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Design of coherently radiating structures in a linear array geometry using genetic algorithms

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Abstract

The design problem of coherently radiating structures in a linear array geometry is dealt with. The key idea is to accept the unavoidable presence of the mutual coupling between antenna elements but force it to be coherent by including additional passive elements in between the active ones. This design of coherently radiating structures considers the optimization of the spacing between antenna elements by using the well-known method of genetic algorithms. Simulation results for coherently radiating structures with uniform and non-uniform separation are provided. A comparative analysis of the performance of different coherently radiating structures is achieved in order to set new design philosophies in antenna arrays.

Keywords: Coherently radiating structures; Mutual coupling; Genetic algorithms; Array factor; Linear array

1. Introduction

One of the most important challenges designing an antenna array is the mutual coupling between elements [1–6]. In many applications the design of the antenna array is set in order to avoid or reduce the mutual coupling between elements. However, the mutual coupling in antenna arrays is unavoidable or is not totally under control. In this paper, the key idea is to accept the unavoidable presence of the mutual coupling between antenna elements but force it to be coherent (in phase) by including additional passive radiating elements in between the active ones. These coherently radiating structures consist in using the same type and size of radiating elements used in the array to retain the power under the active elements, i.e., we should force the same dimensions for the passive and the active elements (so that they radiate equally and coherently at resonance). Then, the power coupled to the passive elements will be re-radiated by them, since they are tuned to resonate at the same frequency. Because of the included coupling mechanism, the power finally transferred to the passive elements arrives in phase, and hence the radiation of these passive elements will be coherent with the radiation of the active one form which the power was coupled. The purpose of this paper is to investigate the behavior of the radiation pattern for the design of coherently radiating structures considering the optimization of the spacing between antenna elements by using the well-known method of genetic algorithms (GAs) [7–11]. Due to the great variety of parameters involved, optimization techniques such as GAs are very appropriate tools to search for the best antenna array models. In this paper we apply GA techniques to the design of coherently radiating structures in a linear geometry considering a non-uniform spacing between antenna elements. This work considers the design of coherently radiating structures to be a problem optimizing a simple objective function. This objective function considers the synthesis of the radiation diagram with desired characteristics of the side lobe level and the directivity.

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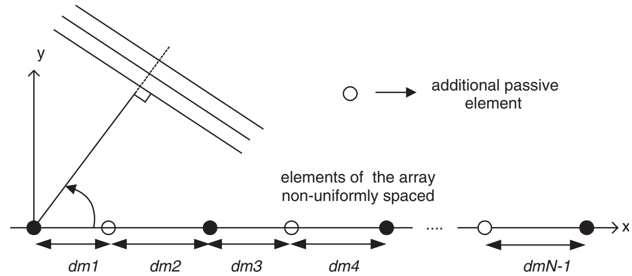

Fig. 1. Coherently radiating structure in a linear geometry with antenna elements non-uniformly spaced.

The contribution of this paper is to present a model for the design of coherently radiating structures that includes the synthesis of the radiation diagram using the method of GAs.

The remainder of the paper is organized as follows. Section 2 states the antenna array design problem we are dealing with and a description of the objective function used by the genetic algorithm is presented. Following this description the experimental setup and results are presented in Section 3. Finally, the summary and conclusions of this work along with some future line of research are presented in Section 4.

2. Problem statement

2.1. Theoretical model

Consider a coherently radiating structure in a linear geometry with N antenna elements non-uniformly spaced, as shown in Fig. 1. If the elements in the linear array are taken to be isotropic sources, the radiation pattern of this array can be described by its array factor [12]. The array factor for the linear array in the x–y plane is given by [13]

$$AF(\theta, \mathbf{I}, \mathbf{dm}) = \sum_{n=1}^{N} I_n \exp(jkd_n \cos(\theta)), \tag{1}$$

where $\mathbf{I} = [I_1, I_2, \ldots, I_N]$, I_n represents the excitation of the nth element of the array, $\mathbf{dm} = [dm_1, dm_2, \ldots, dm_{N-1}]$, dm_n represents the distance from element n to element $n+1$, i.e., $d_1 = 0$; $d_2 = dm_1$; $d_3 = d_2 + dm_2$; $d_4 = d_3 + dm_3$; ...; $d_N = d_{N-1} + dm_{N-1}$, $k = 2\pi/\lambda$ is the phase constant, θ is the angle of incidence of a plane wave, λ is the signal wavelength.

The excitations I_i $(i = 1, \ldots, N)$ at the input terminals are related to the terminal voltages of the antenna elements by the impedance matrix $\mathbf{Z}$:

$$\mathbf{V} = \mathbf{I} \cdot \mathbf{Z}, \tag{2}$$

where $\mathbf{V} = [V_1, V_2, \ldots, V_N]$, $I = [I_1, I_2, \ldots, I_N]$ and

$$\mathbf{Z} = \begin{bmatrix} Z_{11} & Z_{12} & \cdots & Z_{1N} \\ Z_{21} & Z_{22} & \cdots & Z_{2N} \\ \vdots & & \ddots & \vdots \\ Z_{N1} & Z_{N2} & \cdots & Z_{NN} \end{bmatrix}. \tag{3}$$

Through (2), the terminal voltage of any one element can be expressed in terms of the currents flowing in the others:

$$V_n = \sum_{i=1}^{N} Z_{in} I_i, \quad n = 1, \ldots, N, \tag{4}$$

where Z_{in} is the mutual impedance between elements i and n; Z_{ii} is the self impedance of element i.

In general, numerical techniques such as method of moments can be used to obtain the mutual impedance matrix $\mathbf{Z}$. For dipoles, however, $\mathbf{Z}$ can be determined using classical induced electromotive force (EMF) method. This method has the advantage of being more efficient than a numerically rigorous MoM technique while, at the same time, yielding results that are comparable in accuracy [11]. These properties of the induced EMF method make it attractive for use in conjunction with a GA. For the side-by-side configuration and dipole lengths $l = \lambda/2$, an element of the mutual impedance matrix Z_{in}, where $1 \leqslant i, n \leqslant N$, is given by [13]

$$Z_{in}(d_{in}, l) = 30M_1 + j[30S_i(2kl)], \quad i = n, \tag{5}$$

$$Z_{in}(d_{in}, l) = 30M_2 + j30M_3, \quad i \neq n, \tag{6}$$

where

$$M_1 = 0.5772 + ln(2kl) - C_i(2kl), \tag{7}$$

$$M_2 = 2C_i(u_0) - C_i(u_1) - C_i(u_2), \tag{8}$$

$$M_3 = 30[2S_i(u_0) - S_i(u_1) - S_i(u_2)], \tag{9}$$

$$u_0 = kd_{in}, \tag{10}$$

$$u_1 = k\left(\sqrt{d_{in}^2 + l^2} + l\right), \tag{11}$$

$$u_2 = k\left(\sqrt{d_{in}^2 + l^2} - l\right), \tag{12}$$

and d_{in} is the distance between elements i and n. $C_i(u)$ and $S_i(u)$ are the cosine and sine integral equations, respectively.

We now need to formulate the objective function we want to optimize.

2.2. Objective function of the GA used to optimize the design of coherently radiating structures

The objective function is the driving force behind the GA [14]. It is called from the GA to determine the fitness of each solution string generated during the search. In this case, each solution string represents possible antenna element separations. As already being pointed out, the objective of the present study is to evaluate the radiation pattern for coherently radiating structures in a linear array geometry considering the optimization of the spacing between antenna elements. In this paper, it is studied the behavior of