COMPUTATION OF EM EFFECTS ON LARGE BIOLOGICAL BODIES BY AN ITERATIVE MOMENT METHOD

J. J. H. Wang and J. R. Dubberley

Georgia Institute of Technology, GTRI
Atlanta, Georgia

ABSTRACT

A new iterative moment method algorithm using a conjugate gradient method is developed for a three-dimensional arbitrarily-shaped dielectric or biological body. The algorithm has a restart feature which allows the operator to pause at a preset stage and then resume the iteration in a continuous way, thus making the computation of large bodies a controlled and measured process with minimum cost and time for a desired accuracy.

INTRODUCTION

The interaction of microwaves with a biological body has beneficiary effects such as the hyperthermia treatment of a cancerous tumor and hazardous effects leading to ailments such as cataracts as well. In both cases it is essential to know the field intensity inside the biological body under consideration, especially in the resonance region in which the field intensity can be rapidly varying and difficult to predict, appearing sometimes as "hot spots." Computation of field intensity or energy deposition in the past has been carried out with considerable success by the method of moments (MM) [1]. However, the MM is limited by the capacity of the computer's central memory, and any software techniques such as virtual memory are generally impractical. For example, on a large CDC Cyber 855 mainframe computer, only about 80 volume cells can be accommodated in the central memory.

It has been known for several years that the use of iterative MM can circumvent this memory limitation. However, success in the iterative MM had been limited to two-dimensional (2-D) problem until a 3-D iterative conjugate gradient (CG) algorithm was recently developed by the present authors [2]. Instead of the 80 cell limitation in the direct MM, up to 3,666 cells can be handled by the iterative MM.

In computing large-body problems, an overriding concern is the huge time and cost of the computation. Even when the cost is of no consideration, the operator has a real and constant apprehension that the long computer run may at any time be aborted. To overcome these difficulties, a restart feature was implemented in the algorithm so that the computer run can pause for reevaluation and redirection by the operator and resume afterwards. A closely related issue is the role of initial guess in the iterative process. These are discussed in this paper.

DISCRETIZED VOLUME INTEGRAL EQUATION

Fig. 1 shows (a) a dielectric or biological body illuminated by an incident wave E^i, and (b) replacement of the material volume V by an equivalent volume current **J**. The problem can be formulated with an integral equation of the following form

$$\mathbf{y}(\mathbf{r}) = \int_V \mathbf{x}(\mathbf{r}') \cdot \underline{\mathbf{K}}(\mathbf{r}, \mathbf{r}')\, dv' \quad \textit{for } \mathbf{r} \in \mathbf{V}$$

where **y(r)** is known, $\underline{\mathbf{K}}$ is the kernel, and **x(r)** is an unknown to be solved for. The unknown **x(r)**, which can be either the current **J** or the electric field in V, is first discretized into pulse functions, that is, having a constant value inside individual volume cells that together form the volume V.

SOLUTION BY CG WITH RESTART FEATURE

A 3-D CG algorithm has been presented in Ref. 2. The general restart ideas have been explored in other iterative methods without much success [3,4]. In the literature, a good initial guess was considered by some to be of little help for convergence, while deemed by others to be very helpful and therefore provided the basis for the idea of restart.

The present authors have noted that, especially for the 3-D cases, the initial guess plays a very minor role in convergence, and that the $g^{(n)}$ functions and $A^{(n)}$, which dictate the direction and magnitude for correction in each iteration, are of paramount importance. As a result, our restart algorithm begins with the reading of $A^{(0)}$ and $g^{(0)}$, in addition to the initial guess $\mathbf{x}^{(0)}$, from those of a paused prior iterative run. As a result, the pause and restart do not disturb the continuity of the iterative search except for some numerical round-off errors in the storing and reading of the data files for x, g and A.

NUMERICAL RESULTS

Fig. 2 shows a dielectric block which is discretized into 24 cubic cells. Fig. 3 shows the total electric field at the center of cell No. 22, that is, at

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$x=0$, $y=0.482$ cm, $z=0$. Four sets of computational results are displayed in this figure. The bottom straight line is the result of a direct MM point-matching solution. Three iterative computations, all of which converge to the direct MM result within six significant figures, indicate the equivalence between the present iterative algorithm and the direct MM with point-matching.

Among the three iterative runs, one is a continuous procedure that terminates after a preset 75-iteration run, the second one pauses after the fifth iteration and then resumes, and the third one pauses after the 10th iteration and then resumes. As can be seen, the continuity of the iterative process is not disturbed by the pauses. The pauses allow the operator to evaluate and direct the progress and terminate the iterations in a measured and controlled manner.

A global view of the convergence phenomenon is shown in Fig. 4 in which the simple line is for a straight iterative computation, and the line with crosses is for a restart run with $\mathbf{x}^{(0)}$, $\mathbf{g}^{(0)}$, and $A^{(0)}$ read from $\mathbf{x}^{(20)}$, $\mathbf{g}^{(20)}$ and $A^{(20)}$ from a paused prior run. The rate of convergence is expressed as a normalized integrated square error, defined as

$$ERRN = \frac{ERR^{(N)}}{\int_V |\mathbf{x}(\mathbf{r}')|^2 dv'}$$

where $ERR^{(N)}$ is the integrated square error after the Nth iteration. As can be seen, $ERRN$ in the restart run is 20 iterations ahead of that of a straight run, indicating that the advantage of having a better $\mathbf{x}^{(0)}$, $\mathbf{g}^{(0)}$ and $A^{(0)}$ in restart is maintained until $ERRN$ drops to below 10^{-15}, where numerical round-off errors introduced in earlier input and output at pauses begin to take effect. Now if the restart is carried out with the informed initial guess $\mathbf{x}^{(20)}$ only, without $\mathbf{g}^{(20)}$ and $A^{(20)}$, we would expect the rate of convergence to suffer drastically. This is illustrated in Fig. 5. Thus the initial guess $\mathbf{x}^{(0)}$ plays a very minor role in the rate of convergence, but the direction vectors $\mathbf{g}^{(0)}$ and correction magnitude $A^{(0)}$ have a paramount effect on convergence.

CONCLUSIONS

An iterative CG algorithm with a restart feature has been developed to handle large dielectric or biological bodies. It was also observed that the effect of initial guess has only a small effect, while the direction vectors $\mathbf{g}^{(0)}$ and correction magnitude $A^{(0)}$ are much more important in achieving a faster rate of convergence.

REFERENCES

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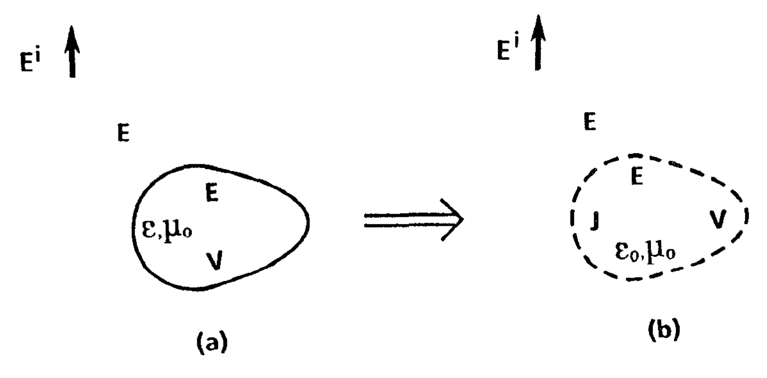

Figure 1. (a) An arbitrarily Shaped dielectric or biological body and (b) replacement of the material volume by an equivalent volume current.

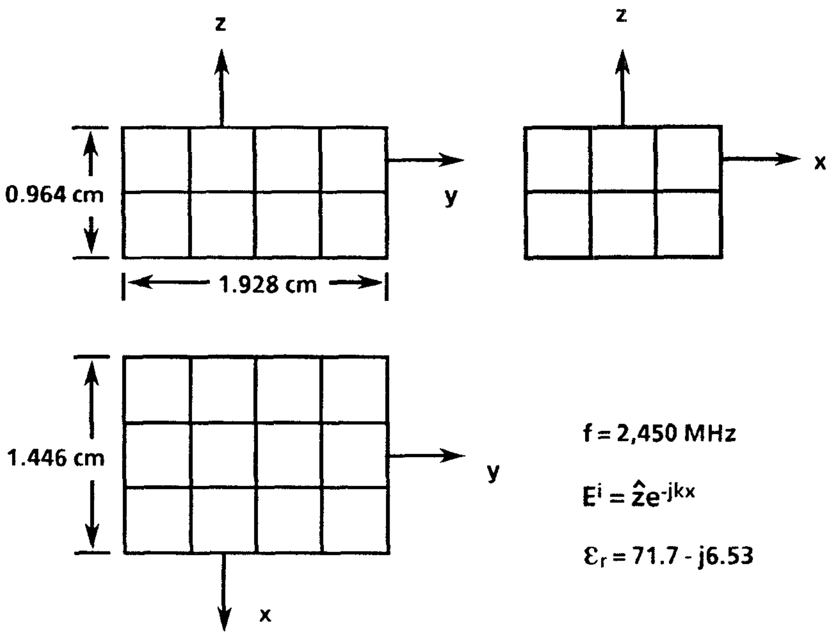

Figure 2 Three views of a dielectric block discretized into 24 cells.

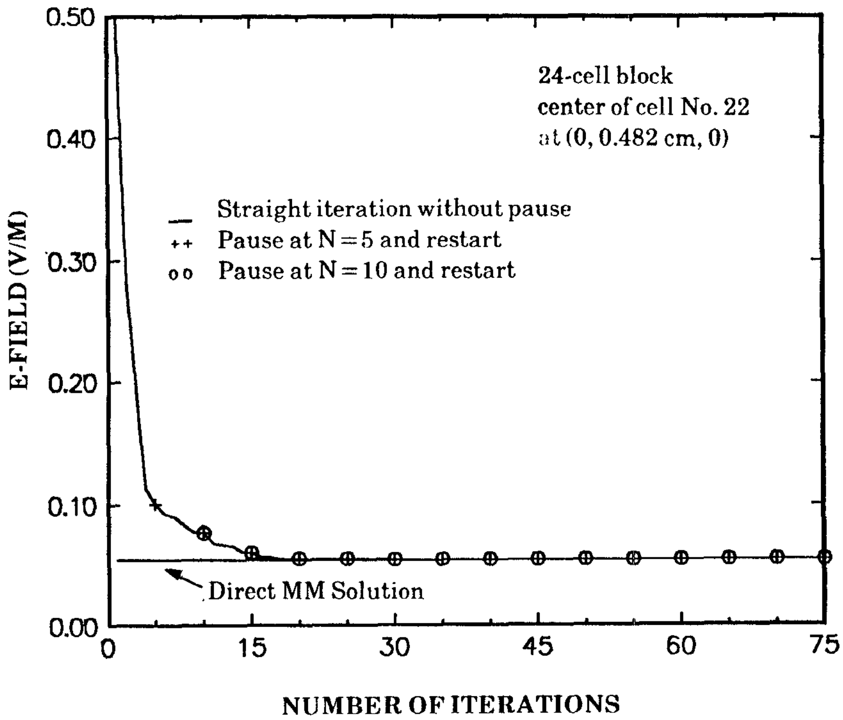

Figure 3. Comparison of computed E-field at cell No. 22 showing the restart feature.

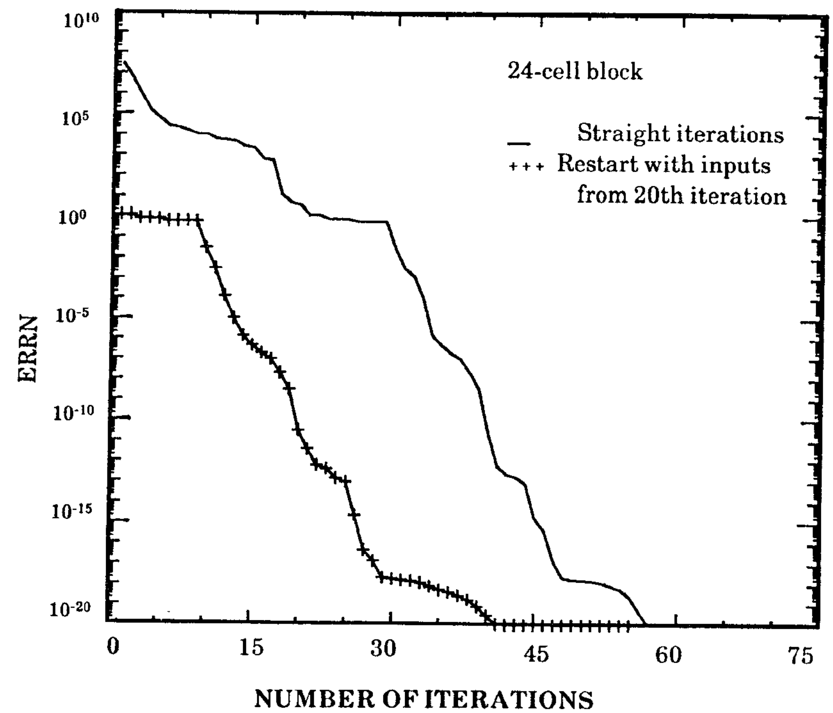

Figure 4. Comparison of the convergence behavior of straight and restart iterative runs

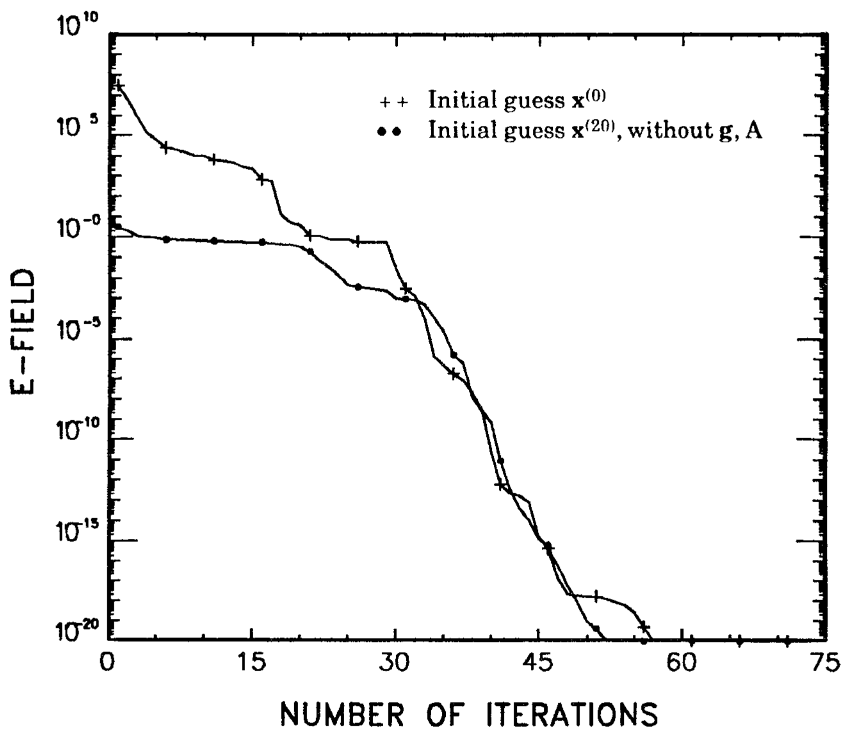

Figure 5. Rate of convergence not improved when only a good initial guess, without good **g** and A functions, is input in a restart.