APPLICATION OF MEI METHOD ON ANTENNAS

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1. Introduction

Since the advent of the measured equation of invariance (MEI) [1,2], the method has been applied by numerous researchers to scattering and IC interconnect problems [3,4,5]. Recently, the MEI method has been applied to antenna problems as well [6,7,8], which include wire antennas, reflector antennas and antenna arrays. This paper summarizes those developments in the published and yet unpublished papers.

2. Wire Antennas

The ability of solving wire antennas of arbitrary shape is very special for the method of moments (MoM). No other method can solve those problems as efficiently as the MoM. The
purpose of this investigation is to show that MEI method is flexible enough to include wire structures within its solution range. One would not expect it to replace MoM, even though the MEI method offers the advantages of higher speed and less storage requirement than the MoM. Simply because the MoM is already very effective, so the extra advantages are no longer very attractive to most the practical engineers. Nevertheless, in the spirit of research in methodology, an alternative to the MoM is still a worthwhile subject. In the followings, we shall discuss the procedures of applying the MEI to wire antennas.

The MEI method is based on the solution to differential equations. The differential operators become very singular on the surface of a very thin wire and the spatial meshes required to fit the surface of a curved wire are also very difficult to construct. So, the MEI was initial not a good candidate to solve wire antennas. However, in the research of applying the MEI method to 3-D problems, it was considered necessary to do on surface MEI (OSMEI), so as to minimize the number of unknowns, which was expected to be very large for any practical 3-D object. In doing so, one immediately realized that the problem of mesh construction had disappeared and the OSMEI should be as simple as the MoM in handling the curved wire problem. The conventional MEI method relates the tangential magnetic and electric fields in discreet form in a linear relation. To find the coefficients of the linear equations, we need to find the fields from Metrons [2]. The spatial derivatives relating **E** and **H** are the difficult part in the application, because they are very unstable on the surface of the thin wire. The key to alleviate this problem is to replace the relations between **E** and **H**, by those of **A** and **H**. Since the in integration for **A** is much less singular than that of **E**, the resulting equations are very stable.

The MEI method for wire antennas, therefore, starts with the relation,

$$\sum_{i=j-1}^{j+1} \left(a_i J_i + b_i A_i \right) = 0 \tag{1}$$

at a point j. Both the J and A are found from the metrons

$$J_m = \sin\left(\frac{m\pi}{L} z\right) \qquad (2)$$

The boundary value of $E = v_o \delta_{(z)}$ is replaced by the boundary values of A with

$$A = \frac{-jV_o}{2Z_o} \int_o^Z E^{iv}(\xi) \sin\kappa(z-\xi)\ d\xi \qquad (3)$$

Figure (1) shows the resulting matrix of the MEI equations, and Figs.(2) and (3) show the input impedance and currents calculated by the MEI method as compare to those by the MoM. They agree remarkably well. The method applies equally well for wire antennas of other shapes.

Parabolic Reflector Antennas

The parabolic reflector antenna is another example of the application of MEI. Because, the reflector type antennas are normally fairly large, the sparsity of the matrix is essential to the numerical solution of the problem. Conventionally, such antennas are solved by either physical optics or by geometrical optics. Numerical solution to the problem has never been tried. We have solved the parabolic reflector antenna with the diameter of the aperture as large as 80 λ.

In this application, we have used the coupled azimuthal potentials to formulate the fields, so only the azimuthal components of the electric and magnetic fields are the unknowns. The other components can be calculated from them. Unfortunately, this problem was investigated before we perfected the OSMEI, so three layers of finite difference meshes are used between the antenna surface and the mesh boundary. Using the OSMEI, we should be able to solve a reflector antenna of aperture dimension at lease 240 λ in diameter with the same effort.

As expected the numerical solutions of the current densities on the antenna surface is almost identical to the physical optics (PO) solutions except near the edge of the reflector, where the normal components of the current densities exhibit large standing waves, as shown in Fig. (4). Those standing waves are known to be present but not predictable by PO. They have no consequence on the main beam of the antenna but may have some effects on the side lobes, and are essential in computing the loss of the antenna.

Large Antenna Arrays

Antenna array theories help us to predict the radiation patterns when the current at each antenna is given. In reality, the currents are not the known quantities. The driving voltages at the terminals of the antennas are the known quantities. Due to mutual couplings, the impedance at each antenna is not exactly known. In order to solve a large coupled array, one has to use the MoM to find the amplitude and the phase of the current of each antenna. If we simplify the problem to one unknown per antenna, this array may still present a very large matrix for the designers. In the process of optimizing the pattern, one may need to solve this large matrix many times over. In this situation, we may use the MEI method to reduce the MoM matrix to sparse matrices.

The principle of the thinning of MoM matrix is slightly different from the original idea of MEI which is based on finite difference formulation. The unknowns in the array problem are not connected, nevertheless they are related by mutual couplings. The objective in this case is to thin the matrix

$$\mathbf{Z}\, I = V \qquad (4)$$

where, the vector I represents the terminal currents of the antennas, **Z** is the impedance matrix obtained from the method of MoM, and the vector V represents the driving voltages at the antenna terminals. Our approach to thin the **Z** matrix is to split it in the following form,

$$\mathbf{A}\, I = \mathbf{B}\, V \qquad (5)$$

where, **A** and **B** are sparse matrices. Equations (4) and (5) are combined to give

$$[\mathbf{A} - \mathbf{B}\,\mathbf{Z}^{-1}]\, I = O \qquad (6)$$

It is noticed that our process is not to thin **Z**, but to split it into two sparse matrices, because the approximation $\mathbf{B}^{-1}\mathbf{A} = \mathbf{Z}$, is not to replace the full matrix **Z** by a sparse matrix, in that $\mathbf{B}^{-1}$ is not sparse even though **B** is sparse. This process is superior to that of thinning the matrix by the wavelet approach, which involves replacing the full matrix by a sparse matrix by regrouping the currents in terms of wavelets.

To find the matrix **A** and **B**, we use the process of measure as proposed in the MEI method. The bandwidth of the matrices depends on the metrons used. It has been found that complex exponential matrons of finite support have been quite effective in reducing the bandwidth of the matrices. Good results have been obtained with the reduction of the matrix to 0.61% of its original number of elements. Figures (5) and (6) show the radiation patterns in the E and H planes respectively of a 20 by 40 dipole array as calculated by the MEI method as compare to those using the direct MoM. The driving voltages are set up to give a main beam at 0 degree in the E-plane and 30 degree in the H-plane. Excepting the discrepancies at the radiation angle larger than 60 degree of the H-Plane, the MEI method almost reproduces those of the MoM. And, the errors are at locations where the side lobes are less than 20 db of the main lobe.

Conclusion

We have shown the recent progress of the MEI method in antenna problems including wire antennas, reflector antennas and antenna arrays. Eight years after the birth of the MEI method, it is still not a method generally accepted by the antenna community. We feel it is a method with great potential to save computational time and memory, but it has to compete with ever faster and larger cheap computers. The practitioners prefer to let the new computers solve larger problems for them than to learn new methods. However, to the theoreticians, finding new methods is by itself a satisfaction, and we believe that even the speed and memory of computers increase every year, there is still a limit to the size of problems they can solve. Eventually, the errors accumulated by the large number of arithmetical operations will come to haunt the engineers. By then, one will find that the efficient methods are indispensable.

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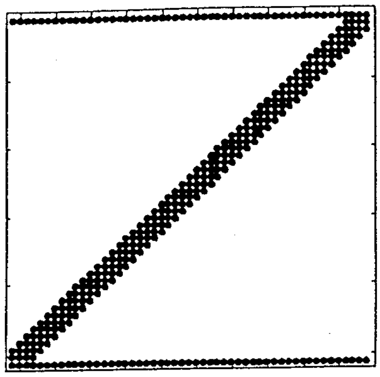
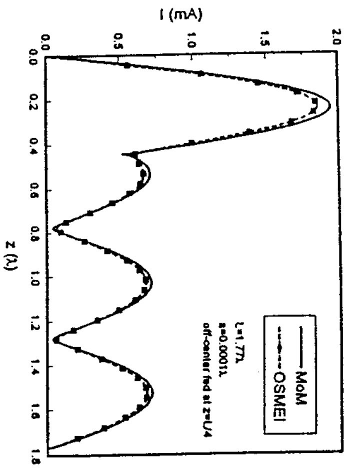


Figure (1) The resulting matrix of the MEI equations



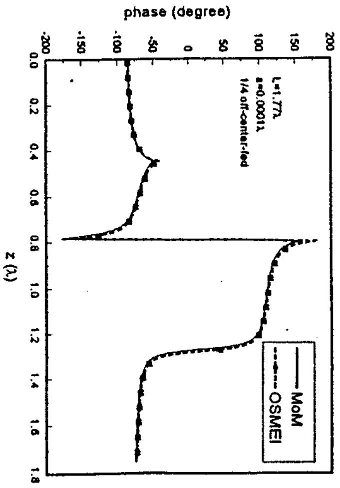


Figure (2) and (3) The input impedance and currents calculated by the MEI method as compare to those by the MoM

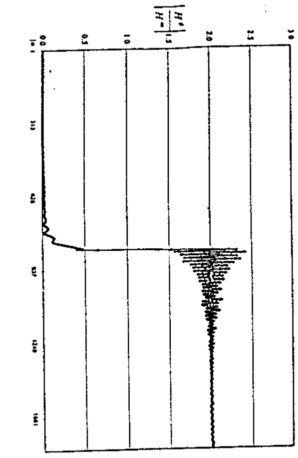


Figure (4) The radial component of the current densities

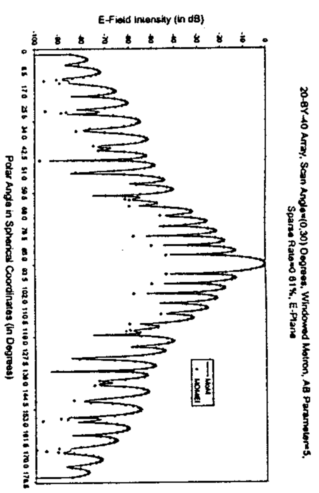


Figure (5) The radiation patterns in the E-plane of a 20 by 40 dipole array as calculated by the MEI method, comparing to those using the direct MoM

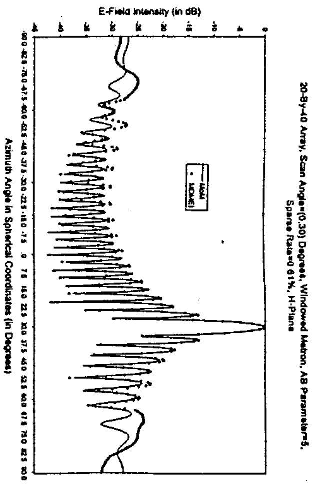


Figure (6) The radiation patterns in the H-plane of a 20 by 40 dipole array as calculated by the MEI method, comparing to those using the direct MoM