COMPUTER SIMULATION AND OPTIMIZATION OF A PLANAR PHASED ARRAY OF CIRCULAR WAVEGUIDE ELEMENTS

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Abstract

Computer-aided optimizations using a Ritz-Galerkin boundary value solution to a planar phased array of circular waveguide elements are presented. Wide angle impedance matching (WAIM) is sought, and mutual coupling and polarization effects are noted.

Introduction

The concern of this paper is with antenna elements capable of producing circular polarization in a phased array environment and specifically with efforts to reduce mutual coupling and driving point impedance variations with scan angle which can lead to severe power and array efficiency losses as the array is scanned away from broadside. Methods exist for wide angle impedance matching, but most of them require quantitative knowledge of the behavior of array coupling with scan angle in order to be applied. To meet this need a digital computer simulation of an important class of radiating elements useful for circular polarization, circular waveguides, was developed independent of, yet similar to, the results of Amitay and Galindo[1]. To avoid duplication, their work is referenced for the analysis of an infinite array of circular waveguide radiators. Using our generalized simulation, wide angle impedance matching (WAIM) methods are employed and computer-aided optimum array designs are determined using Rosenbrock's pattern search method[2,3]. Optimization results are presented for a circularly polarized, equilateral triangular grid array designed for "best" impedance matching within a 120 degree scan cone. Dielectric cover sheets and waveguide plugs[6,7] are incorporated to obtain the matching. Bandwidth effects in the resulting designs are noted.

Wheeler summarized[4] that flush mounted circular elements offer many advantages for use in phased arrays including fit into triangular grids, suitability for circular polarization, reduction of coupling wave effects[5], aerodynamic smoothness, and amenability to simulation using waveguide arrays. The infinite planar array of circular waveguides shown in Fig. 1 are such elements, and this array has been analyzed and simulated on a digital computer with the following design flexibility:

1. Arbitrary Parallelogram grids (α,b,d).
2. Arbitrary dielectric constant in the waveguides (EPS).
3. Dielectric plugs or discs (EPS2, T2) in the waveguides for impedance matching.
4. Dielectric cover sheets (EPS3, T3; EPS4, T4; ...) over the array face for wide angle impedance matching (WAIM). Up to ten sheets can be used.
5. Scan in any direction (THETA, PHI) or across any scan plane.
6. Arbitrary polarization using crossed TE_{11} waveguides modes.

Computer-Aided Optimization Results

Initially, observations based on the results of many computer simulations were made to get physical insight into mutual coupling and impedance matching problems associated with an array of circular waveguide elements. Waveguide diameter, grid element spacing, dielectrics, polarization, and frequency were varied and reflection effects such as cross coupling between guide modes, broadside impedance match, and scan plane sensitivities were observed. The graphical results of some of these tests are contained in Figs. 2 to 4. From these runs it became apparent that the process of matching at broadside was difficult enough, but to choose array parameters to increase usable scan range while maintaining impedance match was next to impossible by human trial-and-error methods. As a consequence, computer optimization methods were investigated as a means for determining array parameters to give a good impedance match over wide scan angles. Optimization procedures (see Bandler[2] for a good survey) are generally separated into two groups: (1) gradient methods and (2) pattern search methods. Since this problem was analytically complex, gradient techniques were abandoned in favor of a pattern search technique originated by Rosenbrock[2,3,7].

In brief, Rosenbrock's method is a coordinate rotation system which for N variable parameters proceeds after each set of N coordinate searches to rotate the coordinates so that the initial increments in the next set of searches are along the N-vector direction determined by the previous N searches. After each successful move the step size is increased by a factor of three (qualitative choice of Rosenbrock), and a quadratic fit is applied after the first unsuccessful move to approximately locate the extremum. The result is an efficient pattern search that keeps the number of function evaluations from an initial set of "user-chosen" parameter values fairly low. As with most computer optimization techniques this one suffers from the fact that it cannot distinguish a local minimum from an absolute one.

In this application optimizations were made to minimize power loss due to impedance mismatch, and from two to four array parameters were allowed to vary. Arrays investigated had equilateral triangular grids and were intended for circularly polarized elements. The first optimization was for an array with a predicted grating lobe at $\theta = 54°$ since it economized on computer time and provided calibration[1]. Subsequently an array with spacings selected for a nominal 120° scan cone was optimized with attention given to polarization degradation. Reflection coefficients at points in the $\phi = 60°$ scan plane were used in optimization test functions since earlier results indicated that reflection peaks and cross coupling between modes tended to be pronounced in this plane. The results for some of the optimizations are summarized as follows (see Figs. 5 and 6):

1. For elements spaced 1.0 cm. apart and operating at a wavelength of 1.4 cm., dielectric plugs (T2 and EPS2) in air-filled waveguides (0.88 cm. diameter) were incremented subject to a test function of $|R_1|^2 + |R_2|^2$ at $\theta = 10°$ and 45°. The Rosenbrock selections reduced the reflection coefficient peak (R_1) to 0.37 and kept the reflected power in this mode under 4% over the rest of the scan range up to the vicinity of the 54° grating lobe peak.

2. Not using matching plugs or dielectric cover sheets but varying waveguide radius (AX) and dielectric fill (EPS) with the above grid, wavelength (1.4 cm.) and test function, the Rosenbrock subroutine chose AX = 0.4555 cm. and EPS = 1.495. With these parameters the

magnitude of the reflection coefficient peak was 0.34 and reflected power was below 5.3% elsewhere.

3. A significant improvement in match over the major portion of the scan range for the geometry in (1) was obtained when four parameters were varied by the Rosenbrock subroutine. In this case a dielectric cover sheet (reference 6) and guide discs were used for matching with the resulting choices being T2 = 0.742 cm., EPS2 = 1.19, T3 = 0.127 cm., and EPS3 = 1.57. The test function was $|R_1(10°)| + |R_1(54°)|$. The scan for this design showed a slight resonant peak of 11% reflected power at $\theta = 43°$, but reflections were lowered to an almost negligible level of under 0.3% over the scan range away from the peak and were under 0.3% at the grating lobe angle of 54°.

4. Excellent impedance match was also obtained for an array with a grid spacing of 0.62 cm. at a wavelength of 1.0 cm. (grating lobes at $\pm 60°$). The Rosenbrock design using waveguide plugs for matching is given in Fig. 6 where the reflection loss is a maximum of 0.8 dB at $\theta = 60°$.

References

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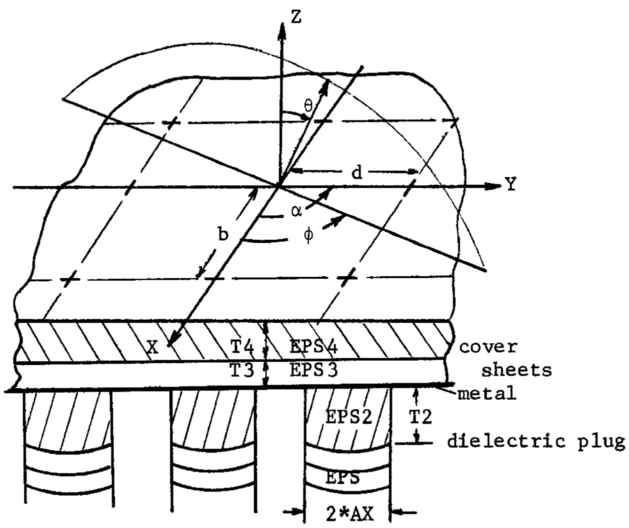

FIG. 1. DIELECTRIC COVERED ARRAY OF CIRCULAR WAVE-GUIDE ELEMENTS

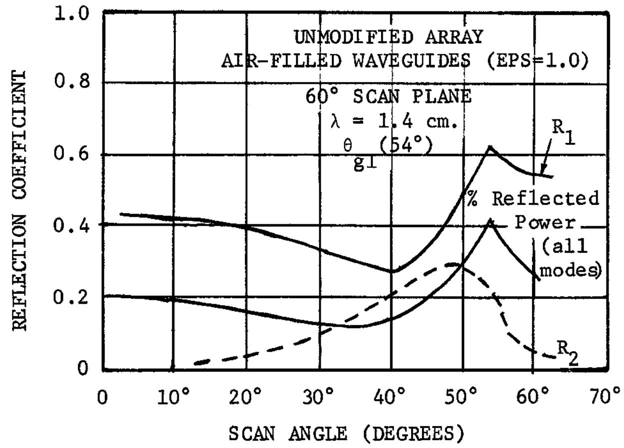

FIG. 2. ARRAY WITH AIR-FILLED GUIDES: 60° SCAN PLANE, a=0.44, λ=1.4, EPS=1.0, b=d=1.0

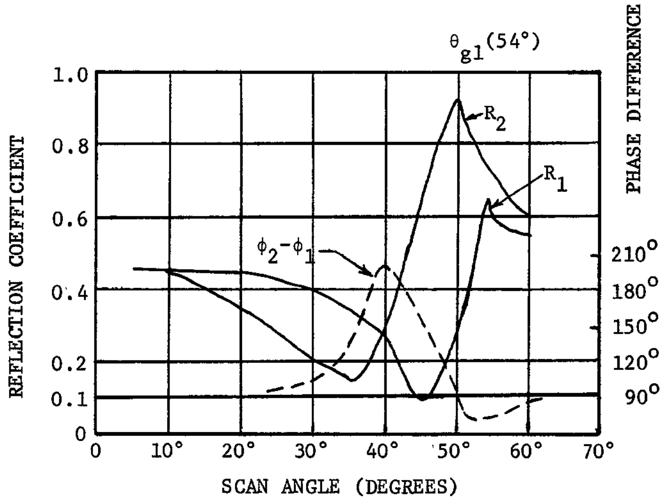

FIG. 3. CIRCULARLY POLARIZED ARRAY OF CIRCULAR WAVE-GUIDE ELEMENTS

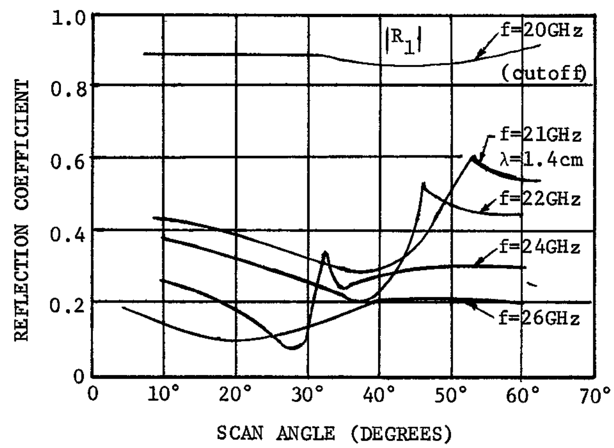

FIG. 4. FREQUENCY SCANNED ARRAY OF AIR-FILLED GUIDES: a=0.44 cm., EPS=1.0, b=d=1.0cm.

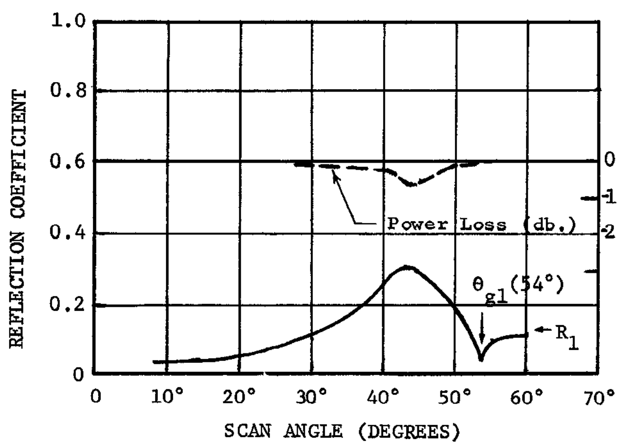

FIG. 5. OPTIMIZED ARRAY WITH COVER SHEET AND DIELECTRIC PLUGS FOR MATCHING a=0.44, b=d=1.0, EPS=1.0, EPS2=1.189, T2=0.742, EPS3=1.57, T3=0.127

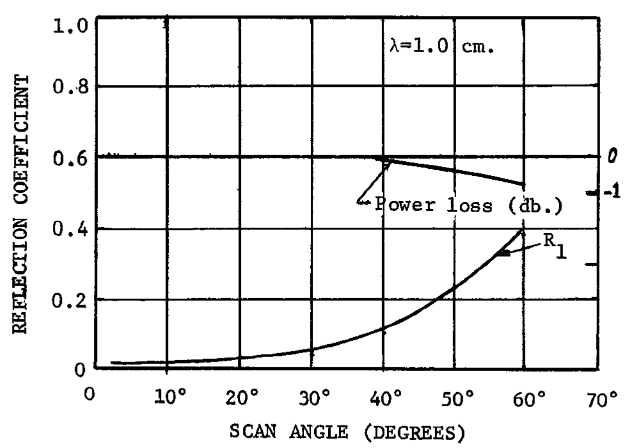

FIG. 6. 60° SCAN PLANE: ROSENBROCK SELECTION OF DIELECTRIC PLUGS a=0.29cm., b=d=0.62cm., λ=1.0cm., EPS=2.0, T2=0.37cm., EPS2=1.26