Nonstandard FDTD Realization of Radiation Behaviour of Epsilon Negative Metamaterial Corner Reflector Antenna

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Abstract – **The radiation behaviour of a corner reflector antenna designed using epsilon negative (ENG) artificial wire medium is realized using nonstandard Finite Difference Time Domain (NS-FDTD) method and the results are compared with standard FDTD algorithm. High accuracy NS-FDTD algorithm which requires less iteration for convergence is for the first time implemented for metamaterial corner reflector antenna. This is achieved by extending this powerful algorithm by addressing the stability related issues in conducting media and the proposed work may find potential applications in the simulation studies of dispersive and metamaterial designs.**

I. Introduction

One of the major issues for the implementation of standard Finite Difference Time Domain (FDTD) method in structural designs related to matematerials is the requirement of large domain space which, in turn, requires high computational cost. A modified form of FDTD, named as nonstandard Finite Difference Time Domain (NS-FDTD), has proved to be highly effective in many aspects like accuracy and speed and it achieves the same result with λ/h (ratio of wavelength to grid space) = 8 which the standard one can only attain with λ/h = 1140 [1]. NS-FDTD has already been successfully implemented for dielectric medium [2] and for structures having low conductivity. Quite recently, this powerful algorithm which considerably enhances the computational efficiency is reported for a plane conducting plasma medium [3]. In this work, for the first time, we have successfully employed NS-FDTD method to analyze the radiation behaviour of a corner reflector antenna designed using conducting wires in the form of an artificial Epsilon Negative (ENG) plasma medium by considering the stability issues related to the convergence of the function used [4]. The already predicted accuracy claims of NS-FDTD is achieved in a metamedium and the results are compared with standard FDTD.

II. Formulation of the problem and Design of the Structure

For employing NS-FDTD, we have incorporated wave equation method instead of using Maxwell's equations. The absorbing wave equation given by Cole [4] is used for designing the ENG medium which made by periodic array of thin conducting wires for the proposed corner reflector antenna and is given by

$$E_z(\mathbf{x}, t+\Delta t) = E_z(\mathbf{x}, t) + (\frac{1-a}{1+a})[E_z(\mathbf{x}, t) - E_z(\mathbf{x}, t-\Delta t))] + (\frac{v^2}{1+a})D_o^2 E_z(\mathbf{x}, t) \quad (1)$$

where v^2 and a are given by

$$v^2 = \frac{1}{\sin^2(\frac{kh}{2})}[\sin^2(\frac{\omega\Delta t}{2})\cosh^2(\frac{\alpha\Delta t}{2}) - \sinh^2(\frac{\alpha\Delta t}{2})\cos^2(\frac{\omega\Delta t}{2}) + \frac{1}{2}\tanh(\alpha\Delta t)\sinh(\alpha\Delta t)\cos(\omega\Delta t)] \quad (2)$$

$$a = \tanh(\alpha\Delta t) \quad (3)$$

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D_o^2 in Eq. (1) is given in terms of independent difference operators D_1^2 and D_2^2 as

$$D_o^2 = \gamma D_1^2 + (1-\gamma) D_2^2 \tag{4}$$

where

$$D_1^2 = d_{xx} + d_{yy} \tag{5}$$

$$2D_2^2 E_z(x,y) = E_z(x+h, y+h) + E_z(x+h, y-h) + E_z(x-h, y+h) + E_z(x-h, y-h) - 4E_z(x,y) \tag{6}$$

The conductivity related factor α and the weighing function γ in terms of wave vector k are given by

$$\gamma = \frac{2}{3} - \frac{1}{90}(kh)^2 - \frac{1}{15120}(kh)^4(11 - 5\sqrt{2}) - ...... \tag{7}$$

$$\alpha = \frac{\sigma}{2\varepsilon_0} \tag{8}$$

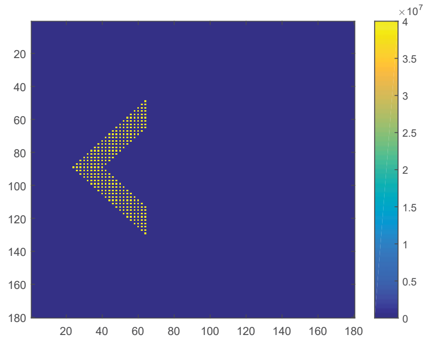
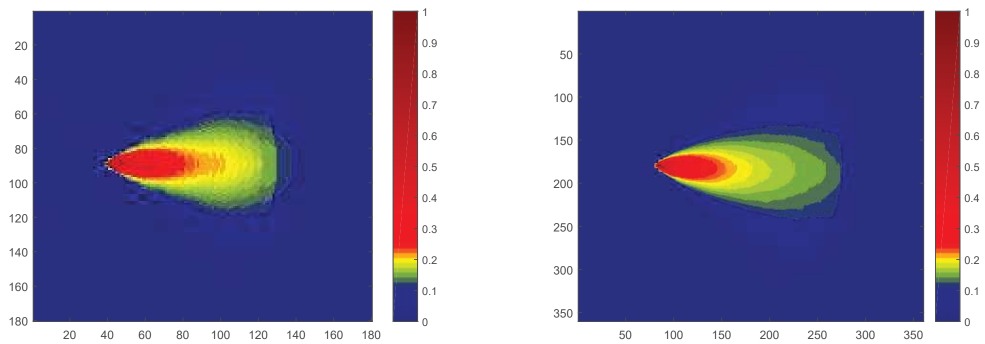


Fig. 1: Position of ENG metamaterial corner reflector antenna in the computational domain

Cole's stability function v^2 is is found to be converging for low loss and loss less medium [1, 4]. But for the case of high conductivity, it is observed that the stability function will converge only for certain specific values for a given conductivity σ and discretization parameter $N = \lambda/h$. Time step used for NS-FDTD is $0.8h/c$.

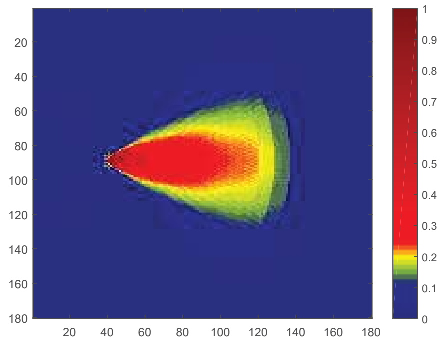
For implementing the standard FDTD, the time step will be $0.7h/c$ and the field equation (Eq. 1) will reduce as given in [4].



[a] [b]

Fig. 2: Radiated electric field distribution near the ENG corner reflector antenna using NS-FDTD for discretization parameter (a) N=8 and (b) N=16

The ENG medium used for the design of the corner reflector antenna (corner angle 90^0) is made using the periodic array of conducting wires having σ around 4×10^7 S/m in the computational domain as shown in Fig. 1. The periodicity in $x-y$ direction is taken as 1.6667×10^{-7} m and the corresponding plasma frequency is 6.4 x 10^{14} Hz [5]. Thickness of the slab is 2λ and the position of the sinusoidal source is at a distance of $\lambda/2$ from the vertex of the corner reflector.



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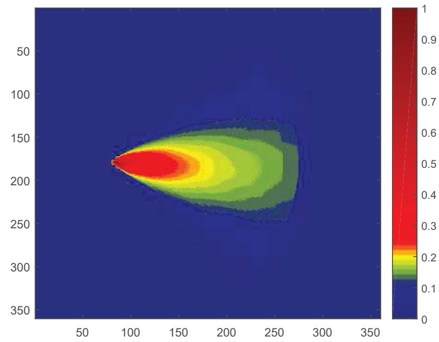

[b]

Fig. 3: Radiated electric field distribution near the ENG corner reflector antenna using standard FDTD for discretization parameter (a) N=8 and (b) N=16

III. Result and Discussion

Excitation source used has frequency 4.5×10^{14} Hz which is less than the plasma frequency of the ENG medium. Studies are carried out with discretization parameter 8 and 16 after carefully analyzing the exact value of conductivity suitable for the stability function to converge. Field distributions obtained for the corner reflector antenna using NS-FDTD is shown in Figs. 2(a) and 2(b) for the discretization parameters 8 and 16. Field distributions obtained for standard FDTD for the same discretization values are shown in Figs. 3(a) and 3(b) for comparison. It is quite evident even from the visualization that for low value of discretization itself, NS-FDTD gives the required field distribution where as standard FDTD algorithm approaches exact result only for higher discretization values.

IV. Conclusion

We have introduced NS-FDTD algorithm to corner reflector antenna designed using metamaterial concept where by we have achieved all the predicted advantages of this new improvised technique. The results are reproduced using standard FDTD for comparison. By extending the advantages of NS-FDTD to the metallic inclusions, we were able to realize the field simulation of complicated structures like ENG wire medium with more accuracy and less number of iteration.

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