Synthesis of Uniform Amplitude Focused Beam Arrays

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***Abstract*—An iterative algorithm to synthesize uniform amplitude focused beam arrays is presented. While the number of array elements and the excitations are fixed and known, the locations of the elements are optimized to radiate a narrow beam low sidelobe pattern. The method can be applied to both linear and planar arrays composed of elements having arbitrary radiation patterns. Although any excitation can be considered, elements having the same fixed amplitude and phase are targeted because of their pratical interest. On top of being easy to implement, the proposed procedure leads to array designs that compare favorably to solutions found in the literature.**

***Index Terms*—Antenna arrays; antenna synthesis; convex optimization**

I. Introduction

The use of antenna arrays is often limited by the complexity of the beamforming network. In order to simplify the array implementation, one solution is to minimize the number of amplifiers and phase shifters [1]. Therefore, many approaches mainly based on global optimization algorithms [2] and deterministic techniques [3] have been proposed to synthesize uniform amplitude arrays, i.e. arrays with uniform amplitude and equi-phase excitations.

In this paper, a method is presented to synthesize uniform amplitude arrays that radiate a focused beam. Specifically, the goal is to optimize the locations of a fixed number of array elements with known excitations in order to generate a pattern having the lowest possible sidelobes for a given beamwidth. An iterative algorithm that consists in solving a sequence of convex optimization problems is proposed to achieve this purpose.

II. Problem Formulation and Resolution

A. Antenna Array Synthesis Problem

Let us consider a linear array composed of N elements. Each element radiates a pattern $g_n(\theta)$ and is fed by a complex excitation w_n, with $n = 1, \cdots, N$. In the synthesis problem, both $g_n(\theta)$ and w_n are fixed whereas the element locations x_n are left free. In practice, a very interesting specific case is the synthesis of so-called uniform amplitude arrays, i.e. arrays with excitations of the same magnitude and phase: $|w_n| = A$ and $\angle w_n = \Phi_0 \; \forall n$, where A and Φ_0 are arbitrary constants.

For the sake of clarity but without any loss of generality, one considers uniform amplitude arrays of excitation $w_n = 1/N$ that are composed of isotropic elements $g_n(\theta) = 1$. The far field $f(\theta)$ radiated by such linear array is then:

$$f(\theta) = \frac{1}{N} \sum_{n=1}^{N} e^{j \sin \theta x_n}, \tag{1}$$

where x_n are the element locations in wavelengths.

The sidelobe region S where the magnitude of the field is upper bounded by an envelope $e(\theta, \varphi)$ is introduced. This envelope is considered equal to a constant ρ in the following. The complementary domain of S defines the main beam region and therefore the main beam width. Since the magnitude of the field is equal to one towards broadside, $|f(\theta = 0)| = 1$ (see (1)), the synthesis problem amounts to find the element locations x_n that minimize ρ over S. This problem can be written:

$$\min_{\boldsymbol{x}} \; \rho, \quad \text{under} \quad \sup_{\theta \in S} |f(\theta)| \leq \rho \tag{2}$$

where $\boldsymbol{x} = (x_1, ..., x_N)$ is the N dimensional vector composed of the array element locations to be determined. This optimization problem is not convex and difficult to solve in an optimal way.

B. Resolution Method

An iterative method to solve the problem (2) and therefore to synthesize uniform amplitude focused beam array has been developed. The algorithm, detailed in [4], consists in solving a sequence of convex optimization problems. It is easy to implement, calls for readily available routines and is computationally effective. The method is here applied to synthesize uniform amplitude linear arrays.

III. Numerical Applications - Comparisons with Other Approaches

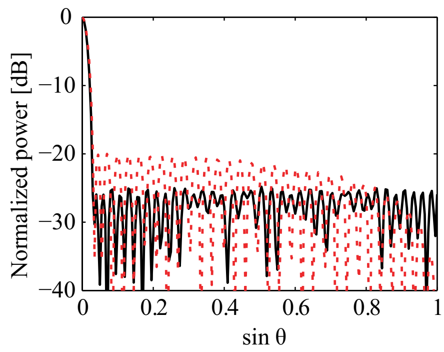
Numerical comparisons with results available in the literature are presented to assess the validity of the proposed procedure. Note that all simulations are carried out on a 2.93 GHz-CPU 8 Go-RAM computer.

A. Comparison with a Deterministic Approach

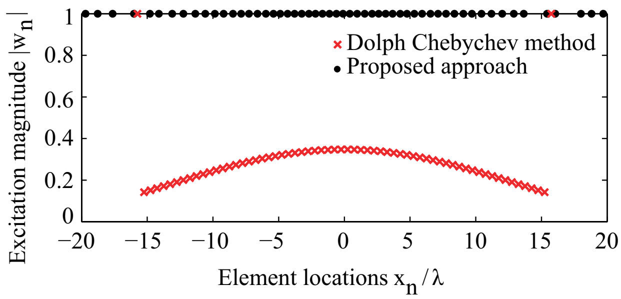
A deterministic approach has been presented in [3] to synthesize uniform amplitude arrays. Thus the locations of a 55 element uniformly excited array with element pattern

$g_n(\theta) = \cos\theta$ have been optimized. The reference source is a Dolph Chebychev array [5] composed of 64 half wavelength spaced elements radiating a pattern with maximum sidelobes of -20 dB.

The proposed approach is applied to synthesize a narrow beam low sidelobe pattern having the same beamwidth $\sin\theta_s = 0.03$ with an uniformly excited array of 55 elements. A maximum sidelobe level of -25.9 dB is obtained, i.e. a reduction of 5.9 dB is achieved as shown in the far field patterns of Fig. 1(a). The optimized element locations and excitation magnitudes are plotted in Fig. 1(b).



(a)



(b)

Fig. 1. Results of the synthesis of an uniformly excited array composed of 55 elements: (a) far fields using the proposed procedure (solid line) and the Dolph Chebychev method [5] (dotted line) and (b) optimized element locations and excitation magnitudes.

B. Comparison with a Global Optimization method

An hybrid genetic algorithm - conjugate gradient method is proposed in [2] to synthesize a linear uniform amplitude array composed of 20 elements. The main beam width is set to 16° and the sidelobe levels are minimized. A maximum sidelobe level of -24.9 dB is obtained with this global optimization method. Similar radiation performances (i.e. same sidelobe level) are achieved with the proposed procedure, as shown in the far field patterns of Fig. 2, in less than 30 s.

IV. Conclusion

An iterative method to synthesize uniform amplitude focused beam arrays has been proposed. Each iteration of the algorithm simply requires solving a convex optimization problem, which means that many readily available routines

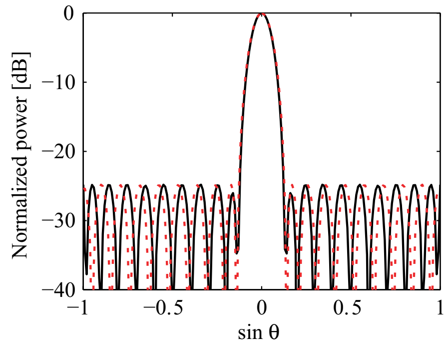


Fig. 2. Narrow beam low sidelobe synthesis of uniform amplitude arrays composed of 20 elements for a 16°beamwidth. Far field patterns synthesized with the proposed iterative approach (solid line) and via genetic algorithm - conjugate gradient (dashed line) [2].

can be used to efficiently solve the problem. On top of being easy to implement and computationally effective, the method can be applied to synthesize both linear and planar arrays and there is no restriction regarding the element patterns.
While the optimality of the solution can not be guaranteed, the performances of the synthesized designs compare favorably to solutions found by previously proposed approaches.

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