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INTERPOLATION SCHEME BASED ON ADAPTIVE INTEGRAL METHOD FOR SOLVING ELECTRICALLY LARGE RADIATION PROBLEM BY SURFACE/SURFACE CONFIGURATION

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Abstract—A novel interpolation scheme based on Adaptive Integral Method (AIM) is presented to solve electrically large radiation problem of conducting surface/surface configurations. For a complex structure that involves wires and surfaces, three basis functions must be assigned to surfaces, wires and wire/surface junctions. To simplify this, the thin strips with no thickness instead of wires are proposed, and the wire/surface junctions can be replaced by surface/surface junctions, thus it is only necessary to define a uniform basis function. The Electric Field Integral Equation (EFIE) is solved using the Method of Moments (MoM) to obtain the equivalent surface current on PEC surfaces. To facilitate the analysis of electrically large radiation problem, the interpolation scheme based on AIM is employed to accelerate the matrix-vector multiplications and reduce matrix storage. Numerical results are presented to demonstrate the accuracy and efficiency of the technique.

1. INTRODUCTION

Electrically large antennas are commonly used in communication systems. Thus the complex antennas which involve wire/surface junctions and surface/surface junctions are essential structures for wireless telecommunications. Different methods have been proposed to model the wire/surface junction in order to consider the rapid current distributions around the junction [1–3]. However, these models are not

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suitable to solve radiation problems involving arbitrary 3D conducting objects.

The attachment mode modeled by triangular patches and a set of triangular patches shared a common node was proposed by Hwu et al. [4], and it can be used in arbitrary connection configurations. Ewe et al. solved the problems with a large number of unknowns by using the same model [5]. Three different basis functions were defined in both of the procedures. The Rao-Wilton-Glisson (RWG) basis functions were assigned to surface. Triangular basis functions were assigned to wire, and junction basis functions were assigned to wire/surface junction. Thus it is complex to fill the impedance matrix. In [6], it was indicated that the thin strip with no thickness can obtain the same results in radiation patterns as the wire, and the surface/surface model can be used.

The Method of Moments (MoM) has been one of the most popular methods for solving electromagnetic radiation. It usually requires $O(N^2)$ memory to store the impedance matrix and $O(N^2)$ operations to perform the matrix-vector product via an iterative solver, where N is the number of unknowns. The memory requirements and CPU time for solving the matrix equation are dramatically reduced by using some fast algorithms in the MoM such as Precorrected-FFT method (P-FFT) [7, 8], Adaptive Integral Method (AIM) [9–14] and Multilevel Fast Multipole Algoithm (MLFMA) [15, 16].

In this paper, the application of surface/surface configurations [6] for solving the electrically large radiation problem using the AIM is described. In the approach, the thin strip with no thickness replaces the wire, and then the surface/surface junction is used. Hence all the conducting surfaces can be modeled by using triangular patches, and three triangles share a common edge at the junction. With the Kirchoff's current law, we will eliminate one pair of triangles to ensure the current continuity. It is convenient to solve the problems by using MoM, and a uniform basis function is applied to all the surfaces without using junction basis function. To facilitate the analysis of electrically large antennas, the AIM has been used to reduce the memory requirements and accelerate the matrix-vector multiplications in the iterative solver. Different from the existing AIM codes [9–14], the Gauss interpolation scheme is used in our implementation of AIM. Numerical results for a cube mounted on a monopole and two monopoles placed on a helicopter are presented in Section 4. The numerical data is compared with the wire/surface model by using AIM [5] since all the examples in this paper are too large for the traditional MoM.

2. SURFACE/SURFACE JUNCTION

As far as impedance and radiation pattern are concerned, a thin strip dipole antenna with no thickness behaves like a circular cylindrical antenna with an equivalent cylindrical wire given by

$$a = 0.25s \tag{1}$$

where a is the equivalent radius, and s is the strip width [6]. Consider that a radiation structure involves conducting wires and surfaces, either wire/surface or surface/surface model can work. However, a special basis function is needed in the wire/surface model [4, 5]. If the wire is equivalent to the thin strip with no thickness, then we can discretize the structure using triangular patches, and the RWG function can be defined all over the surfaces. During the discretization process, the surface/surface junction is processed to be located on a common edge. With the Kirchoff's current law, there are only two independent currents, while the junction can be decomposed into three pairs of triangles (a), (b) and (c), as shown in Fig. 1. Thus we will keep (a) and (c), considering the symmetry.

For the radiation problems, the delta-gap feed model is usually used. At the junction there are two pairs of triangles (a) and (c), thus we must consider all of them. Then the excitation vector will be zero everywhere except these two elements:

$$V_{n1} = l_{n1}V, \quad V_{n2} = l_{n2}V, \quad l_{n1} = l_{n2} \tag{2}$$

where V_{n1} and V_{n2} represent the excitation of (a) and (c), respectively. l_{n1} and l_{n2} are the length of the common edge at the junction. V is usually assigned a value of unity for convenience.

3. ADAPTIVE INTEGRAL METHOD

The principal idea of AIM is to approximate the far-zone interaction using the fast Fourier transform (FFT) and then to compute the near-zone interaction directly using conventional MoM. The procedures of AIM can be summarized as follows:

1) project the current densities on to the surrounding grids;
2) compute the grid potentials with the aid of fast Fourier transform;
3) interpolate the computed potentials back to the elements; and
4) compute the near-zone interactions.

To employ the AIM, the object is enclosed in a rectangular region and then recursively subdivides it into small rectangular grids. Instead of matching the multipole moments to basis functions, the

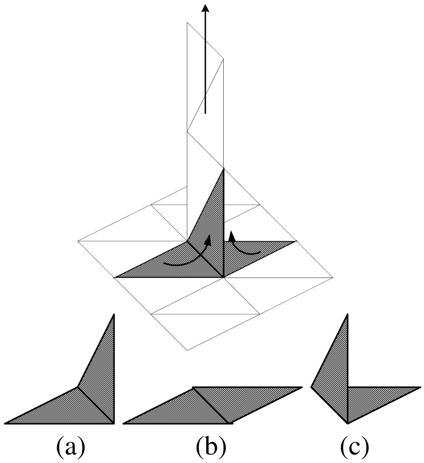

Figure 1. Surface/Surface model.

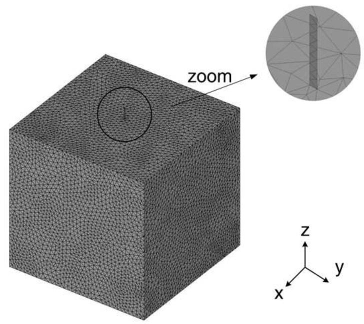

Figure 2. The meshed cube fed by a monopole.

interpolation in our implementation of AIM is the Gauss interpolation operator given by

$$\bar{\mathbf{\Lambda}} = \sum_{u=1}^{(M+1)^3} \prod_{a=1,a\neq u}^{M+1} \prod_{b=1,b\neq u}^{M+1} \prod_{c=1,c\neq u}^{M+1} \Phi_u \frac{\sin\left(\frac{1}{2}(x-x_c)\right)}{\sin\left(\frac{1}{2}(x_u-x_c)\right)} \frac{\sin\left(\frac{1}{2}(y-y_b)\right)}{\sin\left(\frac{1}{2}(y_u-y_b)\right)} \frac{\sin\left(\frac{1}{2}(z-z_a)\right)}{\sin\left(\frac{1}{2}(z_u-z_a)\right)} \tag{3}$$

where $\bar{\mathbf{\Lambda}}$ is the interpolation matrix, and M is the order of the interpolation. In the implementation of conventional AIM, we obtain the projection matrix by matching the multipole moments to basis functions, while we can easily obtain the projection matrix from (3) in our implementation. It can be seen that the interpolation scheme is much simpler and easier to implement than the conventional AIM. Then we are able to represent the far zone approximation with $\bar{\mathbf{\Lambda}}\bar{\mathbf{g}}\bar{\mathbf{\Lambda}}^{\mathbf{T}}$, where $\bar{\mathbf{g}}$ represent the Green's function matrix. The matrix $\bar{\mathbf{g}}$ is a Toeplitz matrix, and this enables the use of FFT for efficiently computing the convolution. It is noted that the inaccurate contributions from the near-zone grid sources need to be removed.

By using the AIM, we can represent the matrix-vector multiplication as

$$\begin{aligned}\bar{\mathbf{Z}}\mathbf{I} &= \left(\bar{\mathbf{Z}}^{near} - \tilde{\mathbf{Z}}\right)\mathbf{I} + \bar{\mathbf{Z}}^{far}\mathbf{I} \\ &= \left(\bar{\mathbf{Z}}^{near} - \tilde{\mathbf{Z}}\right)\mathbf{I} + \bar{\mathbf{\Lambda}}\, FFT^{-1}\{FFT(\bar{\mathbf{g}}) \cdot FFT(\bar{\mathbf{\Lambda}}^{\mathbf{T}}\mathbf{I})\}\end{aligned} \tag{4}$$

where $\bar{\mathbf{Z}}^{near}$ and $\bar{\mathbf{Z}}^{far}$ stand for near-zone and far-zone interactions, respectively. $\bar{\mathbf{Z}}^{near} - \tilde{\mathbf{Z}}$ is the so-called precorrection.

4. NUMERICAL RESULTS

In this section, some numerical examples will be presented to show the accuracy and capability of AIM for solving electrically large radiation problem associated with surface/surface configurations. All the computations were carried out on a Pentium 2.8 GHz PC, and the bi-conjugate gradient stab method (BICGSTAB) solver is used with all the data stored in double precision.

In the first example, we consider a monopole mounted on a $3\,\mathrm{m} \times 3\,\mathrm{m} \times 3\,\mathrm{m}$ PEC cube. The monopole at the center of top surface of the cube is a 0.25 m high and 0.02 m wide thin strip. The cube is discretized into 16,304 triangles, leading to 24,448 unknowns, as shown in Fig. 2. The working frequency is 300 MHz, and the grid distance is 0.08λ. Fig. 3 shows the radiation pattern in the XZ plane by using surface/surface model and wire/surface model. The results are compared with the results obtained from the traditional AIM, and a good agreement is observed. The input impedance computed by surface/surface model and wire/surface model are $93.38 + 42.39\ \Omega$ and $93.21 + 42.29\,\Omega$, respectively.

The second example is two monopoles placed on a helicopter as shown in Fig. 4. The length, height and wingspan of the helicopter are approximately 22, 7 and 18.6 m, respectively. Both

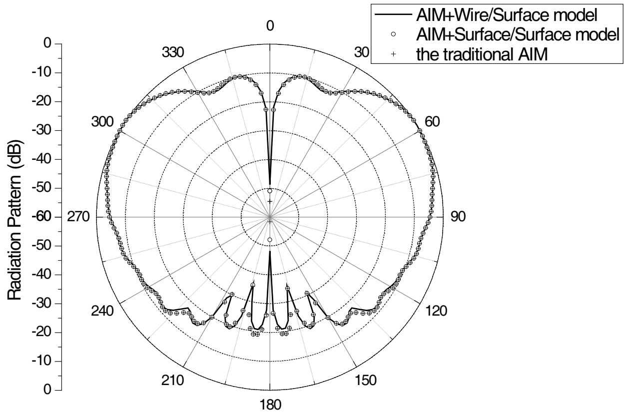

Figure 3. Radiation pattern of the monopole mounted on a cube in XZ plane.

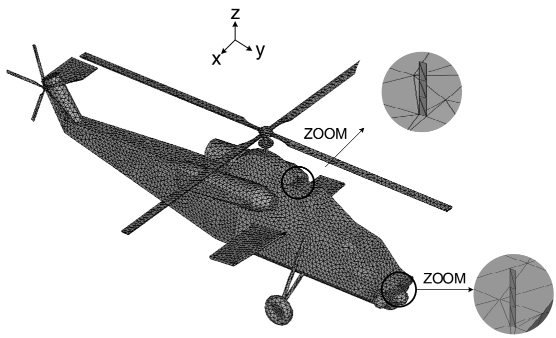

Figure 4. The geometry of the meshed helicopter.

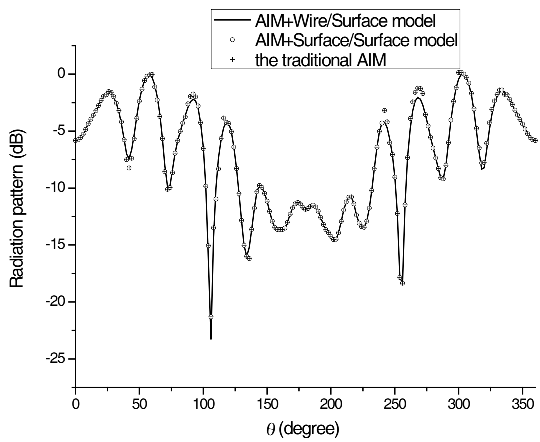

Figure 5. Radiation pattern of the monopoles placed on a helicopter in XZ plane.

of the monopoles are 0.45 m high and 0.02 m wide. The structure is discretized into 17,998 triangles resulting in a total of 26,991 unknowns. The working frequency is 200 MHz, and the grid distance is 0.12λ. Fig. 5 shows the radiation pattern of the antennas in the XZ plane by using surface/surface model and wire/surface model. The results are compared with those obtained from the traditional AIM, and an excellent agreement is observed. The total CPU time and memory requirement of the examples are shown in Table 1.

In the above examples, the traditional MoM requires 8.9 GB and 10.86 GB in computation, respectively, while the AIM only used 129.89 MB and 346.45 MB. Thus, it is easy to solve the electrically large radiation problem by using AIM.

Table 1. Total CPU time and memory requirement of the monopoles placed on a cube and a helicopter for three methods.

Problem	Method	No. of unknowns	No. of grid points	Memory requirement	Total CPU Time
Fig. 2	The traditional AIM	24002	$41\times41\times44$	110.78 MB	72.3 min
	AIM+ Wire/ Surface	24002	$41\times41\times44$	110.64 MB	69.8 min
	AIM+ Surface/ Surface	24448	$41\times41\times44$	129.89 MB	74.0 min
Fig. 4	The traditional AIM	26898	$107\times126\times43$	345.48 MB	442.7 min
	AIM+ Wire/ Surface	26898	$107\times126\times43$	342.32 MB	434.4 min
	AIM+ Surface/ Surface	26991	$107\times126\times43$	346.45 MB	451.1 min

5. CONCLUSION

This paper presents a novel interpolation based on AIM for solving electrically large radiation problem of conducting surface/surface configurations. Firstly, all the wire/surface models are replaced by surface/surface models using the thin strips with no thickness, and then the problem is converted into a matrix equation using MoM. The matrix equation is solved by using an iterative solver, and the AIM is applied to accelerate the matrix-vector multiplication and also to reduce memory storage requirement. Numerical results are presented to demonstrate the accuracy and application of the AIM for solving the electrically large radiation problem associated with arbitrary conducting surface/surface configurations.

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