Synthesis of Linear Antenna Arrays for Radio Base Stations

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***Abstract*—This paper presents the application of optimization methods for the synthesis of a linear array for radio base stations of mobile communications systems. The desired pattern shall exhibit squared-cosecant shape, so as to provide uniform distribution of power inside the base station cell and to reduce co-channel interference. The synthesis is performed by a combination of optimization methods: the genetic algorithm is used for the initial global search, then the sequential quadratic programming is applied for local search. This approach allows faster convergence than using only one kind of optimization method. The technique is demonstrated for a linear array of isotropic elements and, subsequently, for an array of microstrip antennas.**

I. Introduction

The appearance of mobile radio systems has brought great convenience and flexibility, as they allow the communication among mobile users. The capacity of such systems is mainly limited by the signal-to-interference ratio produced by co-channel cells [1]. Some techniques have been proposed for reducing co-channel interference aiming to increase the system capacity, such as cell splitting and sectoring [2], [3]. In [4], an approach based on the antenna pattern has been proposed, where a squared cosecant-shaped radiation pattern was considered to provide uniform distribution of power along the cell. Radiated power in the direction of co-channel cells was also minimized, hence reducing interference. The drawback of the formulation proposed in [4] is that the synthesized pattern was obtained considering an antenna array composed of isotropic elements. For practical purposes, however, the array elements do not have isotropic radiation characteristic. Therefore, the real element pattern must be considered in order to obtain reliable results.

This paper presents the synthesis of a linear array with squared cosecant-shaped pattern. In contrast to [4], it will be demonstrated that the inclusion of the radiation characteristic of the array element is important to obtain an optimized pattern. In the next section, the optimization techniques will be briefly discussed. Section III presents numerical results for the synthesis of linear arrays composed of isotropic and microstrip antennas. Comparison between both results will be shown to demonstrate the need of including the real radiation pattern of the array element in the optimization process.

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II. Genetic Algorithm and Sequential Quadratic Programming

In this paper, two optimization methods have been employed to find the excitation coefficients of linear arrays. Initially, genetic algorithm (GA) was used to search for a set of coefficients that correspond approximately to the specified pattern; then, sequential quadratic programming (SQP) was applied to refine the optimization. The SQP is always started with the best individual obtained by the GA.

The concept of the GA was formulated by Holland and applied in [5] to obtain the excitation coefficients of arrays, aiming to steer the main beam in a specific direction and to control the sidelobe levels (SLL). The SQP is a method of nonlinear programming, which performs optimizations based on gradients and approximates the sequential nonlinear programming problem as a quadratic programming problem [6]. This allows finding the best local solution.

In the optimization with GA, individuals in the population are treated as potential solutions to the problem, where an initial population suffers crossover and mutation over generations. With the evolution of the individuals, the GA finds better results to solve the problem. The fitness of each individual is given based on the evaluation of its chromosome as a cost function. The cost function used in this study for both methods is based on the error, calculated by

$$e(\theta) = S(\theta) - F(\theta), \theta \in [0°, 180°], \tag{1}$$

where $S(\theta)$ is the desired pattern, and $F(\theta)$ is the obtained pattern (dependent on the chromosome of each individual), given by

$$F(\theta) = w \,.\, v(\theta). \tag{2}$$

In (2), w is the excitation vector (chromosome) of the *N*-element array and $v(\theta)$ is the vector associated with the pattern of the array elements, denoted by

$$v(\theta) = \left[g_1(\theta)e^{i\psi_1}; g_2(\theta)e^{i\psi_2}; \ldots;\ g_N(\theta)e^{i\psi_N}\right]^t, \tag{3}$$

with g_i representing the pattern of each array element.

The estimated pattern $F(\theta)$ is analyzed in two regions: the first (*m = 1*) is defined by the region of the side lobes, whereas the second (*m = 2*) is the region of the $\csc^2(\theta - 90°)$ function. The mean square error for the side lobe region (R_1) and for the region of the squared cosecant function (R_2) is given by

$$R_m = \left[\frac{1}{L_m}\sum_{i=1}^{L_m}|e(\theta_i)|^2\right]^{1/2}. \quad (4)$$

Considering the number of samples L_1 in the side lobe region and L_2 in the cosecant region, the final cost function is computed by

$$fitness = R_1 P_1 + R_2 P_2 , \quad (5)$$

where P_1 and P_2 are the weights defined for each region.

III. Results

To demonstrate the optimization approach, a linear array with 26 elements uniformly spaced ($0.5\,\lambda$) along z was considered. The GA was initialized with a population of 70 individuals, with crossover probability of 80%, mutation of 13%, and 7% of individuals treated as elite. The limits of variation of chromosome genes were set to [0, 1] for the amplitude and [-π, π] for the phase. Initially, a linear array with 26-isotropic elements was optimized over 1000 generations with the GA, followed by the sequential quadratic programming started with the best individual. The side lobe region was defined between [0°, 86°] with maximum allowed SLL 40 dB below the maximum of the pattern, and the squared cosecant region between [92°, 180°]. Both regions have been assigned with equal weights, *i.e.* $P_1 = P_2$ in (5). The desired pattern and the optimization result are shown in Fig. 1, where the fulfillment of all requirements is verified.

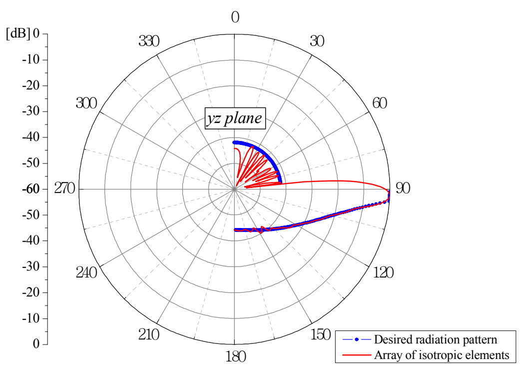

Figure 1 – Radiation pattern of a linear array with isotropic elements.

In order to demonstrate the influence of the array element radiation characteristic on the synthesized pattern, the isotropic elements were replaced by microstrip antennas. The result is shown in Fig. 2, where one can observe that the power level is strongly reduced as θ approaches 180°. The array pattern does not satisfy the specifications anymore. A new optimization was carried out now considering the microstrip antenna as array element. The same simulation setup up was used for GA and SQP. The final result is shown in Fig. 3, where a much better representation of the desired pattern has been obtained.

IV. Conclusion

This paper presented the synthesis of squared cosecant-shaped pattern obtained with a linear antenna array. The main goal was to obtain uniform distribution of power along the coverage area of a radio base station. The synthesized pattern exhibits low power levels in the angular region above the horizon. This contribution demonstrated that the radiation characteristic of the array element influences the final pattern and must be considered since the beginning of the optimization process.

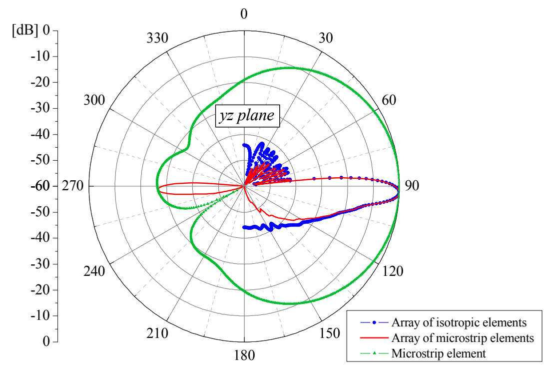

Figure 2 – Influence of the radiator element on the pattern optimized for isotropic elements.

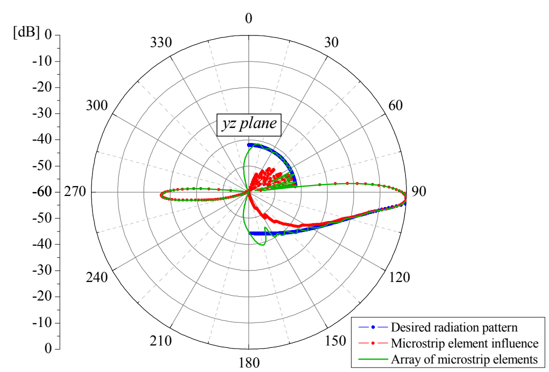

Figure 3 - Radiation pattern of a linear array with microstrip elements.

References

[1] T. S. Rappaport, *Wireless Communications: Principles and Practice, 2nd ed.*, vol.1. Prentice Hall, 2001, pp. 25-41.

[2] V. H. Mac Donald, "Advanced Mobile Phone Service: The Cellular Concept", *The Bell System Technical Journal*, vol. 58, p.15, Jan. 1979.

[3] W. C. Y. Lee, "Elements of Cellular Mobile Radio Systems," *IEEE Trans. on Vehic. Tech.*, vol. VT-35, pp.48-56, 1986.

[4] J. L. Hu, C. H. Chan and S. M. Lin, "Synthesis of Shaped-Beam Pattern for Mobile Antenna". *IEEE Antennas and Propagation Society International Symposium*, vol.3, pp 1596-1599, Aug. 1999.

[5] J. M. Johnson and Y. Rahmat-Samii, "Genetic Algorithm Optimization and its Application to Antenna Design," *IEEE Antennas and Propagation Society International Symposium*, vol.1, pp. 326-329, Aug. 1994.

[6] M. L. Teles and H. M. Gomes, "Genetic algorithms and sequential quadratic programming comparisons for engineering problems optimization". *Theory and Practice in Engineering*, pp. 29-39, April 2010.