Image Cover Sheet

CLASSIFICATION UNCLASSIFIED	**SYSTEM NUMBER** 151842

TITLE

ANALYSIS OF INTERACTION OF HPM WITH COMPLEX STRUCTURES

System Number:

Patron Number:

Requester:

Notes: Paper #8 of Multipart document, Sysnum 151750

DSIS Use only:

Deliver to: NL

ANALYSIS OF INTERACTION OF HPM WITH COMPLEX STRUCTURES

S. Kashyap and A. Louie
Defence Research Establishment Ottawa
Ottawa, Ontario, Canada
K1A 0Z4

#151842

ABSTRACT

This paper concerns the use of time- and frequency-domain methods for computing the interaction of high power microwaves with simple and complex structures. Effects of various factors — the geometric modelling of the structure, the Fourier transformation, the shape of the incident pulse, etc. — on the CPU-time and the accuracy of the solution are demonstrated. Results of our computations for various structures are presented.

INTRODUCTION

Use of time-domain methods such as the FDTD for modelling a wide variety of electromagnetic interaction problems has been increasing in popularity for a number of years. Application of the FDTD method has included modelling very complex structures such as the human body, microstrip and microwave structures, radar cross-section computations and inverse scattering [1]. Response can be obtained directly in the time domain, or in the frequency domain through a fast Fourier transformation (FFT).

Frequency-domain codes such as the NEC [2] and JUNCTION [3] have also been extensively used for electromagnetic analysis of a wide variety of structures. Response obtained in the frequency domain can be converted to time domain using an inverse fast Fourier transformation (IFFT).

The choice between a frequency-domain method and a time-domain method for modelling and analyzing a specific electromagnetic interaction is not always straightforward. This paper investigates the effect of a number of factors on the accuracy of the solution obtained. These factors include incident field wave shape, geometric modelling of the structure, Fast Fourier Transformation (FFT or IFFT), and computer time considerations.

PROCEDURE

Figure 1 shows some of the cylindrical structures with apertures and slots chosen for this study. A plane wave with a Gaussian waveform is assumed to be incident on the structure. The FDTD method is used to compute time-domain fields at various points inside and outside the cylinder for two incident plane wave polarizations. Frequency-domain response is obtained by taking an FFT of the time-domain response, with de-convolution of the incident waveform, resulting in a waveform-independent frequency response (i.e. the transfer function). This response is then compared with the frequency domain response obtained by the moment method implementation of the electric field integral equation (EFIE).

Since both the FDTD method and the EFIE method have been well described in the literature only a minimal description essential for this paper is given here. The theme of this paper is the *comparison* of frequency-domain results obtained from the two methods, rather than the intricacies of the methods themselves.

a. FDTD Method:

The FDTD method is a direct implementation of the time-dependent Maxwell's equations:

$$\begin{aligned} \varepsilon\frac{\partial \boldsymbol{E}}{\partial t} + \sigma \boldsymbol{E} &= \nabla \times \boldsymbol{H} \\ \mu\frac{\partial \boldsymbol{H}}{\partial t} &= -\nabla \times \boldsymbol{E} \end{aligned} \qquad (1)$$

The finite-difference procedure proposed by Yee [4] positioned the $\boldsymbol{E}$ and $\boldsymbol{H}$ fields at half-step intervals around a unit cell (Yee cell), where $\boldsymbol{E}$ and $\boldsymbol{H}$ are evaluated at alternate half time steps, effectively giving centred difference expression for both space and time derivatives. For example, taking one of the three partial differential equations associated with each of the vector equations above gives

Paper presented at the Sensor and Propagation Panel Symposium on "High Power Microwaves (HPM)" held in Ottawa, Canada 2-5 May 1994.

$$\frac{\partial E_z}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right)$$
$$\frac{\partial H_z}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x}\right) \qquad (2)$$

Rewriting them in finite difference form yields a complete system of six finite-difference equations which then provides a computational scheme: the new value of a field vector component at any point depends only on its previous value and on the previous values of the components of the other field vector at adjacent points. Thus at any given time step the computation can proceed one point at a time for a single processor, or several points at a time for a machine with parallel processors.

b. EFIE Method:
Reference [5] describes a simple and efficient numerical procedure for scattering by arbitrarily shaped bodies, using the moment method to solve the electric field integral equation (EFIE). The object surface is modelled as a finite union of planar triangular patches. Because of the EFIE formulation, this procedure is applicable to both open and closed surfaces. It has been applied to a wide variety of electromagnetic interaction problems and has yielded excellent correspondence with measurement and other numerical methods. In JUNCTION, the EFIE approach is extended to analyze an arbitrary configuration of conducting wires and bodies. The algorithm developed [5] can handle wire-to-wire, surface-to-surface, and wire-to-surface junctions. A modified version of JUNCTION is used here as the "EFIE method".

PLANE WAVE FORM

In this study, the time-domain incident wave on a structure is a Gaussian plane wave (Figure 2a). Figure 2b shows the frequency spectrum of this pulse. Note that 1% and 0.1% of peak value are reached at about 2.9 GHz and 3.6 GHz, respectively. A narrower time-pulse will have a wider frequency spectrum.

GEOMETRIC MODELLING

All electromagnetic simulation codes require the structure to be represented geometrically in a specified manner. DIDEC.DREO is a program used for this purpose. It creates wire grid, surface patch and cell models for electromagnetic interaction analysis. Figure 3 shows a block diagram of the DIDEC.DREO structure. The program allows a structure to be created or altered interactively. Several files can be merged together, allowing the creation of complicated structures by parts. The results associated with one or multiple input or output files can be displayed dynamically on one or more viewports. The structure to be analyzed can be input in various ways. Numerical entry of vertices on a keyboard, digitization of a blueprint with a graphics tablet, input files of one of the EM analysis programs (NEC, EFIE, FDTD, etc.), a built-in library of shapes which can be merged, and AutoCAD DXF files are the present means for creating a structure. Once a structure has been stored in DIDEC format, the program allows one to create input files for a number of electromagnetic analysis codes such as NEC (Numerical Electromagnetic Code), TWTDA (Thin Wire Time Domain Analysis Code), EFIE (Electric Field Integral Equation Code) and FDTD (Finite Difference Time Domain Code). Figure 4 shows a cylindrical structure modelled as triangular patches for analysis using the EFIE code. Figure 5 shows the same cylinder as a union of Yee cells for analysis using the FDTD code.

EFIE RESULTS FOR A CYLINDER WITH OPENINGS

Figure 6 shows a cylinder with an aperture and three slots used in the study. It also shows a rectangular metal plate to simulate a circuit board. Three configurations of the connection between the cylinder and the metal plate, as well as two different pulse directions, are used. Figure 7 shows some of the EFIE results for one of the configurations at 1.1 GHz. It shows a three dimensional E-field plot at a transverse section at the centre of the cylinder. It also shows the corresponding E-field contour plot. The three dimensional plot and the contour plot show the distribution of E-fields in and around the cylinder and the concentration of these fields at the slots.

FDTD RESULTS AND COMPARISON IN THE FREQUENCY DOMAIN

The surface of the cylinder and plate occupies about 2800 Yee cells, centrally located within an FDTD cell space of 81×81×81 cells. The centre of the cylinder is chosen for comparison and only the Ez-field is shown for both axial and transversal illuminations. A Gaussian pulse as described before is assumed to be incident on the cylinder. Figures 8 and 9 show the Ez-field obtained from a Fast Fourier transformation with de-convolution of the incident pulse. For comparison the corresponding results from the EFIE-based JUNCTION method are also shown. The comparison between the two methods is very good. Some disagreement exists between the peak magnitude at the resonance frequencies.

CPU-TIME CONSIDERATIONS AND MODELLING GUIDELINES

We have shown that in computer simulations of the interaction of electromagnetic waves with geometric structures, both time- and frequency-domain codes may be used. The two independent methods are comparable — as long as proper precautions are taken — and can be used as verification of the accuracy of each other.

From an efficiency, i.e. CPU-time economy, point of view, the FDTD method with an incident Gaussian pulse is the approach of choice. For this example, running EFIE takes about 4 hours of CPU-time on a VAX 6420 *for each frequency*, running FDTD with the Gaussian pulse (2049 time steps) takes 14 hours. Other geometric configurations also have a similar CPU-time ratio, that the CPU-time taken for EFIE(one frequency) :: FDTD(Gaussian) is 1::3.5.

The reason that FDTD(Gaussian) is the most efficient is that the time-domain response decays back to zero rapidly, and that after a complete run, one can Fourier-transform the results (with de-convolution of the Gaussian pulse) and obtain the field response *for all frequencies* (within the wide frequency spectrum of the Gaussian pulse). In other words, in the time it takes EFIE to run less than four frequencies, the process

FFT/Gaussian [FDTD(Gaussian)]
= EFIE(all frequencies)

gives the whole frequency spectrum of responses. Because frequency-domain response comparison, with FFT(FDTD) versus EFIE, has been shown to be reasonably accurate, this process is a reliable and time-saving method in obtaining frequency-domain data.

Thus, in summary, the merits of the FDTD method with an incident Gaussian pulse, followed by a time-to-frequency Fourier transform, are:

a. large frequency content of the incident pulse,
b. pulse decays down to zero rapidly, minimizing running time, and
c. efficiency: one time run to obtain all frequencies.

(Note, however, there is nothing "magical" about the Gaussian pulse itself: any time-domain pulse of narrow pulse width would share the same merits. The Gaussian pulse is chosen because of its simple analytic form and because it is a "standard".) The main disadvantage is due to computer resources, that only the chosen field quantities at several specified points are written to the output (although all six field components at all the Yee cells are evaluated at each time step, due to the constraint of the size of the output file only those chosen ones are written out). The code must be run again for computation of other field components and at other points. (As a contrast, in EFIE the currents on all the edges are stored in an output file. So the field values at any other points *at the same frequency* can be calculated from this "currents file" and EFIE does not have to be rerun.)

Time-domain response comparison has some inherent inaccuracies, mainly due to the fact that difference equations are by definition *approximations* to differential equations. In FDTD versus IFFT(EFIE), care has to be taken in finding the correct field locations for direct comparisons.

Finally, it must be remembered that discretization errors can be significant. In the FDTD approach one must keep in mind that the minimum reliable wavelength is ten times the size of the Yee cell (hence setting the limit for the maximum reliable frequency). Also, using smaller cells (hence more cells), within the limit of the host computer, to model the geometric object may improve the accuracy of the comparison. The availability of the field quantities only at discrete points due to the lattice structure can create some problems. In the frequency-domain code EFIE, discretization affects both the high and the low frequencies: on the one hand there is the one-fifth wavelength rule, setting the limit for the maximum frequency, and on the other hand at low frequencies there must be enough spatial resolution to reflect highly varying fields in neighbourhoods of "boundary edges". It must be remembered that the discretization guidelines of "10 cells/λ" and "edges $\leq \lambda/5$" are "traditional" ones based on experience from many studies in computational electromagnetics. They are sometimes more stringent than necessary and useful results may be obtained even above the high-frequency threshold. This is why in sometimes we may present the high-frequency results well above the threshold. The point of caution is that if the guidelines are violated, one must seek independent verification of the results obtained.

CONCLUSIONS

In this study, the penetration of HPM inside an cylinder with openings and loaded with a rectangular metal plate has been studied. The FDTD code has been used to calculate the time-domain response for a Gaussian pulse. Comparison, in the frequency domain, has been made with the results obtained by using the frequency-domain method EFIE. Effects of various factors such as wave shape, structure discretization, and fast Fourier transformation on CPU-time and accuracy of the results were discussed. Guidelines for using the time-domain and the frequency-domain codes were suggested. It was found to be more efficient in most cases to use the time-domain method.

REFERENCES

[1] A. Taflove and K. R. Umashankar, "The Finite-Difference Time-Domain Method for Numerical Modeling of Electromagnetic Wave Interactions with Arbitrary Structures", *Progress in Electromagnetic Research*, Elsevier, 1990.

[2] G. L. Burke and A. J. Poggio, "Numerical Electric Code (NEC) — Method of moments", *Naval Ocean Systems Centre, Technical Document* 116, 1977.

[3] S.-U. Hwu and D. R. Wilton, "Electromagnetic Scattering and Radiation by Arbitrary Configurations of Conducting Bodies and Wires", *University of Houston, Technical Report* 87-17, 1988.

[4] K. S. Yee, "Numerical Solution of Initial Boundary Value Problem involving Maxwell's Equations in Isotropic Media", *IEEE Transactions on Antennas and Propagation*, AP-14, 302-307, 1966.

[5] S. M. Rao, D. R. Wilton, and A. W. Glisson, "Electromagnetic Scattering by Surfaces of Arbitrary Shape", *IEEE Transactions on Antennas and Propagation*, AP-30, 409-418, 1982.

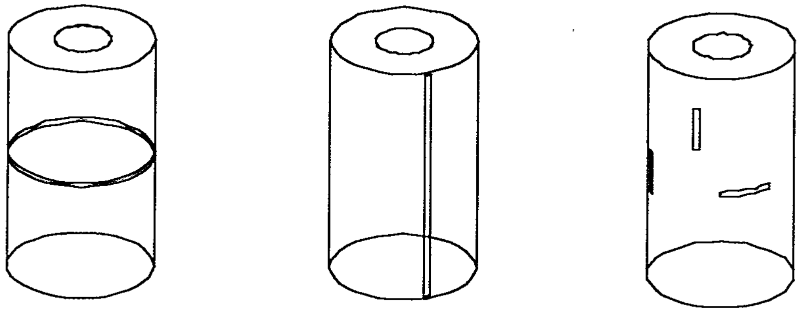
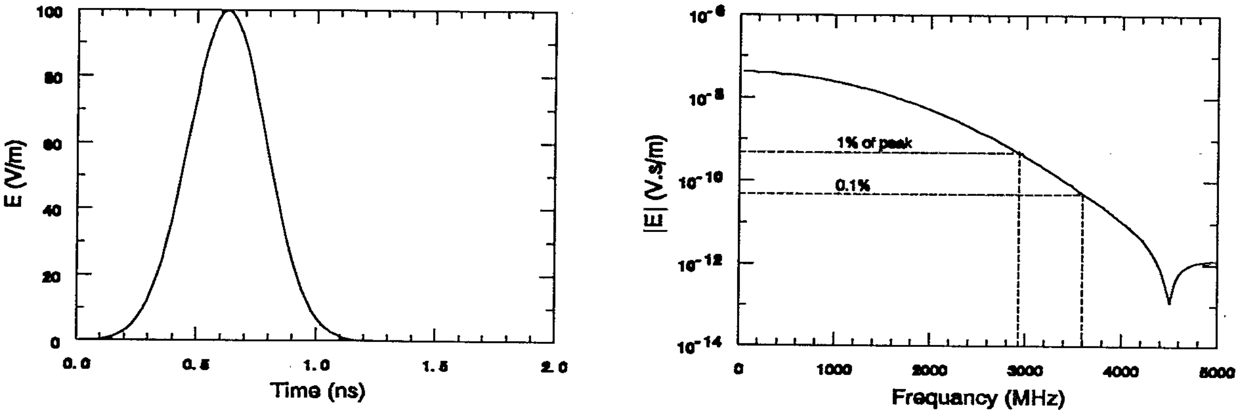


Figure 1. Some of the cylindrical structures under study.



a

b

Figure 2. Gaussian pulse in time and frequency domains.

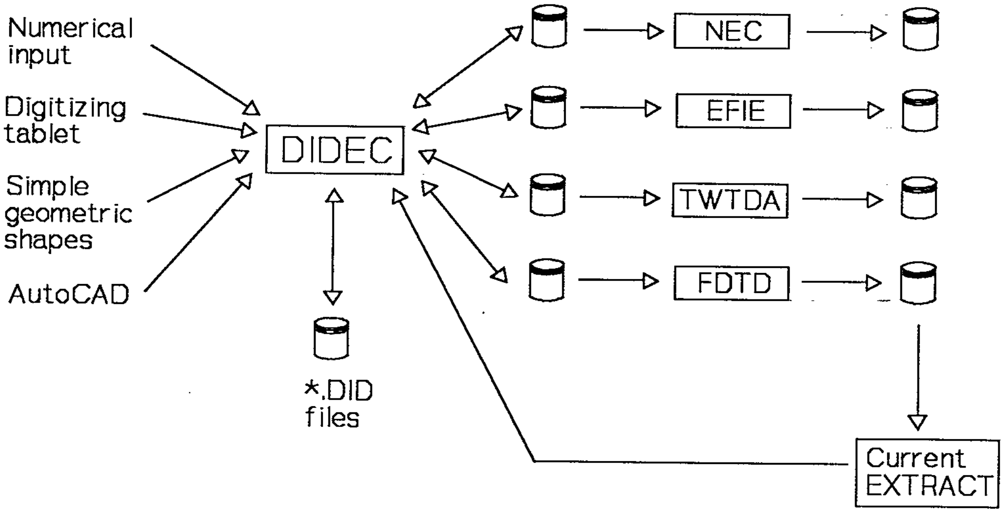


Figure 3. The block structure of the geometric modelling DIDEC.DREO program.

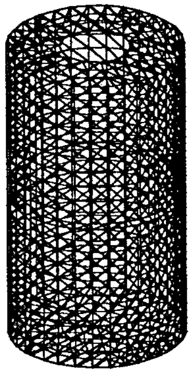


Figure 4. Example of a triangular surface-patch model for EFIE.

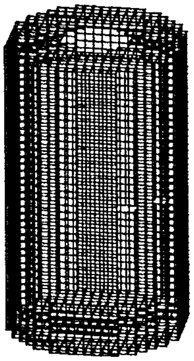


Figure 5. FDTD model of the same cylinder.

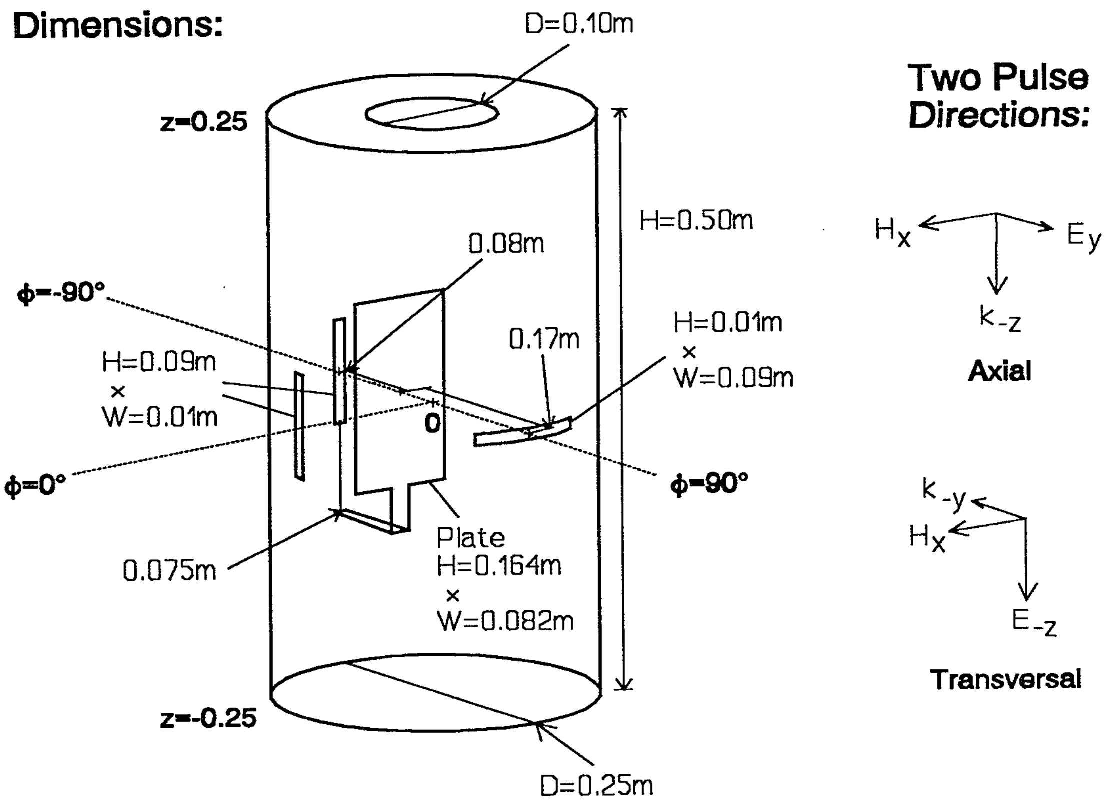


Figure 6. Cylinder dimensions and pulse orientations

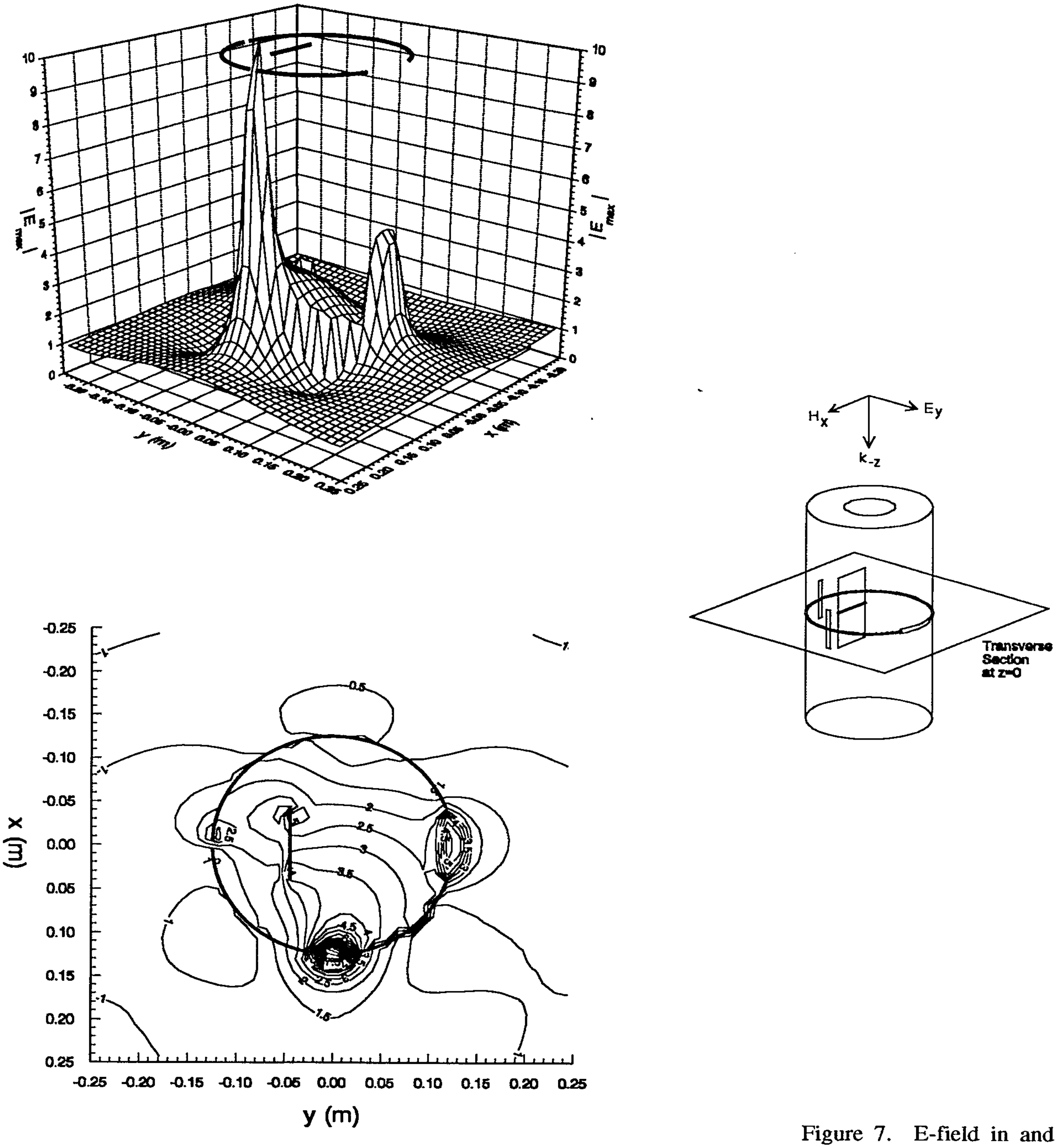


Figure 7. E-field in and around a cylinder with slots and floating plate.

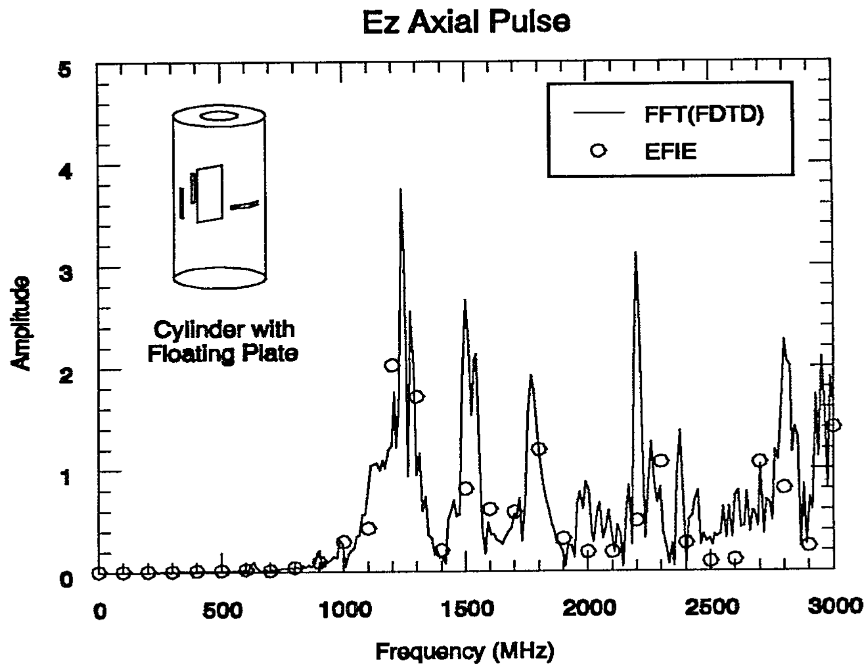


Figure 8. Ez-field at the centre of cylinder under an axial pulse: FDTD versus EFIE in frequency domain

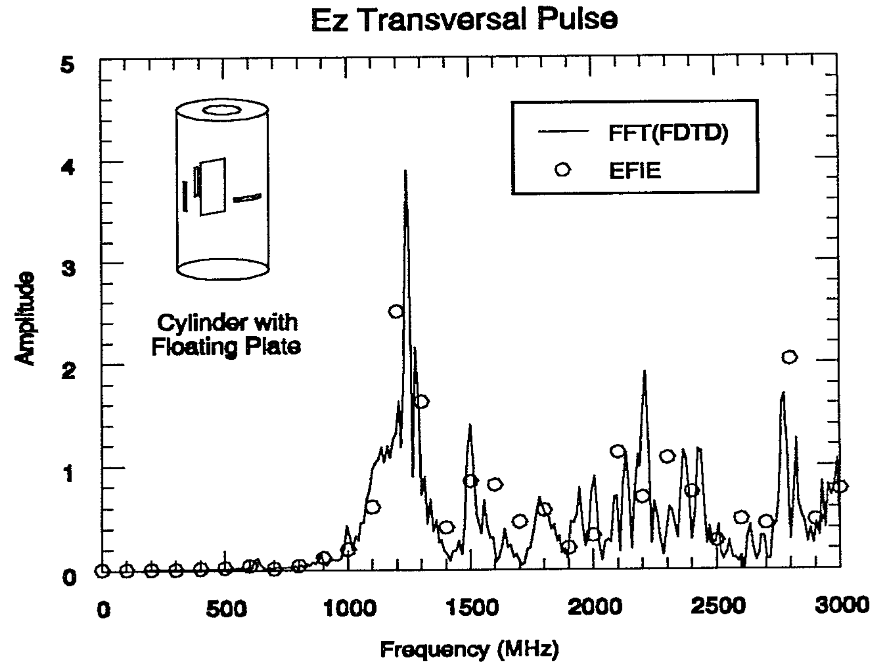


Figure 9. Ez-field at the centre of cylinder under a transversal pulse: FDTD versus EFIE in frequency domain

DISCUSSION

MALABIAU

1/ Quelle est la fréquence maximale correspondant à la discrétisation effectuée sur le modèle de frégate qui a été présenté ?

2/ Quelle est la taille maximale des matrices utilisés dans les calculs ?

AUTHOR'S REPLY

1/ La discrétisation a été effectuée pour pouvoir être valide jusqu'à 100 MHz environ.

2/ La taille maximale des matrices est de 5000 à 10000 x10000.

E. SCHWEICHER

Did you validate your code by calculating the pulse response of a perfect conducting spherical target ?

AUTHOR'S REPLY

Yes, the code was validated for a number of targets, including a perfect conducting sphere.

Translation:

Q.

1. What is the maximum frequency of the digitizing carried out on the model of the frigate which was presented ?

2. What is the maximum size of the matrixes used in the calculations ?

A.

1. Digitizing was carried out for validation up to about 100MHz.

2. The maximum size of the matrices is 5000 t0 10 000 x 10 000.