Novel TE01δ Dielectric Resonator Design: Fabrication Simplicity and Frequency Tunability

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Abstract: In this article we report a novel TE01δ Dielectric Resonator which is excited by a modified spilt ring resonator. Unlike traditional dielectric resonators which require specialist fabrication techniques to achieve precise High-Q dielectric properties the proposed method simply relies on the design of TE01δ Dielectric Resonator on FR4 material and microstrip copper elements used in the modern patch type antenna. The TE01δ mode is observed at a frequency of 3.11GHz and HEM01δ mode is observed at 4.056 GHz. Applications of this work can be- high dielectric and loss tangent measurement, MIMO circuits, RF optimization of components and circuits.

Keywords: Electromagnetics; high-k; Ring Resonator, RF, TE01 δ mode;

Introduction

Microwave systems rely on high-dielectric materials to achieve various operations such as filters, oscillators, waveguide. The dielectric materials play an important role in miniaturization of the radio frequency (RF) circuits and systems. While the losses in metal persist throughout the microwave regime, the dielectric materials only have loss tangent which can be optimized using various RF techniques [1]. Dielectric resonators (DR) date as far back as 1920's which was extensively studied by Rayleigh, Bose, Sommerfeld and Debeye [2,3].

Related work in DR

The research by Chen in 2012 investigates how the size of the cavity affects both the resonance frequency and strength of the TE01δ mode within the split postdielectric resonator (SPDR) technique, utilizing comprehensive simulations. These findings offer guidance on adjusting the setup's dimensions to ensure optimal excitation of the TE01δ resonance mode. Proposed designs for scaled SPDR fixtures are tailored to frequencies relevant for practical applications, employing standard ceramic materials for fabrication. Furthermore, the study demonstrates the ability to fine-tune the resonance frequency of the TE01δ mode by adjusting the gap in the split dielectric resonator (DR) [4]. In their 2009 study, Wang and colleagues propose a fresh method for creating left-handed metamaterials (LHMs) using readily available dielectric resonators known for their low loss and high temperature stability. They enhance desired resonance modes and suppress undesired ones by simply adding metallic strips onto the resonators' surfaces. This technique enables precise tuning of resonance frequencies to specific ranges of interest. As an illustration, they introduce a wide-angle polarization-independent planar LHM based on disk-like dielectric resonators. They achieve negative permeability and permittivity by etching metallic strips along the electric field orientations of TE01δ and HEM11δ modes, respectively [5].

Simulation and Results

The resonator system has two parts (a) The Excitation base on the FR4 Substrate and copper microstrip quarter split ring and (b) the dielectric resonator itself as shown in Figure 1. The Overall view of the setup to test the frequency shift properties has been shown in the Figure 1 A and B, the excitation ring is shown on the FR4 substrate in the figure 1C.

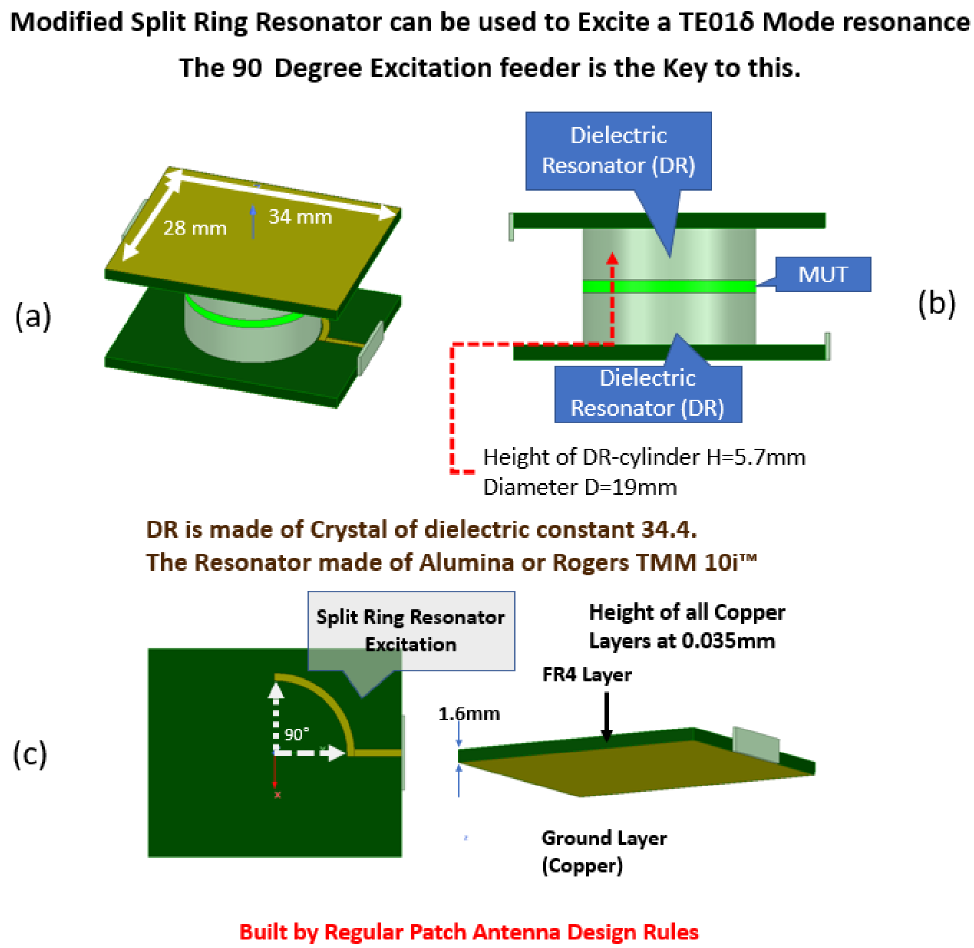

Figure.1. Proposed Design of the TE01δ Dielectric Resonator

The governing equations for the Frequencies of the modes TE01δ and HEM11δ are [2]:

$$f_{TE01\delta} = 2.921 \times \frac{C\epsilon_r^{-0.465}}{2\pi r_d} \times \left\{0.691 + 0.319 \times \frac{r_d}{h_d} - 0.035 \times \left(\frac{r_d}{h_d}\right)^2\right\} \quad (1)$$

$$f_{HEM11\delta} = 2.735 \times \frac{C\epsilon_r^{-0.436}}{2\pi r_d} \times \left\{0.543 + 0.589 \times \frac{r_d}{h_d} - 0.05 \times \left(\frac{r_d}{h_d}\right)^2\right\} \quad (2)$$

The dimensions mentioned in table 1 give the values for equations 1 and 2 as 3.17 GHz and 4.05 GHz, respectively.

Table 1. Parameters for DR

Dielectric Cylinder Height h_d	5.7 mm
Dielectric Cylinder radius r_d	9.5 mm
Dielectric constant ϵ_r	34.4

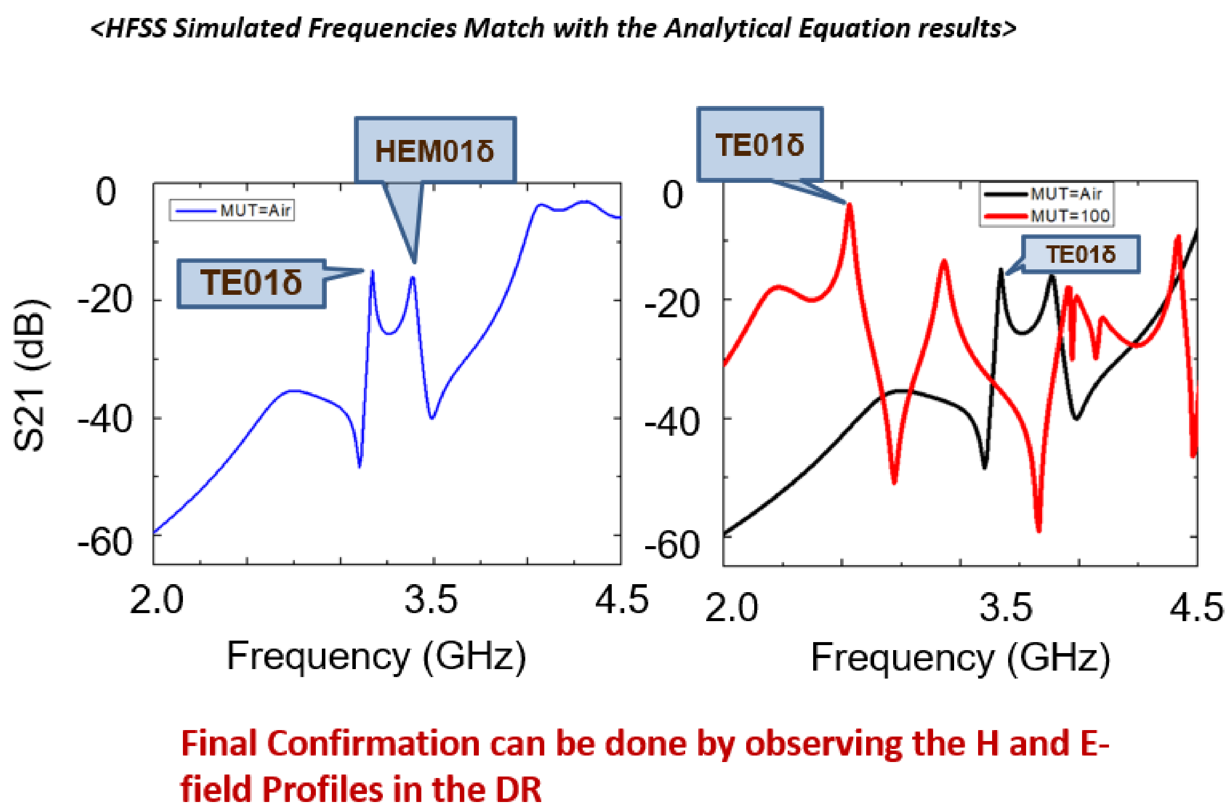

Figure.2. Issues with Parallel Plate Measurement method uses Agilent Dielectric Material Test Fixture (16453A). The measurement of high dielectric constant materials leads to resonant peaking beyond 800MHz.

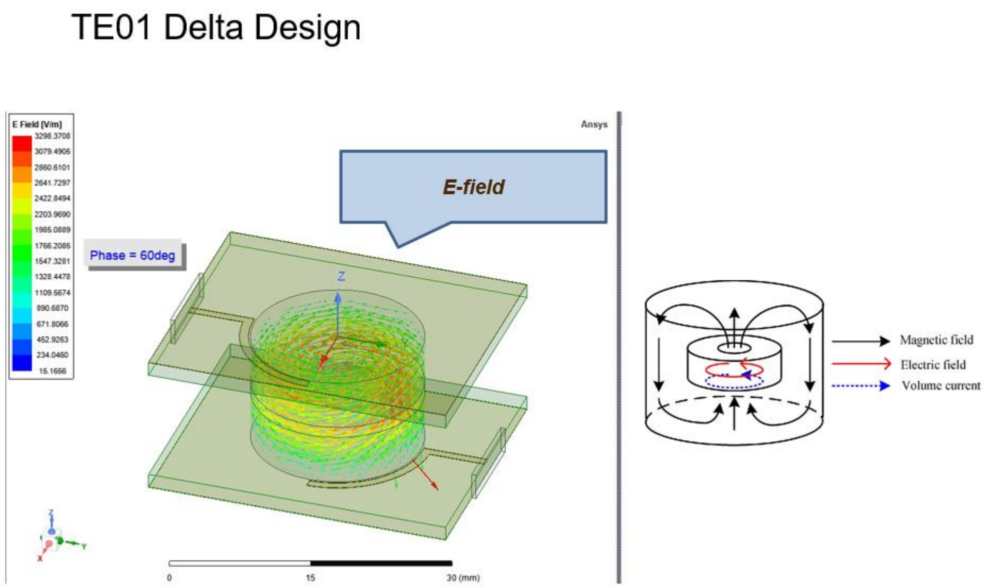

Figure.3. E-field profile inside the DR at the TE01δ frequency governed by equation (1).

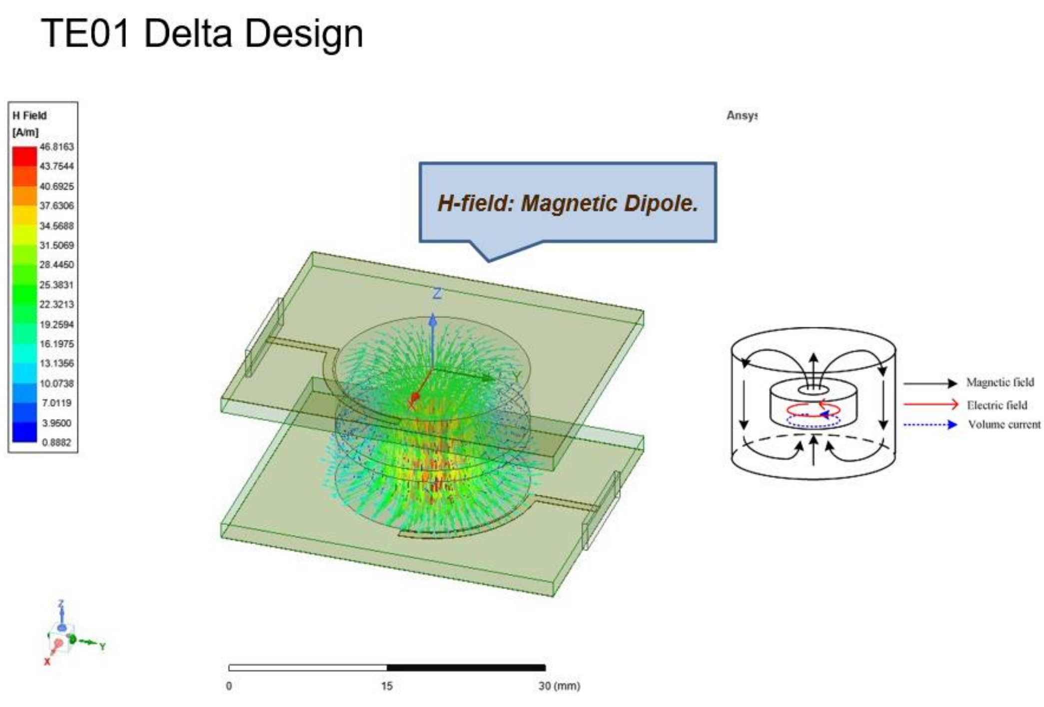

Figure.4. Issues with Parallel Plate Measurement method uses Agilent Dielectric Material Test Fixture (16453A). The measurement of high dielectric constant materials leads to resonant peaking beyond 800MHz.

HFSS Simulations

The figure 2 shows the S21 plot for the setup shown in Figure 1 A. The frequencies TE01δ and HEM11δ match with the calculated frequencies based on equations (1) and (2).

Likewise, the second half of the figure 2 shows the shift in the frequencies based on the change in the MUT dielectric property (Air to media dielectric constant 100). The plots in figure 2 are hallmark of a TE01δ and HEM11δ dielectric resonators [-].

Discussions

The plots in the figure 2 show the existence of TE01δ and HEM11δ at frequencies 3.17 and 4.05 GHz. The final confirmation of these modes is done by looking at the field profiles. The electric field of the TE01δ mode revolves horizontally and aligns tangentially with the circular surface of the cylinder, some authors have called it Azimuthal circulation []. This aspect is clear when one looks at the simulated E-field profiles at 3.17GHz in the figure 3. Likewise the H-field profile is shown in figure 4 which is normal to the circular plane of the dielectric resonators.

Conclusions

In conclusion, our study introduces a novel TE01δ Dielectric Resonator design, which simplifies fabrication by utilizing FR4 material and microstrip copper elements commonly found in modern patch-type antennas. We successfully observed the TE01δ mode at 3.11 GHz and the HEM01δ mode at 4.056 GHz. This design holds promise for various applications including high dielectric and loss tangent measurements, MIMO circuits, and RF optimization of components and circuits.

Our findings build upon previous research, particularly Chen's investigation into cavity dimensions' effects on resonance frequencies and strengths, and Wang et al.'s method for creating left-handed metamaterials using dielectric resonators enhanced with metallic strips.

Simulation results confirmed the effectiveness of our proposed design, showcasing successful excitation of the TE01δ and HEM11δ modes at calculated frequencies. Additionally, changes in dielectric properties led to shifts in resonance frequencies, demonstrating the tunability of our resonator system.

In our discussions, we emphasized the distinctive field profiles of the resonator modes, with the TE01δ mode exhibiting azimuthal circulation and the HEM11δ mode showing a normal alignment to the circular plane of the resonators.

Overall, our study presents a promising approach to TE01δ Dielectric Resonator design, offering practical applications in microwave systems and providing valuable insights for future research in dielectric resonator technologies.

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