

Design of Irregular Embedded Antenna Arrays for Shaped-Beam Radiation Using Reciprocity and Sparse Optimization

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Abstract—In this article, the sparse optimization based methodology for designing irregular arrays of antenna radiating in free space for various beam pattern objectives is extended to the case of realistic antennas embedded in an arbitrary hosting structure. To reduce the computational complexity involved in this extension, which lies in the need to numerically calculate the far-fields of the antennas for many possible placements while accounting for the effect of the embedding structure, we resort to the reciprocity theorem. Once the far-fields have been computed, we can proceed and employ any sparse optimizer to design the array. To demonstrate this approach, we apply it to the design of an electrically short dipole array embedded in a dielectric substrate above a finite ground plane for various beam pattern objectives. The sparse optimization is shown to yield arrays with more desirable beam patterns (better in terms of least squares error) than achieved by commonly used uniformly spaced planar arrays.

Index Terms—Antenna pattern synthesis, computational electromagnetics, irregular antenna array, reciprocity theorem, shaped-beam antennas, sparse optimization.

I. INTRODUCTION

ANTENNA array design and shaped-beam synthesis are used in many applications such as communications, radar, and RF sensors. To design irregular arrays with good performance while maintaining a small number of elements, sparse optimization was proposed in various studies (e.g., [1], [2], [3], [4], [5], [6], [7], [8], [9]). The goal in sparse optimization is to find a sparse solution (small number of non-zero elements) that satisfies certain constraints and/or optimizes some objective. An example of sparse optimization (written in mathematical language) is

$$\begin{aligned} & \text{minimize } \|[A]\vec{x} - \vec{b}\|_2 \\ & \text{subject to } \|\vec{x}\|_0 \leq K \end{aligned} \quad (1)$$

where $[A]$ is a matrix, $\vec{b}$ is a column vector, and $\vec{x}$ is a variable column vector and $\|\cdot\|_2$ denotes the L2 norm. Also, in (1),

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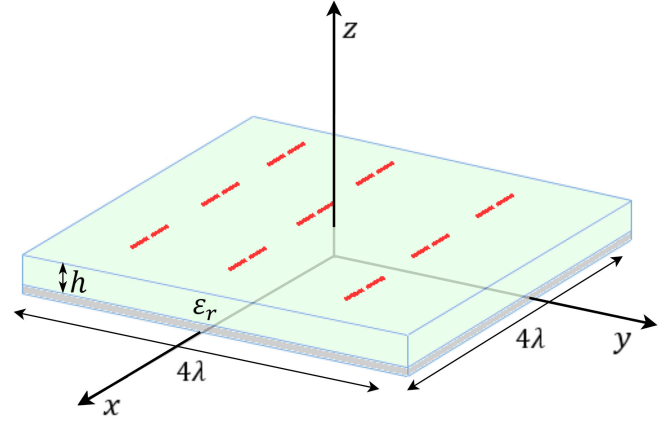


Fig. 1. Illustration of an array of electrically short dipoles embedded in $4\lambda \times 4\lambda$ dielectric substrate above a copper plane (λ is the free-space wavelength).

$\|\vec{x}\|_0$ is the number of non-zero elements in the vector $\vec{x}$, which in this example is limited by some integer K . In the aforementioned studies, sparse optimization has been utilized to select, from all possible antenna placements, a small set of antenna placements that allows one to achieve a beam pattern that satisfies certain requirements (such as beamwidth, bandwidth, etc.). However, in most of these studies, it is assumed that the antenna elements are radiating in free space, whereas in practical antenna designs, the antennas are often placed near or embedded within a structure as in the example shown in Fig. 1. Since the structure generally has a significant effect on the radiation pattern of the array, it needs to be accounted for in the design process, but, to the best of our knowledge, there are no simple methodologies for antenna array design that accounts for an arbitrary hosting structure.

To utilize sparse optimization for designing an array with a small number of elements, we must first obtain the far-fields of the antennas for each of the possible antenna placements. Computing the fields of antennas for many possible placements is costly, and in cases of large structures with many possible placements, is likely to be the computational bottleneck in this design process. To reduce the computational load, we propose an efficient method to compute these far-fields. Specifically, we do not derive the far-fields directly but rather by placing auxiliary dipoles in the far-field of the structure, calculating their fields