RCS Reduction of Dielectric Cylinders Using the Simulated Annealing Approach

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***Abstract*— A novel technique is presented for reducing the bistatic scattering of dielectric struts for radomes, modeled herein as infinite dielectric cylinders, that are illuminated by TMz plane waves. The reduction is achieved by loading the cylinders with perfectly-conducting narrow strips oriented parallel to the cylinder axis, and the strip configurations are obtained iteratively by using the technique of simulated annealing. The technique is useful for systematically deriving strip configurations that reduce the RCS simultaneously for different observation angles and/or frequencies.**

I. Introduction

DIELECTRIC struts are often used as supports in antenna and radome systems and their presence deteriorates the performance of the overall system. However, the scattering from these supports can be reduced by loading the cylinder with perfectly conducting strips [1] and by taking advantage of the fact that, for certain specific strip configurations, the far fields radiated by the polarization currents in the dielectric partially cancel the corresponding fields generated by the currents on the strips, thereby reducing the RCS of the overall structure. In this letter, a technique is presented for systematically designing these RCS-reducing strip loadings using the method of simulated annealing [2]–[3], which enables one to circumvent the conventional, trial and error approach that is very time-consuming. The problem is formulated for the TMz plane wave incidence, for which the scattering is significant, and the loading strips are orientated parallel to the cylinder axis. An important feature of the simulated annealing approach is that, using this technique, the strip configurations can be designed such that the bistatic RCS of the cylinder can be simultaneously minimized for different observation angles. Simultaneous optimization for different frequencies is also possible, but is beyond the scope of this letter.

II. Formulation

Given a dielectric cylinder illuminated by a TMz wave, the optimal strip loading is designed by iteratively selecting different subsets $\{S_i\}$ from a predefined set $\{S_G\}$ of potential candidates. This is accomplished by minimizing the following objective function :

$$F(\{S\}) = \max_j [\mathrm{RCS}(\{S\}, \phi_j)]. \tag{1}$$

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Equation (1) implies that the maximum RCS occurring over the observation angles ϕ_j $(j = 1, \cdots, N)$ is minimized. The vector $\{S_G\}$ represents the ensemble of strips, which can be large in number, and whose width as well as possible locations are pre-chosen such that they are distributed uniformly over the cylinder cross-section. During each iteration cycle, a different trial configuration $\{S_i^t\} \subset \{S_G\}$ is obtained by perturbing the strip configuration vector $\{S_{i-1}\}$ obtained in the previous cycle. The perturbation procedure consists of randomly removing some strips from $\{S_{i-1}\}$, and randomly adding to some strips from $\{S_G\}$, which are not present in $\{S_{i-1}\}$, with the starting configuration, $\{S_0\}$, containing no strips. The objective function is evaluated for the perturbed configuration and compared to $F(\{S_{i-1}\})$. When $F(\{S_i^t\}) < F(\{S_{i-1}\})$, the perturbed configuration automatically replaces $\{S_{i-1}\}$ at the beginning of the next iteration cycle, i.e., $\{S_i\} = \{S_i^t\}$. When $F(\{S_i^t\}) > F(\{S_{i-1}\})$, $\{S_i^t\}$ is accepted $(\{S_i\} = \{S_i^t\})$ with a probability p, which is given by

$$p = e^{-\left[\frac{F(\{S_i^t\}) - F(\{S_{i-1}\})}{T_i}\right]}, \tag{2}$$

where T_i is a parameter called the control temperature. The trial configuration is rejected, i.e., $\{S_i\} = \{S_{i-1}\}$, with a probability $1 - p$. This mechanism allows the process to escape the local minima, a feature not provided by many traditional minimization techniques. The control temperature T_i is gradually lowered during the iteration process, making it increasingly unlikely to accept strip configurations that result in an increase of the objective function as the iteration process is continued.

The p.e.c strips are typically narrow, and it is usually adequate to model the current on the strips by using a single basis function, provided that it satisfies the edge condition on the strips. In order to efficiently evaluate the objective functions for the many different strip configurations that are encountered during the optimization process, a Green's function matrix for the currents on the strips is constructed. Each entry of this matrix corresponds to the electric field at a potential strip location, produced by a unit current residing at one of the potential strip locations (which could be collocated with the position where the electric field is being evaluated), and radiating in the presence of the unloaded dielectric cylinder. A variety of approaches, including the volumetric and surface integral equation techniques [4]–[5], can be employed to evaluate the Green's function matrix. Once this matrix has been constructed, the evaluation of the RCS of a configuration containing N_s strips, only requires the inversion of an $N_s \times N_s$

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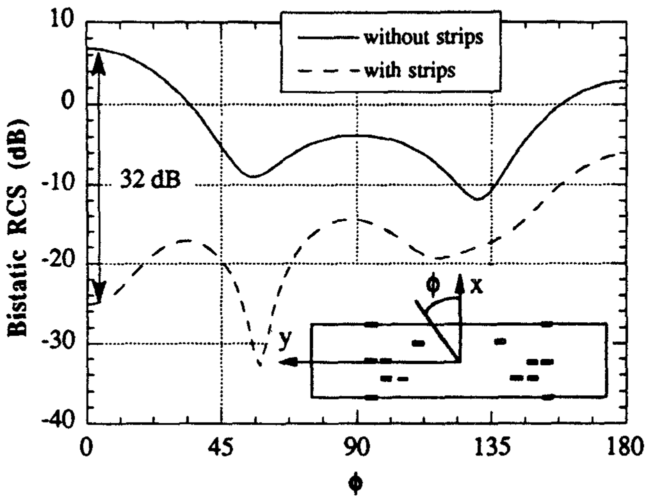

Fig. 1. Bistatic RCS of purely dielectric cylinder and of the loaded cylinder and of the loaded cylinder that minimizes the bistatic RCS for $\phi = 0°$.

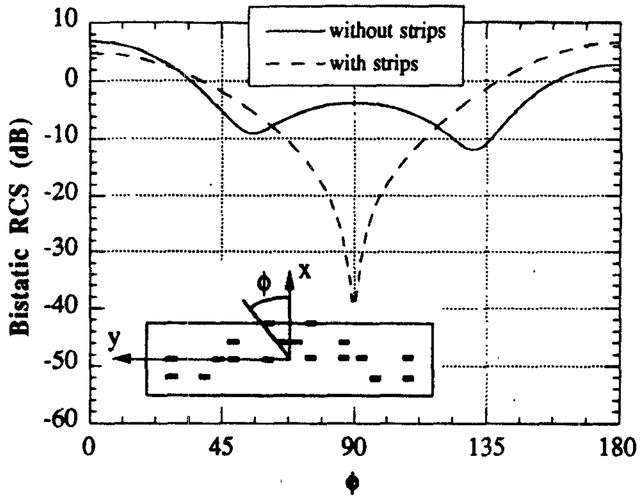

Fig. 2. Bistatic RCS of purely dielectric cylinder and of the loaded cylinder and of the loaded cylinder that minimizes the bistatic RCS for $\phi = 90°$.

matrix. This results in considerable time-saving because it circumvents the step of deriving the solution of the combined dielectric-p.e.c. cylinder problem during each iteration cycle.

III. Representative Results

This section presents representative results derived by using the simulated annealing technique for reducing the bistatic RCS of a homogeneous rectangular dielectric cylinder with relative permittivity $\epsilon_r = 3$, with dimensions $\Delta x = 1\lambda_0$ by $\Delta y = 0.2\lambda_0$. The cylinder is illuminated by a normally incident TM_z plane wave, which travels in the positive x direction.

In order to minimize the bistatic RCS in the forward scattering direction ($\phi = 0°$), the simulated annealing algorithm is provided with a set $\{S_G\}$ of 100 strip candidates, each with a width of 0.01 λ_o, and distributed uniformly over the cylinder cross section. The optimal strip configuration is obtained after approximately 900 iteration cycles, and is shown in Fig. 1, together with the bistatic RCS of the loaded and unloaded cylinders. This configuration consists of 14 strips placed symmetrically with respect to the short axis of symmetry. This strip configuration was selected from all symmetrical subsets of $\{S_G\}$. Thus, the symmetry of the strip configuration did not result automatically, but was imposed as an additional restriction. The strip loading reduces the RCS in the forward scattering direction by about 32 dB. Although the RCS is only optimized for $\phi = 0°$, the bistatic RCS of the loaded cylinder is lower than the bistatic RCS of the unloaded cylinder, for all ϕ. This strip configuration reduces the bistatic RCS of the cylinder in the $\phi = 90°$ direction by 10 dB. In order to achieve better performance for $\phi = 90°$, the simulated annealing technique is used to optimize the RCS in this direction, without placing any constraints on the RCS in the forward scattering direction. The optimal strip configuration, which contains 18 strips, is obtained after approximately 500 iteration cycles, and is shown in Fig. 2 together with the bistatic RCS of the loaded and unloaded cylinder. For $\phi = 90°$, a null occurs in the scattered field pattern of the loaded cylinder. Consequently, the original goal of reducing the RCS in the latter direction is obviously accomplished. In contrast to the previous example, the optimal strip loading does not reduce the RCS for all ϕ; for instance, the backscatter RCS ($\phi = 180°$) is seen to increase by 3.7 dB. Although the RCS does reduce along $\phi = 0°$, it does so only by 2 dB. In order to achieve a good performance both for $\phi = 0°$ and $\phi = 90°$, a strip configuration is designed which simultaneously minimizes the RCS in both directions. Again, the symmetry requirement for the strip configuration is automatically imposed, which eliminates the need for simultaneous optimization in three directions, viz., $f = 0°$, $90°$, and $270°$. The optimal strip configuration and the corresponding bistatic RCS are shown in Fig. 3. Compared to the case of the unloaded dielectric cylinder, the RCS of the loaded structure is reduced by 29.5 dB along $f = 0°$ and by 14 dB along $\phi = 90°$. Also, compared to the configuration of Fig. 1, which was obtained by optimizing the RCS solely in the forward scattering direction, there is a gain of 4 dB along $\phi = 90°$, and a loss of 2.5 dB along $\phi = 0°$.

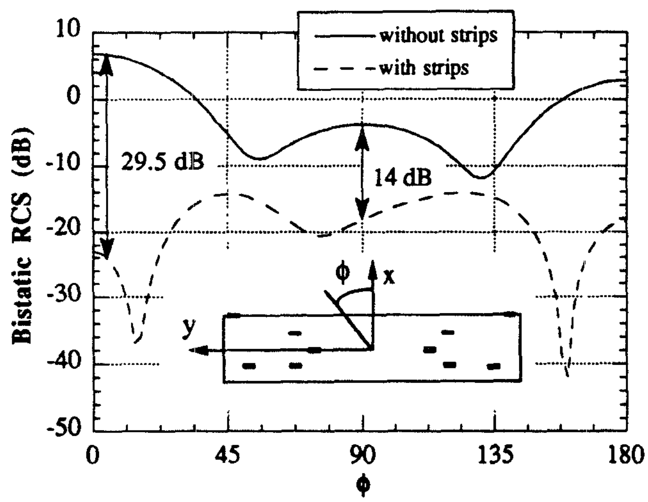

Fig. 3. Bistatic RCS of purely dielectric cylinder and of the loaded cylinder and of the loaded cylinder that minimizes the bistatic RCS simultaneously for $\phi = 0°$ and $\phi = 90°$.

IV. Conclusion

In this letter, a novel technique based on simulated annealing approach has been presented for reducing the bistatic RCS of dielectric cylinders for TMz plane wave incidence. The algorithm has been successfully applied to minimize the RCS of dielectric cylinders of rectangular cross-section.

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