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**Electronics
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**Organized by
Ministry of Science and Technology**

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ELECTRONIC ENGINEERING

Time Reversal Electromagnetic Simulation Using FDTD with MATLAB

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Abstract— The Finite Difference Time Domain method (FDTD) uses centre-difference representations of the continuous partial differential equations to create iterative numerical models of wave propagation. Initially developed for electromagnetic problems the technique has potential application in acoustic prediction. In this paper the time reversal electromagnetic simulation has been discussed. That work is based on the sensor management for a room. The reversal time for sensor from the different source of transmission could be viewed on the MATLAB command window. This research aims to develop the signal processing of the sensor management within 3 meters around signal source.

Keywords— Time Reversal Mirror, Electromagnetic, FDTD, Simulation, MATLAB

I. INTRODUCTION

The acoustic application of the technique considers wave propagation in a medium using the equations for change of acoustic particle velocity w and pressure p with respect to time.

$$\frac{\partial w}{\partial t} = -\frac{1}{\rho} \nabla p \quad (1)$$

$$\frac{\partial p}{\partial t} = -K \nabla \cdot w \quad (2)$$

Where ρ is the medium density and K is the medium bulk modulus.

Gradient operator

$$\nabla f = \left(\frac{\partial f}{\partial x}, \frac{\partial f}{\partial y}, \frac{\partial f}{\partial z} \right)$$

Divergence operator

$$\nabla \cdot f = \frac{\partial f_x}{\partial x} + \frac{\partial f_y}{\partial y} + \frac{\partial f_z}{\partial z}$$

By writing these equations as 1D centre differences we can show

$$w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} = w_{x_i+\frac{1}{2}}^{n-\frac{1}{2}} - \frac{\partial t}{\rho \partial x} \{p_{i+1}^n - p_i^n\} \quad (3)$$

$$p_i^{n+1} = p_i^n - K \partial t \left\{ \frac{w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} - w_{x_i-\frac{1}{2}}^{n+\frac{1}{2}}}{\partial x} \right\} \quad (4)$$

Where i is a spatial index n is a temporal index.

II. IMPLEMENTING PERFECTLY MATCHED LAYERS

When a wave reaches the ends of the waveguide it is reflected back into the medium. This is a problem for most simulations that can be solved with the implementation of perfectly match layers (PMLs). Originally developed by Berenger [5], the technique specifies a new region that surrounds the FDTD domain where a set of non physical equations are applied giving a high attenuation. For our 1D case the equations are

$$\frac{\partial w_x}{\partial t} + K \alpha w_x = -\frac{1}{\rho} \frac{\partial p}{\partial x} \quad (5)$$

$$\frac{\partial p}{\partial t} + K \alpha p = -K \frac{\partial w_x}{\partial x} \quad (6)$$

Where α is the attenuation coefficient.

Equations (5) and (6) give the solution

$$w_x = \psi \quad p = z \psi \quad \psi = e^{-i\left(\frac{\omega}{c} x w\right)} e^{-z \alpha a w} \quad (7)$$

Clearly by setting attenuation factor $\alpha = 0$ we get back to the original FDTD equations (1) and (2) hence it can be shown that the wave speed is the same for medium and PML region as is the impedance

$$Z_{PML} = \frac{|p|}{|w_x|} = Z_{Medium} \quad (8)$$

Berenger hence showed that the PML boundary is theoretically reflection less, though in practice one has to give the PML boundary a width of say 10 elements and gradually introduce the absorption.

To implement in 1D our update equation (5) for the PML can be given using exponential differencing

$$K\alpha \frac{w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} - w_{x_i+\frac{1}{2}}^{n-\frac{1}{2}} e^{K\alpha\delta t}}{(1-e^{K\alpha\delta t})} = -\frac{1}{\rho\delta x} \{p_{i+1}^n - p_i^n\} \quad (9)$$

$$w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} = w_{x_i+\frac{1}{2}}^{n-\frac{1}{2}} e^{-K\alpha\delta t} - \frac{(1-e^{-K\alpha\delta t})}{K\alpha} \frac{1}{\rho\delta x} \{p_{i+1}^n - p_i^n\} \quad (10)$$

Similarly (6) becomes

$$\frac{K\alpha \{p_{i+1}^n - p_i^n e^{-K\alpha\delta t}\}}{(1-e^{K\alpha\delta t})} = -K \left\{ \frac{w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} - w_{x_i-\frac{1}{2}}^{n+\frac{1}{2}}}{\delta x} \right\} \quad (11)$$

$$\Rightarrow p_i^{n+1} = p_i^n e^{-K\alpha\delta t} - \left(\frac{1-e^{-K\alpha\delta t}}{K\alpha} \right) K \left\{ \frac{w_{x_i+\frac{1}{2}}^{n+\frac{1}{2}} - w_{x_i-\frac{1}{2}}^{n+\frac{1}{2}}}{\delta x} \right\} \quad (12)$$

For our implementation we'll create a PML region of 10 elements and hence gradually introduce the absorption such that

$$\alpha_i = \alpha \left(\frac{x_i}{x_{PML}} \right)^2 \quad (13)$$

Where the maximum absorption for 1/10 of the PML will be

$$e^{-K\alpha\delta t} = 0.1 \quad \Rightarrow \alpha = \frac{1}{K\delta t} \ln(10) \quad (14)$$

Where x_i the distance is moved into PML and x_{PML} is PML width.

III. SOFTWARE IMPLEMENTATION

The FDTD simulation functions in MATLAB environments which implemented in this paper are based on 1D and 3D methods. For the 1D FDTD methods, the algorithm of MATLAB functions is illustrated in Fig. 1.

According to the Fig. 1, the FDTD simulation of sensor data will be displayed on the computer. After declaring the physical and simulation constants, we must define source and location for FDTD simulation. In the defining stage, it has two methods to simulate the FDTD. The first method is based on the "Gaussian_pulse" function. The peak to peak distance of FDTD output is far away from one peak to another. The second one is based on the left edge and right edge of the PML regions. The simulation results are shown in the following figures.

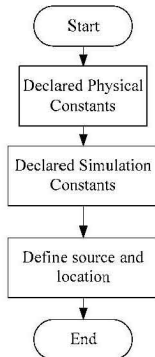


Fig. 1 Flowchart of 1D FDTD method

For the 3D FDTD methods, the algorithm of MATLAB functions is illustrated in Fig. 2.

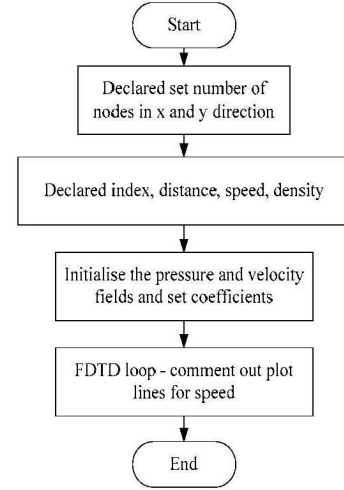


Fig. 2 Flowchart of 3D FDTD method

Figure 2 shows the 3D FDTD simulation. After declaring the set number of nodes in x and y direction, index, distance, speed and density of the PML, we have to write the FDTD loop- comment out plot lines for speed of FDTD simulation. The simulation result is shown in Fig. 7. The limited time for 3D simulation is 82.46ms.

IV. EXPERIMENTAL RESULTS

A. Calculating the Frequency Domain Output

Up until now, the output of our FDTD programs has been the E field itself, and we have been content to simply watch a pulse or sine wave propagate through various media. Needless to say, before any such practical applications can be implemented, it will be necessary to quantify the results. Suppose now that we are asked to calculate the E field distribution at every point in a dielectric medium subject to illumination at various frequencies.

One approach would be to use a sinusoidal source and iterate the FDTD program until we observe that a steady state has been reached, and determine the resulting amplitude and phase at every point of interest in the medium. This would work, but then we must repeat the process for every frequency of interest. System theory tells us that we can get the response to every frequency if we use an impulse as the source. We could go back to using the Gaussian pulse, which, if it is narrow enough, is a good approximation to an impulse. We then iterate the FDTD program until the pulse has died out, and take the Fourier transform of the E fields in the slab.

If we have the Fourier transform of the E field at a point, then we know the amplitude and phase of the E field that would result from illumination by any sinusoidal source. This, too, has a very serious drawback: the E field for all the time

domain data at every point of interest would have to be stored until the FDTD program is through iterating so the Fourier transform of the data could be taken, presumably using a fast Fourier transform algorithm. This presents a logistical nightmare.

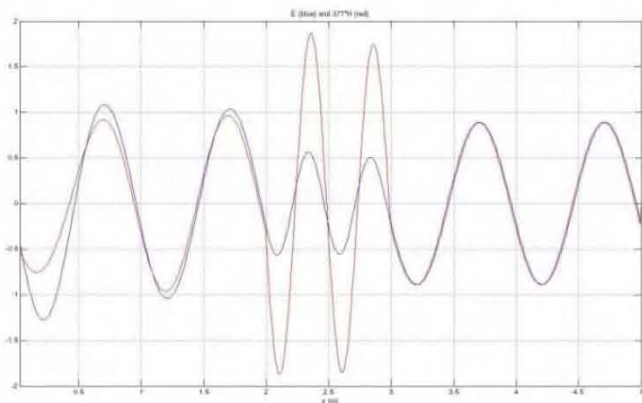


Fig. 3 Result of 1D FDTD Method

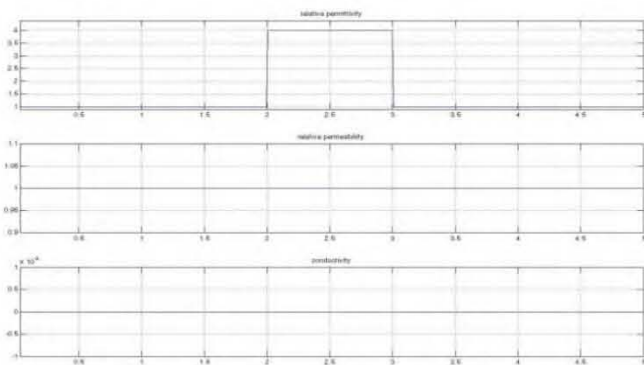


Fig. 4 Result of Output Conductivity and permeability

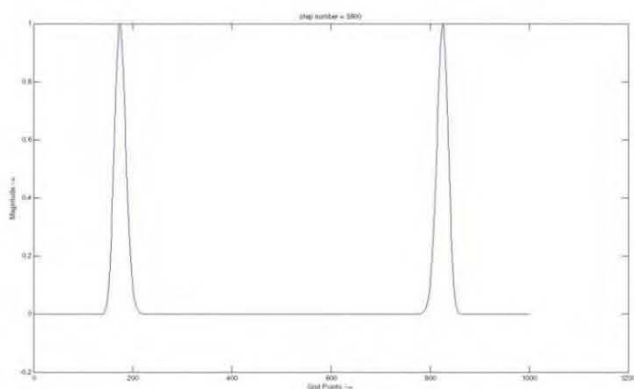


Fig. 5 Result of Test Script 1

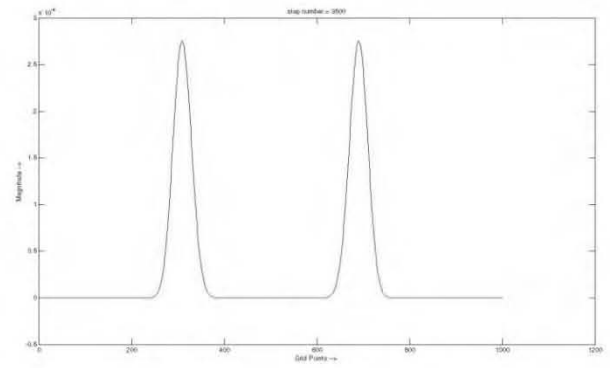


Fig. 6 Result of Test Script 2

FDTD Time = 82.46 msec

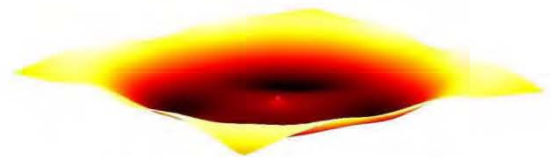


Fig. 7 Result of 3D Time Reversal output

V. CONCLUSIONS

In this paper, the array output of FDTD results are illustrated in the above figures. Based on the simulation results, we can conclude the following comments. In the 1D FDTD simulations, we can study the result from using “Gaussian_pulse” function and others. The FDTD results cannot be limited to definite region but the results that shown in this paper are limited by PML region for simulation only. The 3D result in Fig. 7 is the same condition as the 1D case. MATLAB scripts for `fdtd_1d` and time reversal functions are very efficient data for simulation of electromagnetic in sensor management. By changing the simulation parameters from this paper, we could analyze difference applications for electromagnetic simulation as radar target imaging system or underwater acoustic communication system.

ACKNOWLEDGMENT

I would wish to acknowledge the colleagues at Mandalay Technological University who have contributed to the development of this paper.

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