Materials Physics and Mechanics 42 (2019) 617-624 Received: May 9, 2019

THE EFFECT OF CONDUCTIVITY AND PERMITTIVITY ON PROPAGATION AND ATTENUATION OF WAVES USING FDTD

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Abstract. The purpose of this study was to investigate the effect of conductivity and permittivity on wave propagation and attenuation on the plate using FDTD (The Finite Difference Time Domain). The FDTD method is used to describe electromagnetic waves. The method used in this study was the basic principle of the numerical approach of differential equations by taking into account boundary conditions, stability, and absorbing boundary conditions. The results of the simulation showed that if the permittivity of the material increased, the propagation would increase as well; however, the attenuation would decrease exponentially. If material conductivity increased, propagation and attenuation would increase. Attenuation and propagation produced the same value when the permittivity value was 2. This simulation could be used to select materials and identify physical phenomena related to electromagnetic waves.

Keywords: conductivity, permittivity, propagation, attenuation, FDTD

1. Introduction

Electromagnetic waves are waves that are difficult to visualize like real conditions in our lives; thus, we need the right method to overcome this problem. The Finite Difference Time Domain (FDTD) method was first introduced by Kane Yee in 1966 to analyze electromagnetic fields [1]. FDTD is a simulation method used in the simulation of electromagnetic waves which uses the basic principle of a numerical approach of differential equations in the domains of space and time. FDTD is applied to various problems such as propagation, radiation, and the spread of electromagnetic waves. The Maxwell Curl equation shows the location of the electric and magnetic fields. This is because the charge and movement of the charge are combined with each other so that the both of them guard each other even when there is no charge or current [2].

Previous research on the use of the FDTD method on the numerical formulation of Maxwell's equations in time-dependent scattering processes has been conducted [2]. The FDTD method is further formulated in a computational form by Taflove [3]. Other studies related to FDTD are mostly carried out in regional hyperthermia [4]. Meanhile, the influence of dispersive media absorption for the process of scattering with a femtosecond scale pulse was developed by R.M. Joseph [5]. Further research was conducted on the influence of electromagnetic waves on biological materials [6]. The use of FDTD methods in various fields is also in the process of increasing MPI (Message Passing Interface) performance [7]. Furthermore, this method is also used for ADI-R-FDTD 3-D modeling with regard to

http://dx.doi.org/10.18720/MPM.4252019_15

divergence [8]. FDTD can also be used for frequency modeling shifted using CPML and radar cross section (RCS) [9-10]. In the material field, FDTD is used to estimate and calculate bands in phononic crystal [11], while in the telecommunications sector, FDTD is used for acoustic analysis and antennas [12-13].

Based on previous studies, research related to the use of FDTD in various fields requiring telecommunications and materials has developed in various fields. However, there is no research using FDTD that develops, calculates, and explains how to use wave propagation in materials that have permittivity and conductivity about propagation and attenuation. This simulation can be used to select materials and identify physical phenomena related to electromagnetic waves. In the telecommunications sector, it can be used to calculate profits and losses on the antenna. The purpose of this study was to investigate the effect of conductivity and permittivity on wave propagation and attenuation on the plate using FDTD.

2. Method

Approximation of Differential Equations. Differential equations for one propagating wave dimension can be explained and elaborated on time-dependent equations from Maxwell's equation [14]. The equation is written:

$$\frac{\partial E_x}{\partial t} = -\frac{1}{\varepsilon_0}\frac{\partial H_y}{\partial_z}, \quad (1)$$

$$\frac{\partial H_y}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_x}{\partial z}. \quad (2)$$

Equations (1) and (2) describe the travel of the electric field in the direction of the *x*-axis, the magnetic field in the direction of the *y*-axis, and the direction of wave propagation towards the *z*-axis. The approximate form of temporal and spatial differential equations can be written in the following equation

$$\frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{\Delta t} = -\frac{1}{\mu_0}\frac{H_y^{n}(k+1/2) - H_y^{n}(k-1/2)}{\Delta x}, \quad (3)$$

$$\frac{H_y^{n+1}(k+1/2) - H_y^{n}(k+1/2)}{\Delta t} = -\frac{1}{\mu_0}\frac{E_x^{n+1/2}(k+1) - E_x^{n+1/2}(k)}{\Delta x}. \quad (4)$$

Equations (3) and (4) describe the distribution of electric and magnetic fields depending on the time step and the step of distance.

Stability FDTD. FDTD stability discusses how we determine the interval Δt [2]. An electromagnetic wave propagating in free space cannot go faster compared to the speed of light. To spread the distance of one cell requires minimal time $\Delta t = \Delta x / c_0$. For the form of two-dimensional simulations, we must allow propagation to be in diagonal directions, which carries time requirements for $\Delta t = \frac{\Delta x}{\sqrt{2}c_0}$ and requires three-dimensional simulations $\Delta t = \frac{\Delta x}{\sqrt{3}c_0}$. This is summarized by the "Courant Condition" for n dimensions with equations

$$\Delta t \le \frac{\Delta x}{\sqrt{n}c_0}. \quad (5)$$

Absorbing Boundary Condition (ABC Theory). This theory introduces the absorption of the boundary conditions needed to maintain the *E* out and the *H* plane from being reflected back. Usually, in calculating the *E* field, we need to know the surrounding of *H* value, this is the basic assumption of the FDTD method, in boundary conditions we will not have a value to one side [15]. But, this has an advantage because there are no sources outside the boundary field. Thus, the boundary field must spread outside. These two facts were used to estimate the value at the end using the value next to it. At the boundary conditions where k = 0, the wave will go to the boundary in free space. This will lead to the movement on Co the speed of light meaning that in one time step of the FDTD algorithm, it moves.

$$\text{distance} = Co.\Delta t = Co.\frac{\Delta x}{Co} = \frac{\Delta x}{2}. \tag{6}$$

This equation basically determines that it takes two steps for the wavefront to cross one cell so that the common sense approach tells us that boundary conditions are acceptable. The equation is as follows

$$E_x^n(0) = E_x^{n-2}(1). \tag{7}$$

It can be said that the system is relatively easy to be implemented, in which this can be done by just saving the E_x value (1) for two-time steps, and then putting it in $E_x(0)$. A wave originates in the middle propagates outward and is absorbed without being reflected back.

Areas that can be calculated using FDTD simulation are limited by computer resources. For example, in a two-dimensional simulation, this program contains a two-dimensional matrix of values from all fields. If we simulate a wave produced from a source of propagating points in free space, then what must be done to overcome this is that unexpected reflections will be generated which will return to the inside. There will be no way to determine which waves come and which are reflected. This is the reason that ABC has been the solution to problems during FDTD.

One of the most appropriate uses of the flexible and efficient ABC theory is the Perfect Match Layer (PML) developed by previous researcher [15]. The basic idea from this value can be written: if a wave propagates on medium A and gives effect to medium B, the amount of reflection is determined by the intrinsic impedance of the two media

$$r = \frac{\eta_A - \eta_B}{\eta_A - \eta_B}, \tag{8}$$

which is explained by the dielectric constant and permeability of the two media

$$\eta = \sqrt{\frac{\mu}{\varepsilon}}. \tag{9}$$

Until now, we have assumed that permeability is constant so that when pulses travel from one dielectric to another the dielectric continues constantly. In equation (9) we can see how big the waves are transmitted and reflected. However, if it changes so it remains constant, it will be zero and no reflection can occur. This still does not solve our problem, because pulses will continue to propagate in new media. What we want is media that also decay so that the pulses will die before touching the boundary.

3. Results and Discussion

The propagation of electromagnetic waves in free space or simple media determined by dielectrics is relatively constant ε_r has been done [16]. However, there are many media that also have the term attenuation that is determined by conductivity [17]. Attenuation and propagation are largely determined by material properties in the form of permittivity and conductivity.

The differential equation in the form of electromagnetic wave propagation simulation in media that has conductivity is written on the security of the different approach for both the temporal and spatial derivatives of the electric and magnetic fields as follows [4,18-20]

$$\bar{E}_x^{n+1/2}(k)=\frac{\left(1-\frac{\Delta t.\sigma}{2\varepsilon_r\varepsilon_0}\right)}{\left(1+\frac{\Delta t.\sigma}{2\varepsilon_r\varepsilon_0}\right)}\bar{E}_x^{n-1/2}(k)-\frac{1/2}{\varepsilon_r\left(1+\frac{\Delta t.\sigma}{2\varepsilon_r\varepsilon_0}\right)}\left[H_y^n(k+1/2)-H_y^n(k-1/2)\right]. \tag{10}$$

The equation of the attenuation constant and the propagation of the electric field propagating on the palate can be written as follows

$$\alpha=\frac{\omega}{c_0}\sqrt{\frac{\varepsilon_r}{2}}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon_0\varepsilon_r}\right)^2}-1\right]^{1/2}, \tag{11}$$

$$\beta=\frac{\omega}{c_0}\sqrt{\frac{\varepsilon_r}{2}}\left[\sqrt{1+\left(\frac{\sigma}{\omega\varepsilon_0\varepsilon_r}\right)^2}+1\right]^{1/2}. \tag{12}$$

The discussion on Peper is how to simulate electromagnetic waves on a plate with permittivity and conductivity. The electromagnetic waves emitted in these papers have a frequency of 2.4 GHz using gaussian-shaped pulses. The large plate permittivity of 4 and a large conductivity of 0.04 and 100 plate propagation with n-step 1500 was found.

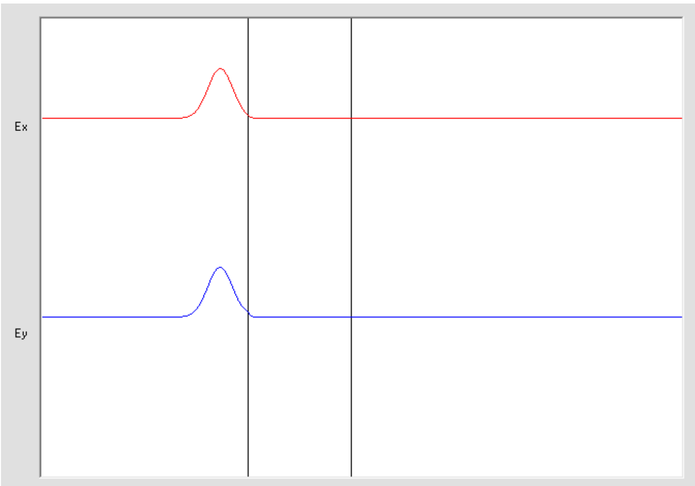

Fig. 1. Electric and magnetic field waves before conductivity

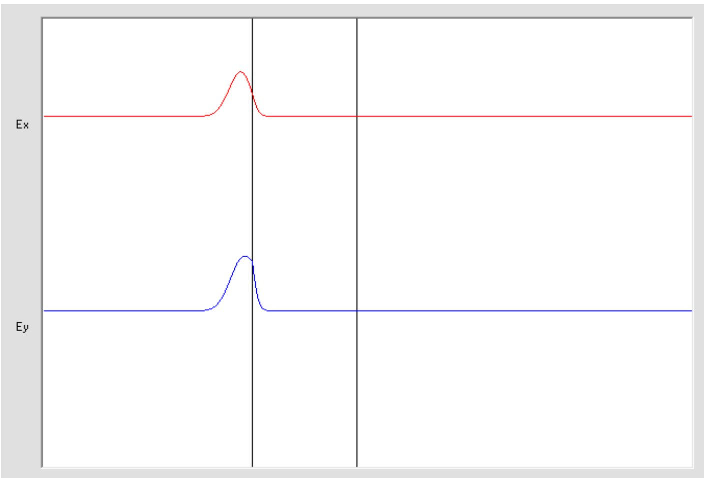

Fig. 2. Instantaneous electric and magnetic field waves regarding conductive materials

Figure 1 describes electromagnetic waves before using materials with conductivity and permittivity in the *E* and *H* fields. The tendency has the same shape on n-step 431. The propagation of waves in the vacuum permittivity does not experience attenuation and propagation as has been done before [2]. Wave propagation constant does not depend on space and time. In the meantime, Fig. 2 shows that when it comes to field materials E_y has a tendency to decay faster, this is due to the field of E_y moving faster than E_x field on n-step 462. Electric field Ey has a step first, and attenuation is caused by changes in wave tensor due to the nature of the permittivity of the material and the propagation rate increases due to increased conductivity of the material. The greater the value of the conductivity rate, the faster it wll also be due to the value of propagation and at a certain distance. The transmitted signal will be different compared to the reflected.

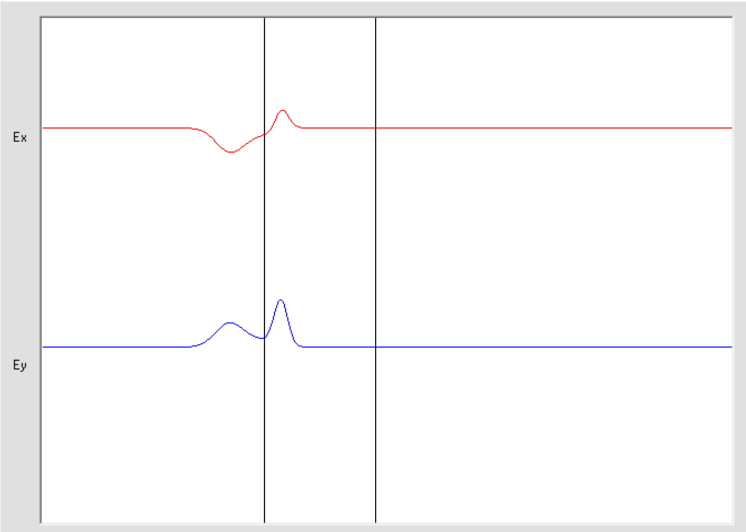

Fig. 3. Electric field E in conductive and conductivity materials

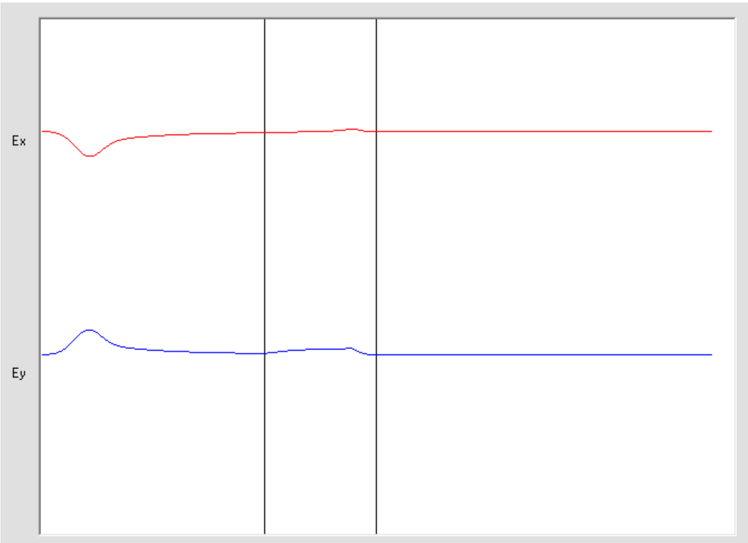

Fig. 4. Reflection and transmission of the electric field E

Figure 3 shows that the *Ex* and *Ey* electric field waves when passing through the plate undergo transmission and reflection. In the process of reflecting the *Ex*-*Ey* field waves, there is a bending phase due to the material properties of permittivity and conductivity. Whereas, in the process of transmitting *Ex* and *Ey* electric field waves decay in n-step 554 Electric field decay due to the reduced intensity or wave energy due to absorption of energy by the permittivity properties of materials. Figure 4 shows when n-step 771 the electric field waves *Ex* and *Ey* over time run out due to absorption from the material in the form of permittivity and conductivity. In addition, the wave after being reflected is subjected to changes in wave phase due to the permittivity and conductivity of the material. In the previous modeling, we have not been able to show the extent of the permittivity and conductivity relationship for a particular medium distance [15].

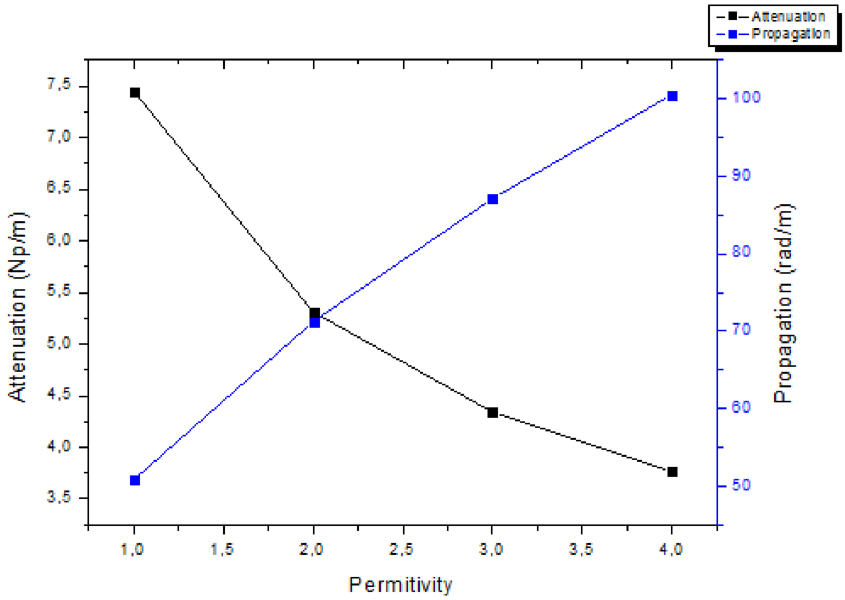

Fig. 5. Changes in attenuation and propagation values for a constant conductivity

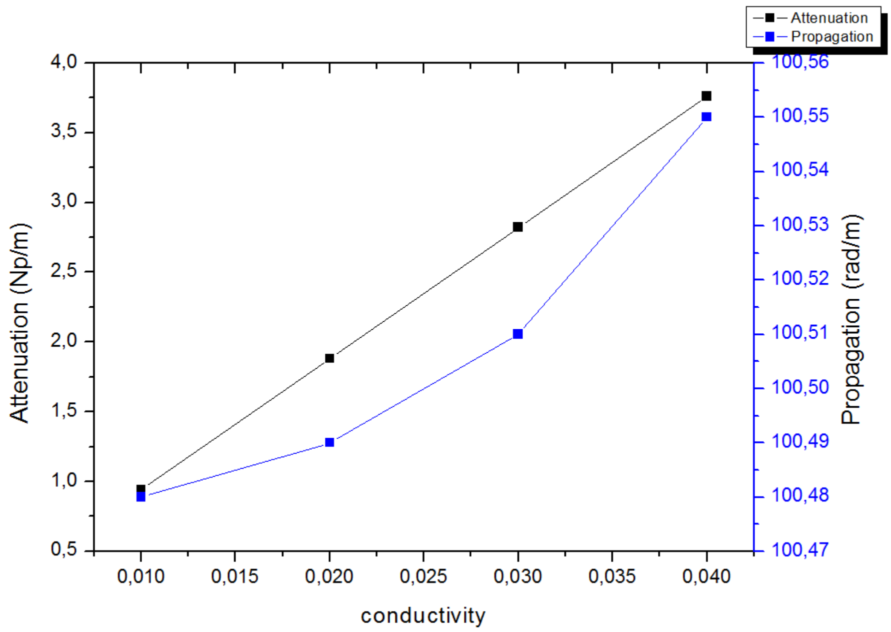

Fig. 6. Changes in attenuation and propagation values for constant permittivity

Figure 5 illustrates changes in attenuation and propagation values for fixed conductivity value at 0.04. Based on the image due to changes in permittivity, the greater the change in attenuation value, the smaller and the greater the propagation will get simultaneously.

Previous studies have not shown any intersection of propagation and attenuation values for certain permittivity values [20], whereas in Fig. 4 the intersections of permittivity values are shown at 2. The intersection of propagation values and attenuation indicates that the values of both are balanced so that the wave whole rate can be observed. Whereas in Fig. 6, changes in conductivity values with permittivity whose value is fixed at 4 indicate that attenuation and propagation change is in line with the increase. Previous research shows more about the influence of conductivity and permittivity on electromagnetic waves but has not shown an effect if there is a change in the value of conductivity and permittivity [8, 20, 21]. This indicates that there are characters that can change the attenuation and propagation constants in reverse between conductivity and permittivity.

4. Conclusion

The conclusion that can be drawn is that the properties of permittivity and conductivity affect the propagation of waves on the plate. Changes in this regard are related to constant attenuation and propagation. Changes in attenuation and propagation value for a fixed conductivity value of 0.04 indicate that changes in permittivity result in attenuation values get smaller and the the propagation value gets greater at the same time. Whereas the change in conductivity value with permittivity which has a fixed value of 4 indicates that attenuation and change in propagation are in line. This shows that characters which can possibly change the attenuation and propagation constants in reverse lie between conductivity and permittivity.

Acknowledgements. *No external funding was received for this study.*

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