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Super Directive Radiation Patterns from Designed Arrays

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Abstract: ***Super directive arrays have been considered unrealizable due to the high elemental currents required and their sensitivity to small variations in amplitude and phase. Efficient superdirective array functions can be generated using an optimized polynomial technique. Methods for the generation of these functions are investigated and the effects of changing the number of elements and array length on the different array parameters are studied. The results of generated super directive patterns are presented in this paper.***

Keywords: Arrays, beam width, transformation, polynomial, cheybyshev polynomial

1. Introduction

Any array with a direct significantly greater than that of a uniform array is a *superdirective* or *supergain* array.The optimized polynomial technique was successfully used to generate efficient superdirective radiations patterns for broadside arrays[1].

Composite polynomial based on Chebyshev polynomials were used, where the coefficients were optimized in the sense of reducing the ripples of polynomial in its range corresponding to the invisible region. The resulting radiation patterns possess higher directivities than the corresponding uniform array while maintaining high radiation efficiencies and tolerances to small variations in the amplitude and phase[2]. The optimized polynomial approach has to be extended to the design of efficient superdirective end fire arrays. Considerable reduction in the beam width of end fire arrays was expected due to the inherent wide beam width of the corresponding uniform case. The reduction in the beam width was combined with high radiation efficiency.

In this original form, the Dolph-Chebyshev array synthesis technique[3] does not generate superdirective functions in the sense of providing a main beamwidth narrower than the uniform beamwidth without increased sidelobes. However, Riblet noticed that, for elemental spacing less than $\lambda/2$, directivity could be further increased. This superdirective regime is always characterized by antiphase currents in the elements of broadside arrays , and the phenomenon is therefore obtained when employing Schelkunoff's method for generating array functions with arbitrarily high directivity [4].

There are two fundamental problems to be overcome in the design of a superdirective array antenna. First is the sensitivity of the superdirective illumination function to changes in elemental values. Second is the mutual coupling which must exist between radiating elements with a physical size. This second problem will interact with the first problem to render the superdirective design inoperative in most cases. If the sensitivity of the illumination function itself could be sufficiently reduced, then superdirective arrays might be realized physically since the effects of mutual coupling can be suppressed, either by suitable feed network and the element design or by using active elements.

The general problem of optimizing array directivity has been considered by several authors, notably Cheng[7] and Tai[8]. However, their methods are unsuitable for generating physically realizable superdirective arrays, since they produce illumination functions which give rise to extremely small radiated fields despite the large element currents and therefore produce low radiation efficiencies. Consequently, these functions are intolerant to the small changes in elemental values. Hence, generation of array polynomials which not only produce radiation patters characterized by substantial reduction in the 3-dB points beamwidth without increasing sidelobe level over that of the uniform case but also maximize radiation efficiency. As a bonus the optimum conditions will be seen to occur at an element spacing which minimizes the mutual coupling problem in the superdirective array.

2. Generation of Efficient Superdirective Array Functions

Dolph used Chebyshev polynomials to represent the array factor of a linear broadside array factor of a linear broadside array of equispaced point sources .The generated radiation patterns are optimum in the sense that they have either the minimum beamwidth for a specified sidelobe level or the lowest sidelobe level when the beamwidth is specified. These results only apply when the array elements is equal to, or greater than, half-wavelength. Riblet extended Dolph's theorems to include spacing d< λ /2, he showed that increased directivity may be obtained by subjecting the abscissa to the translation and the change of scale which places all the ripples of the corresponding polynomial $T_K(x)$ in the visible range of x. This procedure only applies to linear arrays of odd number of elements, since a Chebyshev polynomial T_K (x) represents an array of (2K+1) elements.

Consider the example of the polynomial T_5 (X).

$$\mathbf{T_5(X) = 16x^5 - 20x^3 + 5x \quad --- (1)}$$

The optimized polynomial approach is used to generate efficient and realizable superdirective radiation patterns. The utilization of this technique in the design of endfire arrays is achieved through the use of Legendre and Chebyshev polynomials of variable x. The two classes of polynomials have some common properties which include the presence of ripples in the range |x| <1 and growing proportional to x^n for |x| <1 , where n is the order of the polynomial. They also satisfy the condition

$$P_n(x) = T_n(x) = 1, \text{ for } x=1$$

for all n where $P_n(x)$ denotes Legendre polynomial of order n and $T_n(x)$ is Chebyshev polynomial of order n.

The optimized polynomial design procedure is based on the equivalence between the polynomial representation of the array factor [AF(ψ)] and a general polynomial F(x) of the appropriate degree. The array factor of an array with odd number of element (N) is given by

$$AF(\psi) = A_0 + 2\sum_{n=1}^{N-1/2} A_n \cos n\psi \qquad (2)$$

And the general polynomial is given by

$$F(x) = \sum_{p=0}^{M} B_p x^p \qquad (3)$$

Where the coefficients B_p are chosen according to Legendre or Chebyshev polynomials of the same order M. These coefficients may also be optimized in such a way as to achieve certain radiation pattern characteristics. The correspondence between the two polynomials is achieved through the use of the transformation.

$$x = a\cos\psi + b \qquad (4)$$

Where the coefficients a and **b** are selected in order to achieve the correspondence over a given certain range of the variable x which covers all the roots of the polynomial. The procedure is illustrated by the following example, in which we determine the performance of a two wavelengths-11-element array .

$$P_5(x) = \frac{1}{8}[63x^5 - 70x^3 + 15x] \qquad (5)$$

3. Results and Conclusions

Using equation (1), The transformation of cheybyshev polynomial computed and results are represented in fig(1). Choosing a separation between elements d= λ /2 and a -13.3dB sidelobe level. Using equation (5) the pattern of legendre polynomial computed and results presented in fig (2). The radiation patterns of uniform array and legendre array are presented in figures (3-4).

The directivity of legendry polynomial is better than uniform array. Legendre polynomials preferred for sidelobe levels not exceeding 20 dB. Radiation efficiency is the dominant requirement. A greater number of elements permits greater beam width reduction at the expense of radiation efficiency.

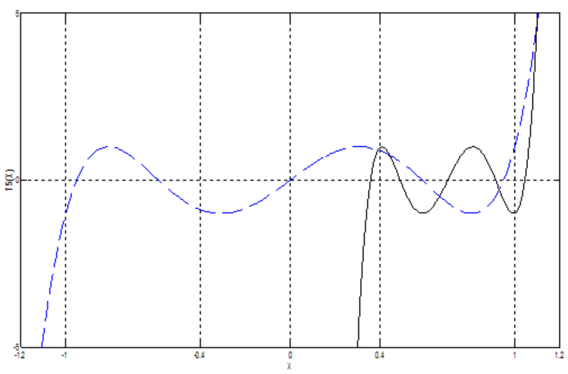

Figure 1: Pattern of transformation of Chebyshev polynomial

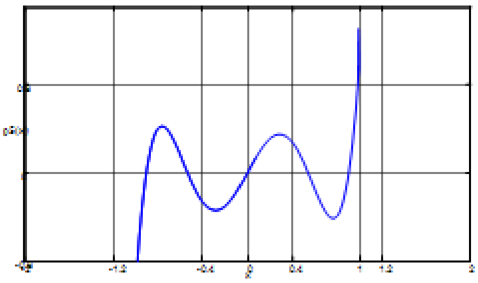

Figure 2: The pattern of legendre polynomial P5(x)

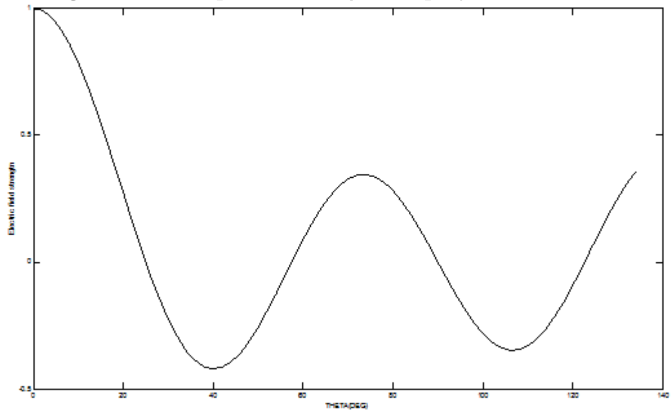

Figure 3: Radiation pattern of uniform array

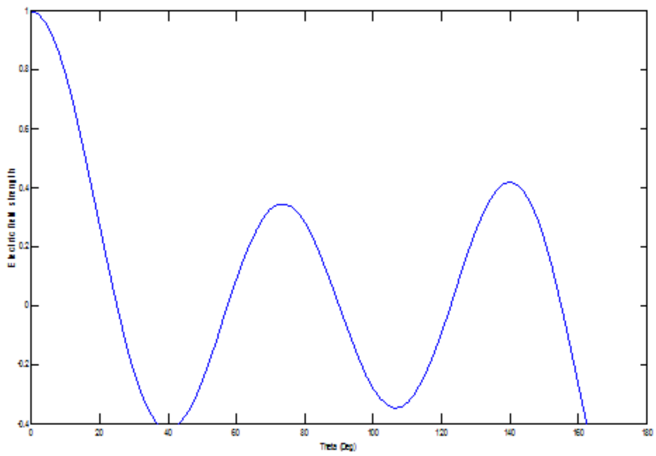

Figure 4: Radiation pattern of Legendre array

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