EFFICIENT FD-TD ANALYSIS OF DIELECTRIC RESONATORS WITH TUNING SCREW AND MULTILAYER STRUCTURE

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ABSTRACT

An efficient finite difference time domain method, coupled with digital filtering and spectrum estimation techniques, is used to analyze the resonant frequencies and field distribution of two resonant structures of practical importance. The semiconductor-dielectric multilayer resonators, which are especially important in optically controlled circuits, are first time analyzed and in reasonable agreement with the experimental results. The results of a practical tuning screw dielectric resonator are also given and compared with the available rigorous results.

INTRODUCTION

A study of dielectric resonators for application in microwave circuits requires accurate and efficient methods to calculate the resonant frequencies and spatial distribution of the field [1]. In this paper, we use an efficient finite difference time domain method coupled with digital filtering and modern spectrum estimation techniques [2-3] to analyze axially symmetric open dielectric resonators. The method, in comparison with other methods [4] and traditional FDTD method [5], allows much quicker and more efficient computation of the global frequency spectrum and distribution of the electromagnetic field. Also, this paper addresses to the open resonant problems using the FD-TD method.

Two structures of practical importance (tuning screw DRs and semiconductor-dielectric multilayer resonators) have been analyzed. The computed results are partly compared with the experimental results and the available theoretical results [4].

NUMERICAL METHOD

Dielectric resonators of cylindrical shape were used in most of the DR application. In this paper, for easy comparison, only result of TE_{018} mode is discussed.

The previous analyses given in [5-6] are limited to a consideration of a closed resonator, where the tangential electrical fields on the outer boundaries are forced to be zero. Actually, by using the well developed absorbing boundary condition (ABC) with the FDTD method, the method can be extended, so that it can deal with the open structure problems. In this paper, Mur's first-order boundary condition is used [7].

Assume that at t=0, an abrupt field excitation is introduced (for instance, zero everywhere except at some localized points) which in turn excites a large number of modes. Using the above algorithm, the resonant frequencies can be got by reading the peaks in the spectrum diagram obtained by taking the Fourier transform of the computed time domain response.

The FDTD method has a bunch of advantages which many papers have mentioned [4-6]. However, it has one significant disadvantage which is that it requires a very long computation time for extracting the resonant frequencies from the FDTD results. For example, in the case of the problem discussed in [5], the time iteration N has to be as long as $N=2^{16}$. In this paper, we use digital filtering and modern spectrum estimation techniques into FDTD method to overcome the above limitation.

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Suppose $\{x_1(n)\}$ is the short sequence consisting of the first two thousand data points from $\{x(n)\}$, which was obtained with traditional FDTD method. For eigenvalue problems, because only the first few modes of the whole spectrum are interested so that we can process $\{x_1(n)\}$ using a low-pass filter to further desampling $\{x_1(n)\}$ to get $\{y(n)\}$. Then using minimum-norm method [8], one of two best high-resolution methods for the estimation of sine wave in noise, to estimate the resonant frequencies of a DR. For similar detailed procedures please see ref.[3].

APPLICATION

Using the above efficient FDTD method coupled with digital filtering and minimum-norm algorithm, we analyzed two structures of practical importance, tuning screw DRs and open semiconductor-dielectric multilayer resonators. The latter was recently proposed to be used at optically control circuits.

The procedure is used to study the variations in the resonant frequency of the $TE_{01\delta}$ mode of a tuning screw DR shown in Fig.1 with respect to different sizes of the structure. This is especially useful to choose an adequate screw diameter to obtain the desired tuning margin. The results are also compared with finite element results [4]. Fig.2 gives its field distribution of $TE_{01\delta}$ mode.

Fig.3 shows the efficiency and accuracy of the present algorithm. The dashed line was obtained by applying a Fourier transform to a very long sequence, corresponding to 2^{15} time iterations in the traditional FDTD algorithm. The dotted curve gives the result of the first 2000 iterations in the former sequence. Comparing dotted line with dashed line, we can see that, just for short data records, the resonant frequencies can not be accurately estimated. The solid line gives the result of application of digital filtering and the minimum-norm spectrum estimation technique to the same shorter sequence. Comparing the solid and dashed line, we can see that the same order of accuracy for resonant frequency estimation is obtained.

An open two layer semiconductor-dielectric resonator is also analyzed by the present algorithm. Fig.4 shows the resonant frequency of $TE_{01\delta}$ mode

changing with different sizes of two layer materials. In this paper, the lower material we used is D8500 of Trans-Tech. Inc., the upper material is silicon semiconductor. An experiment was made for the two-layer semiconductor-dielectric resonator, with dielectric constants $\varepsilon_{r1}=35.76$ and $\varepsilon_{r2}=11.8$. The multilayer DR was mounted on a substrate with $\varepsilon_r=2.2$, and was surrounded by absorbing materials to reduce reflections. The traditional transmission line method was used to measure the resonant frequencies of the DR. The comparison between the resonant frequency of the $TE_{01\delta}$ mode and the experimental results are also given in Fig.4. The comparison results are in reasonable agreement.

CONCLUSION

The rigorous method presented in this paper allows us to calculate, with great precision and high efficiency, the resonant frequencies and field distribution of a dielectric resonator. The requirements for the FDTD algorithm and the time it takes for processing the data can be reduced at least 10 times. Two practical important DRs with open structure are analyzed. Present research is focus on optically-controlled two-layer DR by using frequency dependent FDTD method.

ACKNOWLEDGEMENT

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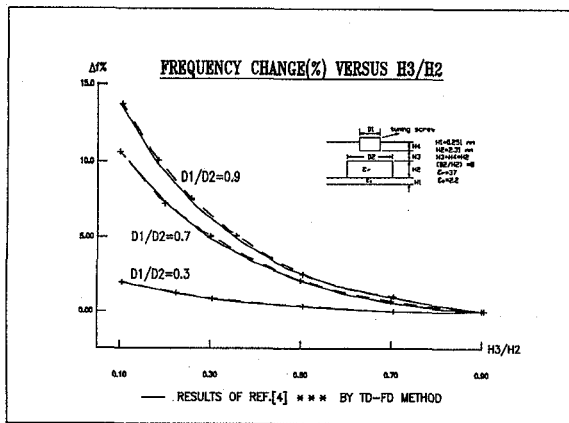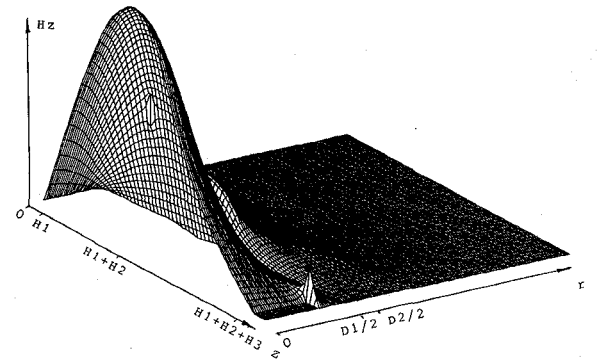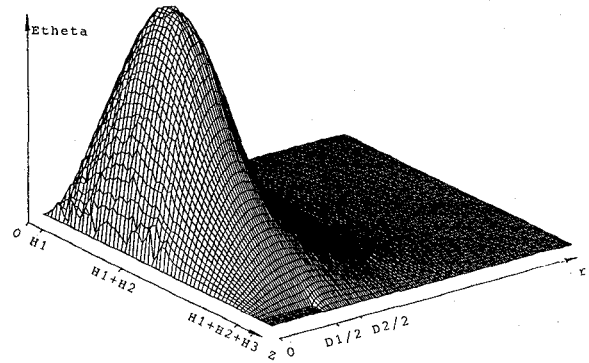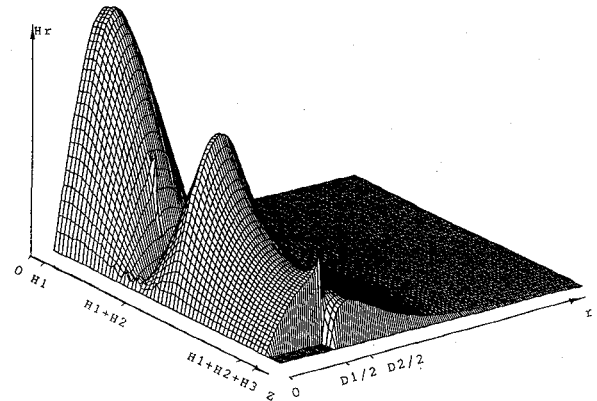8. S. Haykin, "Adaptive filter theory," 2nd Ed., Prentice-Hall, Inc., 1991.

Fig.1 resonator frequency versus different sizes of tuning screw DR

Fig.2 field distributions of $TE_{o1\delta}$ mode in a tuning screw dielectric resonator
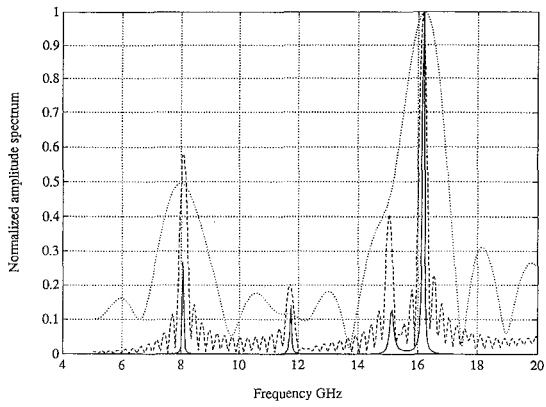
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Fig.3 resonant frequency estimation using
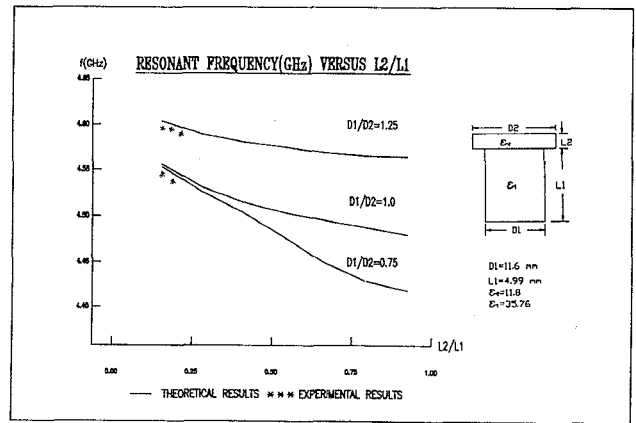different methods

Fig.4 resonant frequency versus different
dimensions of a two-layer semiconductor-
dielectric resonator