# THE NUMERICAL TIME DOMAIN ANALYSIS OF PARTIALLY FILLED RECTANGULAR CAVITY WITH A DIELECTRIC MATERIAL

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## ABSTRACT

**In this study, a rectangular cavity is filled partially by a simple dielectric material. The dielectric material has also rectangular shape. The operational frequency of the cavity is tuned to the resonance frequency of empty $TM_{110}$ cavity mode and the time domain response of the cavity is obtained in the case of partially filled cavity. Then, the frequency response of the cavity is obtained by using Fast Fourier Transform (FFT) of the time domain response for the partially filled cavity. Thus the effect of the simple dielectric material on the field of distribution is observed in the time domain and frequency domain responses. The partially filled cavity problem is solved by Finite Difference Time Domain (FDTD) method. This analysis can be used for the real part of the dielectric permittivity measurement, the microwave material characterization studies, and the analysis of the electromagnetic compatibility problems.**

## I. INTRODUCTION

The microwave material characterization relating to dielectric permittivity measurements is important issue of today. Besides the importance of the many experimental works for different microwave material characterization measurements, the theoretical models and simulations are also important to understand interactions between electromagnetic waves and investigated objects. This is especially important in the time domain measurements. To perform this kind of simulations, the partially filled cavity problem is solved by Finite Difference Time Domain Method (FDTD). The rectangular cavity having perfect electric conductor walls is considered. The cavity is excited by an electric dipole along z direction and soft source is used for FDTD calculations. The cavity is filled partially by a rectangular shaped simple dielectric material. The simple dielectric material is characterized by relative dielectric permittivity as $\varepsilon_r$=25 and $\varepsilon_r$=80. The operational frequency of the cavity is tuned to the empty $TM_{110}$ cavity mode. Then, the time response of the partially filled cavity is obtained. Then the frequency response of the cavity is found by using Fast Fourier Transform (FFT).

## II. FDTD ANALYSIS

The finite difference time domain (FDTD) method has been widely used to analyze the electromagnetic problems. FDTD scheme based on the discretization of Maxwell's equation in space and time with cubic cells was firstly applied to Maxwell's equations by Yee [1]. Then FDTD solutions have been extended to include lossy dielectrics, dispersive materials, scattering problems, and a large geometries and different applications [2]. The geometry of the partially filled cavity rectangular cavity problem is shown in Figure 1.

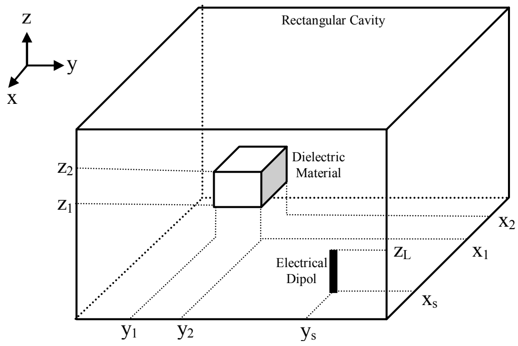

Figure 1. The partially filled rectangular cavity by a simple rectangular shaped dielectric material with an electric dipole source.

In Figure 1, the $x_1$, $x_2$; $y_1$, $y_2$; $z_1$, $z_2$ coordinates show the placement and dimension of the simple dielectric material, the $x_s$, $y_s$; $z_L$ coordinates show the placement and length of the electric dipole source. To perform partial material program code for FDTD algorithm, KONUM ($n\Delta x$, $n\Delta y$, $n\Delta z$) matrix is defined related to dielectric material dimensions and position (n is the number of time recursion). When dielectric material is present KONUM (nΔx, nΔy, nΔz) is taken equal to 1, otherwise it is taken equal to 0. First, free space Maxwell's equations are multiplied by (1 - KONUM (nΔx, nΔy, nΔz)) and solved. Then Maxwell's equations with the dielectric material are multiplied by KONUM (nΔx, nΔy, nΔz) and solved. Thus a compatible system is obtained for the solution of Maxwell's equations of the full problem geometry. The FDTD equation of this system for $E_x$ is shown as follows

$$\begin{aligned}&E_{X1}(n\Delta x, n\Delta y, n\Delta z) = \\ &(1 - \mathrm{KONUM}(n\Delta x, n\Delta y, n\Delta z))\,[E_{X1}(n\Delta x, n\Delta y, n\Delta z) \\ &+(\Delta t/(\varepsilon_0\Delta y))(H_Z(n\Delta x, n\Delta y, n\Delta z)-H_Z(n\Delta x, n\Delta y, n\Delta z)) \\ &-(\Delta t/(\varepsilon_0\Delta z))(H_Y(n\Delta x, n\Delta y, n\Delta z)-H_Y(n\Delta x, n\Delta y, n\Delta z))] \quad (1)\end{aligned}$$

$$\begin{aligned}&E_{X2}(n\Delta x, n\Delta y, n\Delta z) = \\ &(\mathrm{KONUM}(n\Delta x, n\Delta y, n\Delta z))\,[E_{X2}(n\Delta x, n\Delta y, n\Delta z) \\ &+(\Delta t/(\varepsilon_r\varepsilon_0\Delta y))(H_Z(n\Delta x, n\Delta y, n\Delta z)-H_Z(n\Delta x, n\Delta y, n\Delta z)) \\ &-(\Delta t/(\varepsilon_r\varepsilon_0\Delta z))(H_Y(n\Delta x, n\Delta y, n\Delta z)-H_Y(n\Delta x, n\Delta y, n\Delta z))] \quad (2)\end{aligned}$$

$$\begin{aligned}&E_X(n\Delta x, n\Delta y, n\Delta z) = \\ &E_{X1}(n\Delta x, n\Delta y, n\Delta z) + E_{X2}(n\Delta x, n\Delta y, n\Delta z) \qquad (3)\end{aligned}$$

where $\varepsilon_0$ is free-space dielectric permittivity, $\varepsilon_r$ is the relative dielectric permittivity of the inserted material, and Δ shows the time and spatial increments. $H_Y$ and $H_Z$ show the y and z oriented magnetic field components. The number of time recursion (n) is taken as 2000. A soft source is used as an electrical dipole to excite desired cavity mode. $TM_{110}$ cavity mode is excited as an example. For this aim, the electrical dipole is placed in the middle of the (x-y) plane ($x_s$=1/2, $y_s$=1/2) with finite length, $z_L$=1/2. The other modes excitation is straightforward [3]. The cavity dimension is taken as 1 x 1 x 1 m. It may be taken as arbitrary dimensions that only desired cavity mode will be the restriction of the cavity dimensions depending to each other. The dielectric material which is modelled by $\varepsilon_r$=25 and $\varepsilon_r$=80 is inserted in the coordinates at $x_1$=1/5, $x_2$=2/5, y1=1/5, y2=2/5, $z_1$=1/5, $z_2$=2/5. This means the dielectric material has a cubic shape. The time step of the FDTD calculations is $\Delta t = 8.66\times10^{-11}$ second. The Courant stability criteria is also satisfied by taking Δx=λ/10, Δy= λ/10, Δz= λ/10. The observation point is chosen as x=1/2, y=1/2, z=1. The operational frequency of empty $TM_{110}$ cavity mode is calculated with given dimensions as $f=2.119\times10^8$ Hz.

## III. RESULTS

Firstly, the empty cavity results as the $E_Z$ field distribution along (x-y) coordinates at fixed z=1/2 and time response of the $E_Z$ field are given in Figure 2 and Figure 3, respectively. It is clear that the cavity is in resonance. Then, the partially filled cavity results as the $E_Z$ field distribution along (x-y) coordinates at fixed z=1/2, time and frequency response of the $E_Z$ field for $\varepsilon_r$=25 and $\varepsilon_r$=80 are given in Figure 4, Figure 5, Figure 6, and Figure 7, respectively. Later, the frequency responses of the empty and filled cavity are compared in Figure 8.

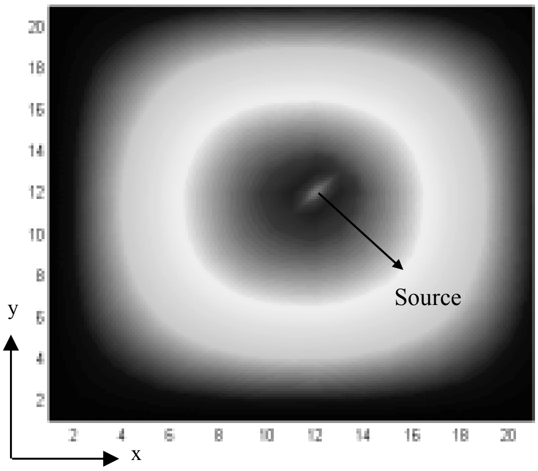

Figure 2. The field distribution of $E_z$ along (x-y) plane at fixed z=1/2 for $TM_{110}$ cavity mode (z is fixed).

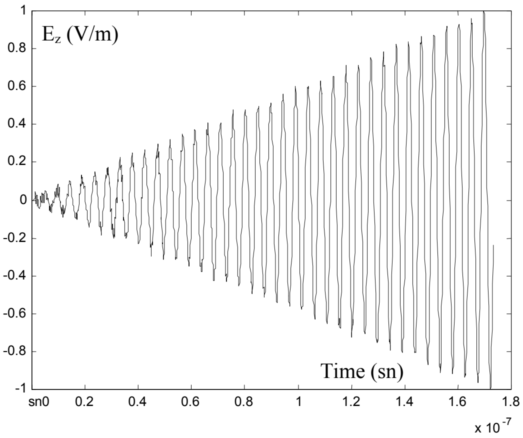

Figure 3. The normalized time response of the $E_z$ for $TM_{110}$ empty cavity mode.

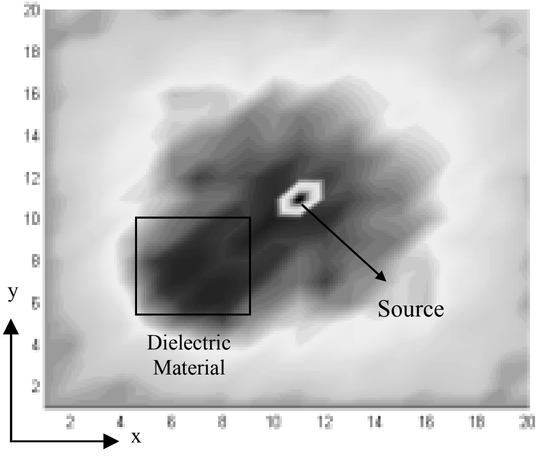

Figure 4. The field distribution of $E_Z$ along (x-y) plane at fized z=1/2 for $TM_{110}$ partially filled cavity mode ($\varepsilon_r$=25).

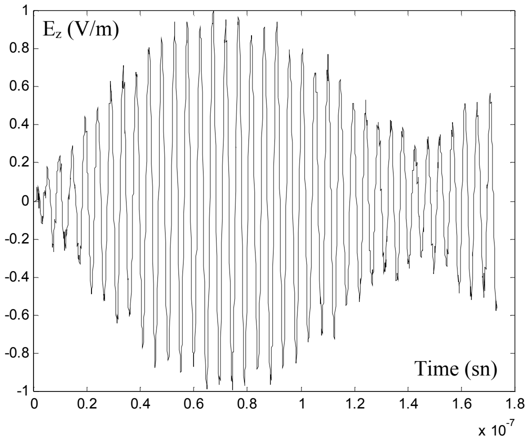

Figure 5. The normalized time response of the $E_z$ for $TM_{110}$ partially filled cavity mode. ($\varepsilon_r$=25)

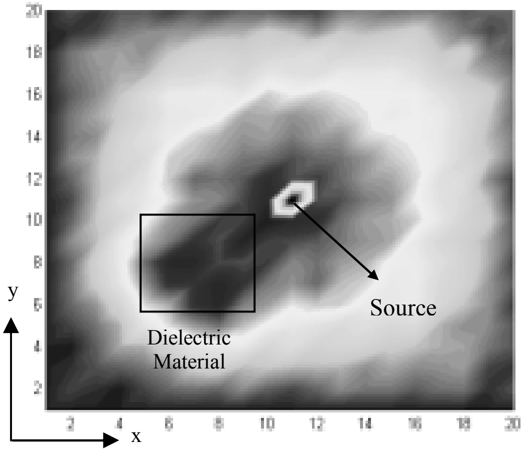

Figure 6. The field distribution of $E_z$ along (x-y) plane at fixed z=1/2 for $TM_{110}$ partially filled cavity mode ($\varepsilon_r$=80).

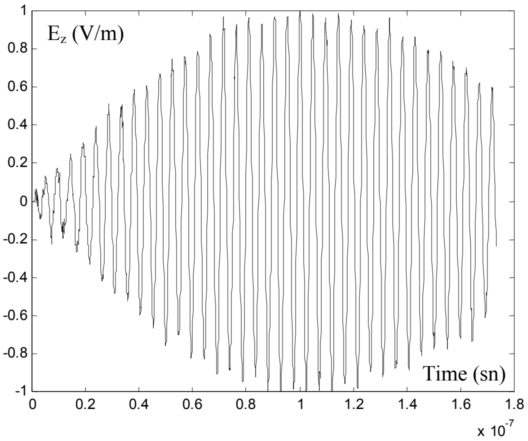

Figure 7. The normalized time response of the $E_z$ for $TM_{110}$ partially filled cavity mode. ($\varepsilon_r$=80)

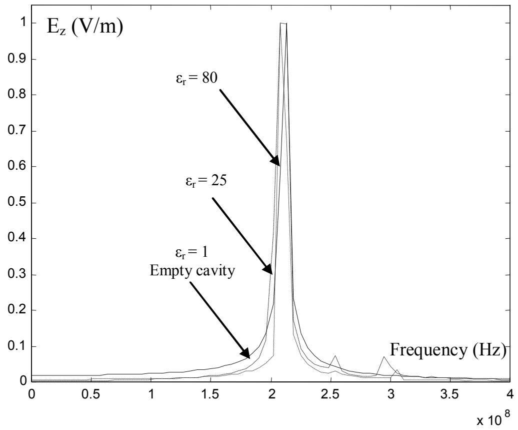

Figure 8. The normalized frequency responses of the $E_z$ for the empty and partially filled for $TM_{110}$ partially filled cavity mode. ($\varepsilon_r$=25 and $\varepsilon_r$=80)

## IV. DISCUSSION and CONCLUSION

The time and frequency domain responses of the partially filled cavity are obtained by using FDTD method. The results show that the time and frequency domain responses are effected from the dielectric material depending on its size, relative dielectric permittivity, and position. This affects give us change to evaluate the dielectric material properties and the position of the investigated object. Therefore the given analysis in this paper may be useful for the real part of the dielectric permittivity measurements, the microwave material characterization studies, and the analysis of the electromagnetic compatibility problems.

The future aim of this work is to simulate similar problem with extension of the modelling of the dielectric material not only as a simple dielectric but also different order lossy dispersive materials and to observe mode coupling phenomena between the degenerated TE and TM cavity modes.

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