the slot orientations were unchanged for other beam pointing directions. One solution is to use radiators with electronically controlled polarization that can be programmed with the beam steering. Cross polarization can be a major problem for tracking antennas since target depolarization will cause null shifts in difference patterns.

These characteristics will be pointed out and discussed in several contributions. Cylindrical arrays are chosen to fit the requirements of a 360° scan in azimuth with the axis of the cylinder vertically situated. Pattern shaping in the vertical plane is achieved by using linear arrays. The paper by A. E. Holley *et al.* discusses an application of a cylindrical array for a beacon using a minimum number of active devices. A rather unique antenna application to the TACAN (Tactical Air Navigation) problem is considered in two papers. The first one by E. J. Christopher outlines the principles of operation and the reasons for choosing an electronically scanned system in preference to a mechanically scanned one. The antenna is required

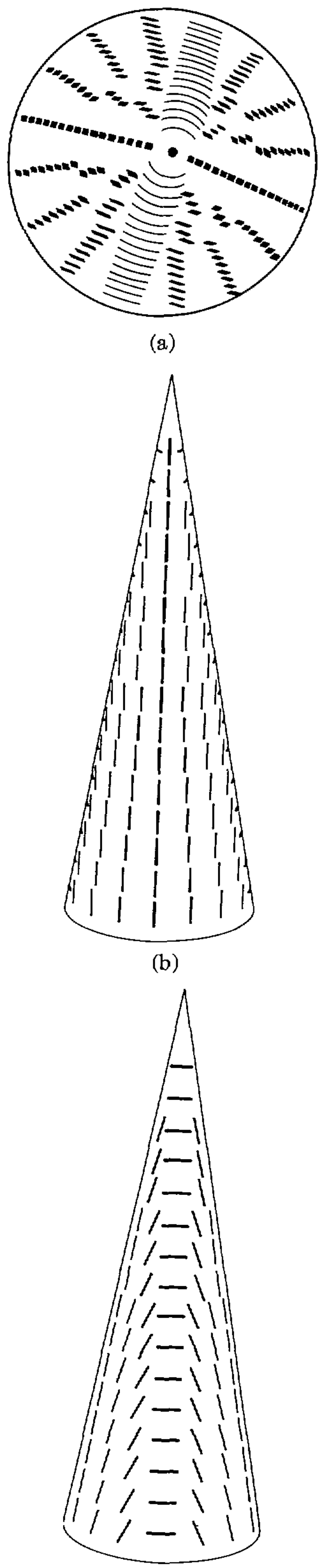

Fig. 1. Conical array. (a) View from axial direction. (b) Side view. (c) Side view rotated 90° from Fig. 1(b).

to generate rotating Limaçon patterns instead of a scanned pencil beam. The paper following, by L. Shestag, discusses an example of a complete system for that application. A communication by W. S. Gregorwich describes a flush mounted cylindrical satellite array that generates a despun pencil beam and operates over a 40 percent bandwidth.

A large cylinder can serve as an idealized shape for an array on the fuselage of large aircraft. The characteristics of radiators covered with a dielectric layer are considered by Q. Balzano, and it is shown that an approximate analysis is adequate for the computation of array element patterns. The use of microstrip techniques to form thin wraparound arrays is outlined by R. E. Munson. It foreshadows the development of low cost electronically scanned conformal arrays. The feeding of cylindrical arrays using a simplified approach is discussed by B. F. Bogner. An approximation to a cylindrical array consists of multifaceted set of planar arrays; the patterns resulting from this arrangement are discussed by J. K. Hsiao and A. G. Cha. Several papers cover the analysis of radiation characteristics from cylindrical arrays. These include a communication by J. D. Blass who presents an asymptotic formulation of the radiation field produced by harmonic excitation of a cylindrical array of directive radiators. J. F. Gobert and F. H. Yang show that patterns for arrays of revolution can be obtained for several types of radiators by a partial differentiation of the array space factor.

Extensive work by A. D. Munger *et al.* shows both experimental and theoretical results for patterns from conical arrays using dipoles as radiators. Comparisons are made with known results for cylindrical arrays. K. E. Golden *et al.* calculate the mutual admittances of slots on metallic cones; special attention is paid to the scattering from the tip. In the paper "Ray Analysis of Conformal Antenna Arrays" two general methods for mutual coupling between slots on cylindrical arrays are extended to slowly curved convex surfaces using geometric diffraction techniques. The paper "Design of a Small Conformal Array" deals with the excitation of a small conical body in order to obtain a minimum value of gain in the forward axial direction over an octave bandwidth. Element patterns in an array of waveguide elements on a cone are calculated using TM and TE modes for different matching techniques of the radiating elements in a communication by Q. Balzano and T. B. Dowling. The article by A. T. Villeneuve *et al.* covers the wide angle scanning of a linear array on a cone of 20° full cone angle. Measured patterns and admittances are compared to a simplified theoretical model.

Research and development that can be anticipated in the next several years include the development of general pattern synthesis techniques that take into account the radiation patterns and mutual coupling effects and the development of phase shifters and feeding techniques appropriate for these arrays. The advances in the use of integrated solid state transmitters, receivers, and phase shifters will need to be tailored to the requirements of conformal arrays so as to provide compact electronics that can fit in the back of every radiating element. For conformal arrays to eventually replace mechanically scanned antennas, more work is needed on ways to reduce production costs and increase components' reliability.

The publication of this Special Issue involved the coordination between the authors, reviewers, and guest editor with ever present deadlines. Thanks go to the authors for their prompt revision and return of the papers with the changes and additions suggested by the reviewers. The latter gave generously of their time and made positive suggestions and recommendations. The list of reviewers appears on the back page of this issue. Credit for handling the many letters and correspondence goes to my secretary, Yvonna Hartke. The processing and handling of the papers was undertaken by my wife, Mary.

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Guest Editor

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An Electronically Scanned Beacon Antenna

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***Abstract*—An electronically scanned cylindrical array having a minimum number of active devices has been designed. A saving of over 3 to 1 in diode elements as compared to conventional approaches has been achieved. In addition to providing instantaneous positioning to any azimuth direction, a constant azimuth beamwidth for an elevation fan beam has been realized. Extremely low azimuth sidelobes are obtained, and a straightforward synthesis procedure can provide elevation aperture designs to meet typical elevation pattern requirements. A modified Myer geodesic lens combined with a diode sequencing switch for coarse steering and a phased matrix feed for fine steering form the basis of the system. Sum and difference patterns show virtually no variation with scan or elevation angle and an omni-pattern is also available. Detailed pattern calculations as well as measured data on prototypes of key elements of the system are presented to verify the feasibility of the approach.**

I. INTRODUCTION

A PHASED array in the form of a right circular cylinder is particularly applicable to systems requiring continuous azimuth coverage such as beacon interrogation systems used for air traffic control. The beam shape requirements for such systems present a number of theoretical and practical problems to the design of this array. For typical applications, it is necessary that the azimuth beam shape not vary with steering and the beamwidth be constant along the elevation fan. Azimuth monopulse is necessary and sidelobes, particularly those in the horizon plane, must be minimized. A capability to generate omni-patterns is also desirable. An antenna system meeting all of these requirements and simultaneously minimizing the number of active devices required to implement electronic scanning has been designed with both theoretical investigations and detailed hardware evaluation of key components.

A cylindrical array composed of vertically oriented linear dipoles together with a geodesic lens and diode switching and phasing networks form the basis of the system. These components are interconnected with appropriate cables and diplexing units to form a complete radiating system capable of meeting the performance requirements of a typical beacon scanner. Fig. 1 shows the interrelationship of these components.

This design concept is not limited to beacon applications. The theory shows separability between the circumferential steering and the phasing of line sources making up the cylinder so that independent control of scanning in two dimensions is possible. A simple procedure is used for development of the required line source distributions for pattern control along the cylinder's axis so that various shaped or pencil beams may be generated as well as the fan described.

The design problems may be divided into two somewhat independent parts. Since the system is rotationally symmetric, the aperture distribution required to produce the desired beam shape may be determined analytically with the second design problem associated with the movement of this distribution around the array to produce the required scanning. It is the second problem which involves

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