Fast Numerical Analysis of Finite Periodic Dipole Array Antenna Embedded in Thin-Stratified Medium Using Novel Characteristic Basis Function Method

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1 Introduction

Periodic structures have been widely used for various applications such as frequency selective surfaces, antenna arrays and reflectarrays [1]. A microstrip periodic structure is known as one of the most popular periodic structures due to its conformality and ease of fabrication. For the design of the microstrip periodic structure, how to deal with a dielectric substrate in numerical simulations is one of the big problems because the performance of the microstrip periodic structure is strongly affected by the dielectric substrate. The Method of Moments (MoM) with volume integral equation (VIE-MoM) is known as one of the powerful techniques for the design of the microstrip periodic structure [2]. An advantage of the VIE-MoM is accurate modeling because both microstrip line and dielectric substrate can be modeled as a finite structure via volume and surface segments. However, a large number of unknowns makes numerical simulation difficult when the size of the periodic structure increases.

Another big problem in the design of the microstrip periodic structure is long CPU time for numerical simulation. Recently, several fast MoM techniques have been developed to reduce the CPU time for numerical simulation [3] ∼ [5]. However, to the best of the authors' knowledge, these fast MoMs are based on iterative solvers and suffer from poor convergence for ill-conditioned problems.

In this paper, a novel Characteristic Basis Function Method (CBFM) for numerical analysis of a large, finite periodic structure is proposed. The proposed CBFM is a kind of an iteration-free approach. A finite microstrip dipole array antenna embedded in thin-stratified medium is numerically analyzed using the proposed CBFM. Green's function for layered medium is used and the number of unknowns can be kept small even when the size of the microstrip array increases [6]. Numerical simulation shows that both CPU time and computer memory required by the proposed CBFM are quite small.

2 Green's Function for Layered Medium

The following layered media Green's function is used here [6].

$$\overline{\overline{G}}^{LM}(\mathbf{r},\mathbf{r}') = \overline{\overline{G}}(\mathbf{r},\mathbf{r}') + \overline{\overline{G}}^{TE}(\mathbf{r},\mathbf{r}') + \frac{1}{k_{nm}^2}\overline{\overline{G}}^{TM}(\mathbf{r},\mathbf{r}') \tag{1}$$

$$\overline{\overline{G}}(\mathbf{r},\mathbf{r}') = (\overline{\overline{\mathbf{I}}} + \frac{\nabla\nabla}{k_m^2})\frac{e^{-jk_m|\mathbf{r}-\mathbf{r}'|}}{4\pi|\mathbf{r}-\mathbf{r}'|} \tag{2}$$

$$\overline{\overline{G}}^{TE}(\mathbf{r},\mathbf{r}') = (\nabla\times\hat{\mathbf{z}})(\nabla'\times\hat{\mathbf{z}})g^{TE}(\mathbf{r},\mathbf{r}') \tag{3}$$

$$\overline{\overline{G}}^{TM}(\mathbf{r},\mathbf{r}') = (\nabla\times\nabla\times\hat{\mathbf{z}})(\nabla'\times\nabla'\times\hat{\mathbf{z}})g^{TM}(\mathbf{r},\mathbf{r}') \tag{4}$$

$$g^{\alpha}(\mathbf{r},\mathbf{r}') = -\frac{j}{8\pi^2}\iint_{-\infty}^{+\infty}\frac{e^{j(k_x(x-x')+k_y(y-y'))}}{k_{mz}(k_x^2+k_y^2)}F^{\alpha}dk_xdk_y \tag{5}$$

Subscripts m and n mean the number of layer where source and observation points are located, respectively. Superscript α is either transverse-electric (TE) or transverse-magnetic (TM) with respect to z axis, and F^{α} is the propagation factor of the TE/TM wave which is obtained by generalized reflection/transmission coefficients.

The self/mutual impedance between source and observation segments is calculated here using the Green's function. Piecewise sinusoidal functions are used as basis/testing function (Galerkin testing) for the printed metallic elements. Fourfold integrals over space coordinates x, x', y, y' are transformed into a sum of double integrals via coordinate transformation [8]. The double infinite spectral integrals over k_x and k_y in Eq. (5) are evaluated as Sommerfeld integrals.

3 Proposed CBFM

As shown in Fig. 1, two kinds of blocks are used in our proposed CBFM. A micro block includes one array element in a finite periodic array, while a macro block includes array elements in central, edge and corner regions of the array, respectively. Different macro blocks are allocated within L spaces from the outermost boundary of the array. According to array theory, current distribution of every micro block in a macro block is assumed to be the same. Therefore, the same characteristic basis function (CBF) of every micro block in the macro block is assumed to have the same weight coefficient. Our proposed CBFM reduces

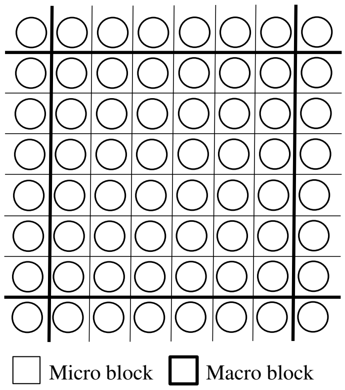

Fig. 1 Micro/Macro block partitioning of loop array antenna ($L = 1$).

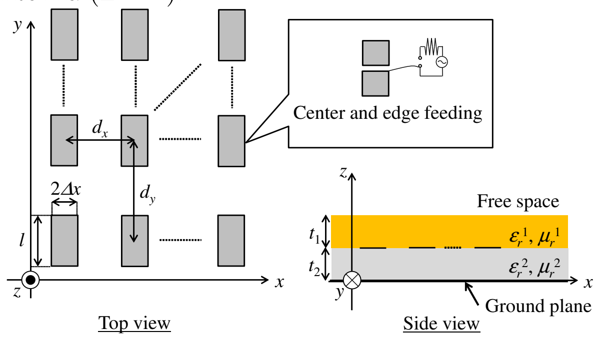

Fig. 2 Microstrip dipole array antenna.

computational cost using such uniformity of CBFs and weight coefficients for the array.

In our proposed CBFM, CBFs of a micro block are obtained using eigenvectors of an isolated element. After that, the same CBFs of micro blocks in the same macro block are joined each other and CBFs of the macro block are obtained. The original $N \times N$ matrix equation can be reduced using CBFs of macro blocks and the resultant reduced matrix can be solved using a direct solver.

4 Results of Numerical Simulation

A microstrip dipole array antenna embedded in two-layered dielectric medium is shown in Fig. 2. The array antenna is backed by ground plane and the effect of the ground plane is included in the numerical simulation using image theory.

The actual gain of the antenna is shown in Fig. 3 for a 25×25 array of dipoles. The actual gain obtained using our proposed CBFM agrees well with that of the full-wave analysis. It is found that the accuracy of our proposed CBFM improves as L increases, as expected because more macro blocks are allocated at the outermost boundary of the array. The CPU time (except for matrix filling) and computer memory of the proposed method are 76 sec. and 69 MB, respectively, while those of the full-wave analysis are 18426 sec. and 1233 MB, respectively.

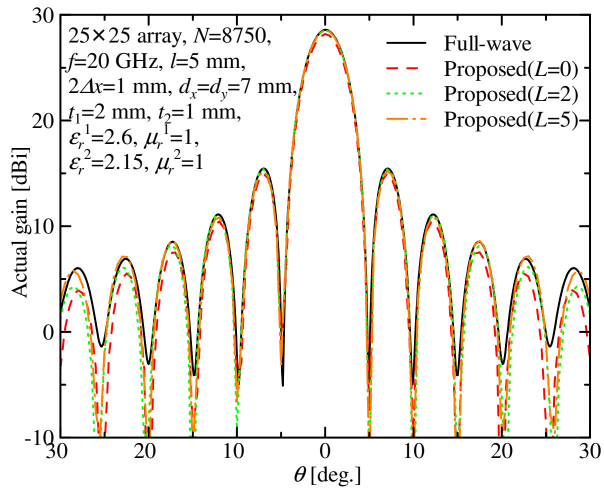

Fig. 3 Actual gain of microstrip dipole array antennas (E_ϕ in xz plane).

5 Conclusions

In this paper, a novel CBFM for numerical analysis of large finite periodic structures has been proposed. A dipole array antenna embedded in thin-stratified media was numerically analyzed and performance of the proposed CBFM was verified. It was found that the CPU time and computer memory of the proposed CBFM are much smaller than those of the full-wave analysis with negligible impact on accuracy.

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