Journal of King Saud University – Computer and Information Sciences (2013) **25**, 117–126

King Saud University

Journal of King Saud University – Computer and Information Sciences

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ORIGINAL ARTICLE

A genetic algorithm for the level control of nulls and side lobes in linear antenna arrays

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Received 3 January 2012; revised 4 June 2012; accepted 26 June 2012
Available online 4 July 2012

KEYWORDS

Side lobe level;
Deeper nulls;
Real coded genetic algorithm;
Linear antenna array;
First null beam width

Abstract The design problem of imposing deeper nulls in the interference direction of uniform linear antenna arrays under the constraints of a reduced side lobe level (SLL) and a fixed first null beam width (FNBW) is modeled as a simple optimization problem. The real-coded genetic algorithm (RGA) is used to determine an optimal set of current excitation weights of the antenna elements and the optimum inter-element spacing that satisfies the design goal. Three design examples are presented to illustrate the use of the RGA, and the optimization goal in each example is easily achieved. The numerical results demonstrate the effectiveness of the proposed method.

1. Introduction

An antenna array is composed of an assembly of radiating elements in an electrical or geometrical configuration. In most cases, the elements are identical. The total field of the antenna array is found by vector addition of the fields radiated by each individual element. Five controls in an antenna array can be used to shape the pattern properly: the geometrical configuration (linear, circular, rectangular, spherical) of the overall array, the spacing between the elements, the excitation amplitude of the individual elements, the excitation phase of the individual elements, and the relative pattern of the individual elements (Ballanis, 1997; Elliott, 2003). Many communication applications require a highly directional antenna. Array antennas have higher gain and directivity than an individual radiating element. A linear array consists of elements placed in a straight line with a uniform spacing between the elements (Haupt and Werner, 2007). The goal of antenna array geometry synthesis is to determine the physical layout of the array that produces a radiation pattern that is closest to the desired pattern.

The increasing amount of electromagnetic pollution has prompted the study of array pattern nulling techniques. These techniques are important in radar, sonar and communication systems to minimize degradation of the signal to noise ratio due to undesired interference (Haupt and Werner, 2007). Much current research on antenna arrays (Haupt, 1997; Steyskal et al., 1986; Yang et al., 2004; Mandal et al., 2010; Guney and Akdagli, 2001) is focused on using robust and easily adapted optimization techniques to improve the nulling performance. Classical gradient-based optimization methods are not suitable for improving the nulling performance of linear antenna arrays for several reasons, including the following:

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Peer review under responsibility of King Saud University.

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http://dx.doi.org/10.1016/j.jksuci.2012.06.001

(i) the methods are highly sensitive to the starting points when the number of variables, and hence the size of the solution space, increases, (ii) they frequently converge to local optimum solutions, diverge or arrive at the same suboptimal solution, (iii) they require a continuous and differentiable objective function (gradient search methods), (iv) they require piecewise linear cost approximation (linear programming), and (v) they have problems with convergence and algorithm complexity (non-linear programming). Thus, evolutionary optimization methods have been employed for the optimal design of deeper nulls. Different evolutionary optimization algorithms, such as fuzzy logic (Mukherjee and Kar, 2012; Anooj, 2012; De and Sil, 2012), the bees algorithm (Fahmy, 2012), the genetic algorithm (GA) (Haupt and Werner, 2007), and particle swarm optimization (PSO) (Mandal et al., 2012), have been widely used in the development of design methods that are capable of satisfying constraints that would otherwise be unattainable. Of these algorithms, GA is a promising global optimization method for the design of antenna arrays.

Several methods for the synthesis of array antenna patterns with prescribed nulls are reviewed below. A method for null control and the effects on radiation patterns is discussed in Steyskal et al. (1986). An approach of null control using PSO, where single or multiple wide nulls are generated by optimum perturbations of the elements' current amplitude weights to create symmetric nulls about the main beam, is discussed in Mandal et al. (2010). An approach for the pattern synthesis of linear antenna arrays with broad nulls is described in Guney and Akdagli (2001). In Yang et al. (2002), a differential evolution algorithm is used to optimize the static-mode coefficients and the durations of the time pulses, leading to a significant reduction of the sideband level. A binary coded genetic algorithm is used in Haupt (1995, 1975) and Yan and Lu (1997) to reduce the sidelobe level of a linear array by excitation coefficient tapering. The spacing is assumed to be equal to half of the wavelength throughout the array aperture. The study shows good sidelobe performance (approximately -33 dB) for a 30 element array. The radiation pattern of linear arrays with large numbers of elements (20–100) is improved using a GA in Ares-Pena et al. (1999). The sidelobes for 20 and 100 element arrays are reduced to -20 dB and -30 dB, respectively. A decimal GA technique to taper the amplitude of the array excitation to achieve reduced side lobe and null steering in single or multiple beam antenna arrays is proposed in Abdolee et al. (2007). In Son and Park (2007), a low-profile phased array antenna with a low sidelobe was designed and fabricated using a GA. The sidelobe level was suppressed by only 6.5 dB after optimization. An approach for sidelobe reduction in a linear antenna array using a GA is proposed in Recioui et al. (2008), Das et al. (2010). In Das et al. (2010), the sidelobes for symmetric linear antenna arrays are reduced without significantly sacrificing the first null beamwidth, and non-uniform excitations and optimal uniform spacing are proposed generate the desired result. Optimal values are found using the real-coded genetic algorithm (RGA). An approach to determine an optimum set of weights for antenna elements to reduce the maximum side lobe level (SLL) in a concentric circular antenna array (CCAA) with the constraint of a fixed beamwidth is proposed in Mandal et al. (2009), Mondal et al. (2010). In (Cafsi et al. (2011), a method of adaptive beamforming is described for a phased antenna array using a GA. The algorithm can determine the values of phase excitation for each antenna to steer the main beam in specific directions.

The goal of this paper is to introduce deeper null/nulls in the interference directions and to suppress the relative SLLs with respect to the main beam with the constraint of a fixed first null beam width (FNBW) for a symmetric linear antenna array of isotropic elements. This is done by designing the relative spacing between the elements with a non-uniform excitation over the array aperture. An evolutionary technique, the RGA (Haupt and Werner, 2007; Haupt, 1995; Holland, 1975), is used to obtain the desired pattern of the array. Several aspects of the RGA are different from other search techniques. First, the algorithm is a multi-path technique that searches many peaks in parallel and hence decreases the possibility of local minimum trapping. Secondly, the RGA only needs to evaluate the objective function (fitness) to guide its search. Hence, there is no need to compute derivatives or other auxiliary functions, so the RGA can also minimize the non-derivable objective function. Finally, the RGA explores the search space where the probability of finding improved performance is high.

A broadside uniform linear array with uniform spacing is considered. The array is symmetric with respect to the origin with equal spacing between any two consecutive elements. The phase difference between any two elements is fixed at zero. The RGA adjusts the excitation coefficients and location of the elements from the array center to impose deeper nulls in the interference directions. A cost function is defined that keeps the nulls and side lobes at lower levels.

The remainder of the paper is arranged as follows. In Section 2, the general design equations for a non-uniformly excited and unequally spaced linear antenna array are stated. A brief introduction to the Genetic Algorithm is presented in Section 3, and the numerical simulation results are presented in Section 4. The paper concludes with a summary of the work in Section 5.

2. Design equation

A broadside linear antenna array (Ballanis, 1997; Elliott, 2003) of $2M$ isotropic radiators, as shown in Fig. 1, is considered. Each element is excited with a non-uniform current. The array elements are assumed to be uncoupled and equally spaced along the z-axis, and the center of the array is located at the origin. The array is symmetric in both geometry and excitation with respect to the center.

The radiation characteristics of antennas are most important in the far field (*Fraunhofer*) region. An array consisting of identical and identically oriented elements has a far field radiation pattern that can be expressed as the product of the element pattern and a factor that is widely referred to as the array factor. Each array has its own array factor. The array factor, in general, is a function of the number of elements, their geometrical arrangement, their relative magnitudes, their relative phases, and their relative spacings. Because the array factor does not depend on the directional characteristics of the radiating elements, it can be formulated by replacing the actual elements with isotropic (point) sources. For the array in Fig. 1, the array factor, $AF(I, \varphi, d)$ Ballanis, 1997; Elliott, 2003 in the azimuth plane (x–y plane) with symmetric amplitude distributions (Ballanis, 1997) may be written as (1):