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RESEARCH ARTICLE

Purity Detection of Some Liquids by Using Reflection Values Based on Metamaterial

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ABSTRACT

The aim of this work is to design and fabricate a type of sensor based on Metamaterials. This structure determines the purity of Methanol and Ethanol mixture in the water by using the Octagonal form of a resonator and sample holder. The proposed structure has been employed in the 8-12 GHZ frequency band. The important thing in the work is the changes of the waveform at the resonance frequency. The output waveform of materials (reflection coefficient S_{11} or transmission coefficient S_{12}) must be changed in the liner figure by considering the dielectric coefficient. We use copper for the metal layer and resonator and Isola IS680 (3.2DK) (lossy) for substrate layer. We simulate one unit cell of this Meta-material sensor by CST microwave software and then achieve the results and evaluate them. Both the numerical and experimental tests, give the same outcomes and results and they will be in good agreement with each other. The proposed structure can be used in many applications where purity and determining of some materials might be necessary.

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1. Introduction

Metamaterials are unnatural materials that have different electromagnetic behaviors and show specific electromagnetic (EM) properties that cannot be found inherently in nature. The mentioned differences are negative refraction index, negative reflection, negative Doppler Effect, negative permittivity, and negative permeability. Metamaterials are usually applied in periodic constructions. It is a good way to design and fabricate by repeating structure with the unit cells. An array of unit cells may be used to get the structure. A unit cell is a combination of SRR and wire structure (Pendry et al., 1999). Metamaterials (MTMs) are defined as artificial electromagnetic (EM) materials that are rapidly developing as a research due to having many potential application areas. Metamaterials are artificially engineered structures that provide extraordinary features such as backward propagation, negative permittivity and/or permeability. The left-handed materials with unusual electromagnetic properties (MTMs) were theoretically proposed by the Russian physicist Viktor Veselago in 1968 (Veselago, 1968) and then the history of these metamaterials started with the speculation on the existence of "substances with simultaneously negative values of ε and μ" (Caloz et al., 2004). After Victor Veselago's paper or proposal in 1967, more than 30 years elapsed and by trying the group of researchers in 2000, the first metamaterial was developed artificially with negative permeability and negative permittivity by using periodic metal resonators. So at the end of the 20th century, the

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first metamaterial exhibit as expected by Veselago, but an artificial effectively homogeneous structure which was proposed by Smith and colleagues at University of California (Smith et al., 2000) and then MTMs were fabricated and began to be used in practical life with the help of Pendry et al. and Smith et al. The original approach proposed by Pendry et al. (1998), was to exploit the inductive response from structured nonmagnetic materials to obtain high-frequency magnetism. In the previous studies, for example, Transmission Line Integrated Metamaterial Based Liquid Sensor (Alkurt et al., 2018) and Chiral Metamaterial Sensor (CMS), Octagonal Shaped Metamaterial Absorber Based Energy (Bakır et al., 2018) have been designed, simulate and fabricate. Metamaterials have many application areas and different study topics due to a high potential of them and therefore application of Metamaterials have been searched and investigated by scientists interestingly. Metamaterials are using in many applications such as diffraction-limit breaking, invisible cloaks (Alitalo et al., 2007), antennas (Metamaterial can increase the gain and reduce the return loss and disadvantage of a patch antenna) (Zhu et al., 2005), filters, polarization converters, optics, cloaking (Pozar, 2004; Alitalo et al., 2007), super lensing, and sensor applications. We can enhance and increase the sensitivity and resolution of sensors with the help of Metamaterials. Metamaterial sensors are used in many fields like agriculture, biomedical etc. The aim of this study is to determine and detect the purity of Methanol's and Ethanol's mixture in the water by using the Octagonal form of resonator and sample holder. Disgned sensors in this study showed positive results in the processes of test. The difficulty of differentiating and detecting, fluids with each other is that the dielectric coefficients might be close to each other. We can see that the designed structure in simulation studies and experimental studies has been successfully exhibited as a sensor, performing the purity determination and detection process in real time, quickly and accurately.

2. Materials and Methods

2.1. Obtaining Parameters and Numerical Results

It is necessary to determine, dielectric constant and magnetic permeability coefficients. With the development of new technologies, the parameters such as refractive index, effective dielectric permittivity and effective magnetic permeability can be easily calculated by using the methods. There are different methods for obtaining these parameters. Each method has several advantages and disadvantages. However, there is the most advantageous method to calculate parameters such as dielectric constant and magnetic permeability coefficients from the s-parameters. An important technique of obtaining and calculating the parameters of Metamaterial, is characterizing EM properties of the medium. Numerical and experimental results are used to design new Metamaterials.-researchers can compare the numerical results of simulation program with the obtaining parameters of the experimental method for structures. Each method includes limitations or specific constraints. By considering of these domains, measurements of the s-parameter of the transmission and reflection are performed with the help of Vector Network Analyzer. Then, by using the obtained S-parameters, the dielectric permittivity and magnetic permeability are calculated by appropriate methods.

The most commonly used methods for measuring S-parameters are listed below.

- Transmission line method
- Chiral method (reflection method)
- Resonance method

The most advantageous method for obtaining parameters such as the refractive index, effective dielectric permittivity and effective magnetic permeability from S-parameters is transmission/ reflection by line method, because in the transmission and reflection by line method, S-parameters are used directly and then parameters such as refractive index, effective dielectric permittivity and effective magnetic permeability are obtained another reason, these methods aren't time consuming and don't need many laboratory equipments.

The resonators at the front and back sides of the structure have symmetry and they could be placed at different angle to each other, in the chiral method (reflection method). There is a loop as a resonator with the gap in the Transmission line method to get strong resonance. CST is software that uses FDTD and FIT methods. The finite integration method is used to solve electromagnetic (EM) field problems in numerical terms. The finite integration method was developed in 1977 by Thomas Weiland (Weiland, 1977), and after many years of research, has been developed by researchers. This method works in the desired frequency domain. The basic approach of this method is to apply Maxwell's equations.

2.2. Structures

In this section, the Metamaterial structure and the processes of works which are used in the study are described. The structure is simulated by using CST Microwave Studio program. We have investigated the structure and the designs of with octagonal shaped resonators-based purity of liquid. Relative dielectric constant and thickness, Isola IS680 (3.2DK) (lossy) material has been used for substrate of structure. Copper is used with the thickness of 0.035 mm as resonators with the electrical conductivity is $5.8 \cdot 10^{-7}$ S/m. In order to reduce the losses on the selected material, the material of Isola IS680 (3.2DK, lossy) is particularly preferred as seen in Figure 1. The technical details and specifications for the mentioned structures are given in the following section and shown in Table 1 and Figures 2 and 3.

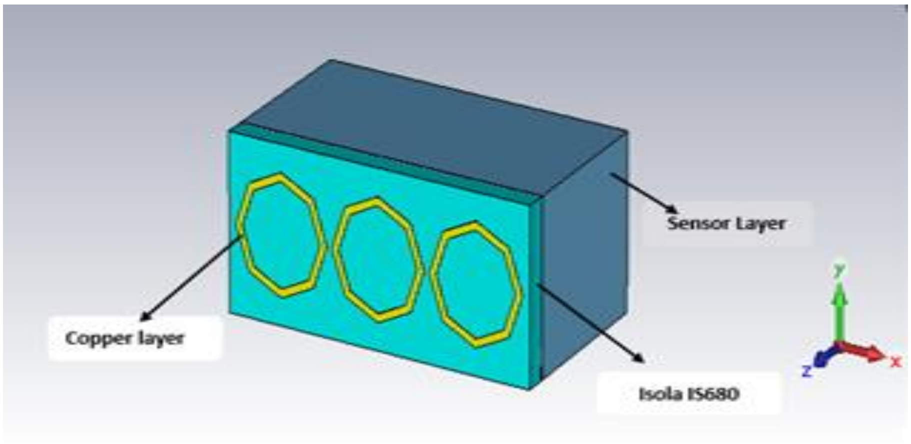

Figure 1. Type of materials use in octogonal-shaped resonator based purity of liquid.

Table 1. Specified Measurements of Octogonal Shaped Resonators to determine purity of liquid

Substrate x (mm)	Substrate y (mm)	Resonator (d1) mm	Resonator (d2) mm
22.86	10.16	2.68	2.30

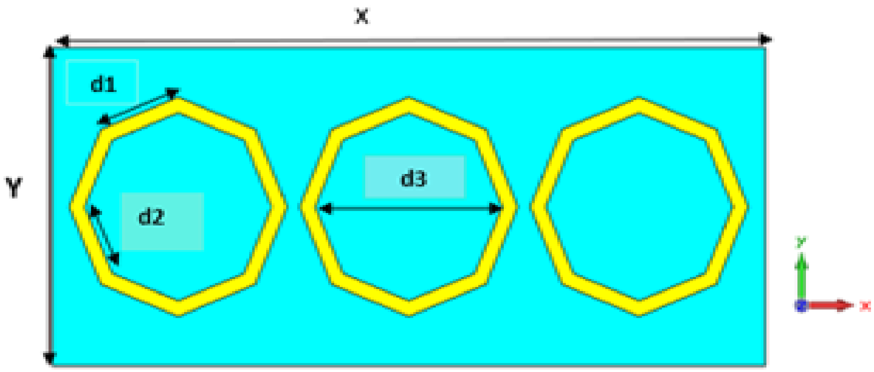

Figure 2. Dimension of octogonal shaped resonators to determine purity of liquid.

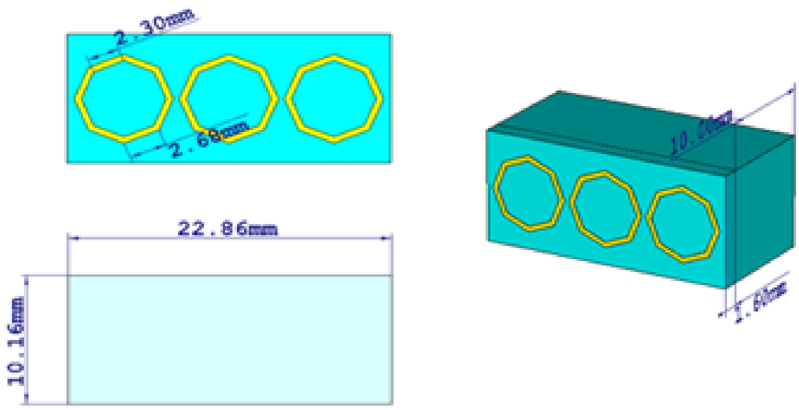

Figure 3. Unit cell's fabrication, front view, side and back view for octogonal-shaped resonator based purity of liquid.

2.3. Defining Ports and Boundary Conditions

We have used waveguide port for this model as seen in Figure 4. Boundary conditions of unit cell, for the octogonal shaped resonator structure, in the X / Y / Z axes, have been selected and proposed, Electric (Et = 0) / Electric (Et = 0) / Open Add Space respectively as shown in Figures 5 and 6. Axes and values are entered in the simulation program, for the characterization of the waveguide. The produced elements are located exactly inside the waveguide.

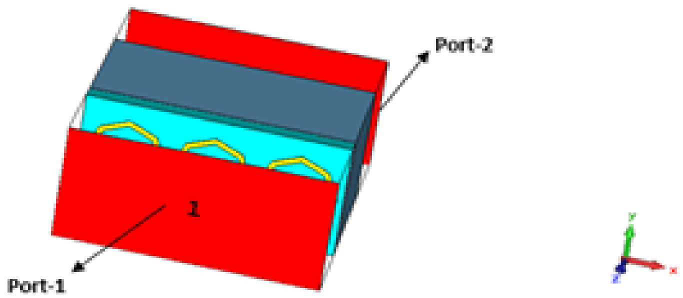

Figure 4. Defining of ports for octogonal-shaped resonator to determine purity of liquid structure.

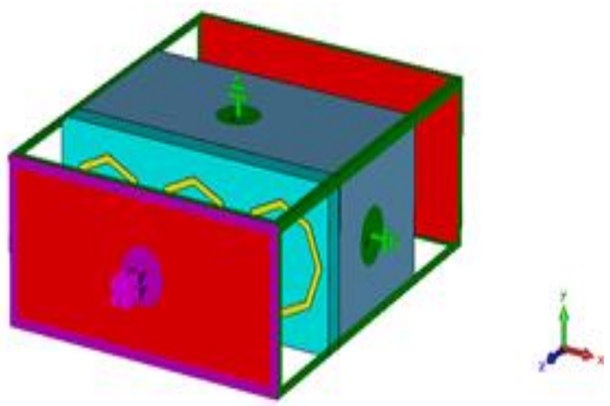

Figure 5. Perspective view of boundary conditions applied for octogonal-shaped resonator.

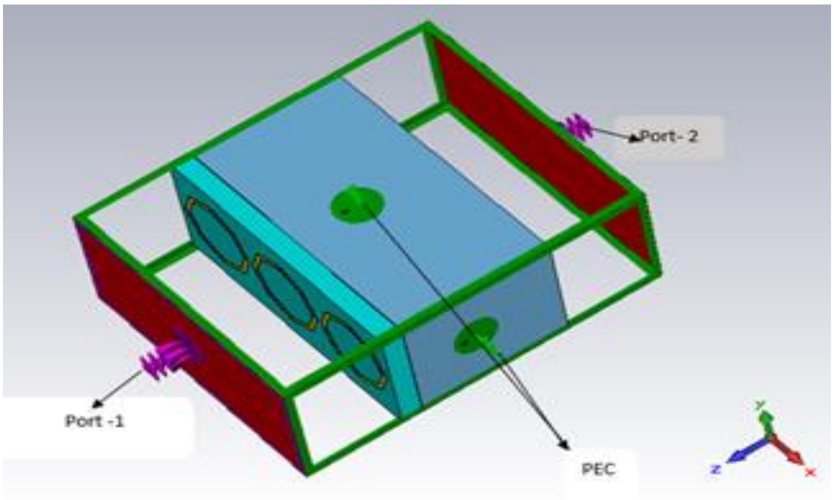

Figure 6. Boundry condition for octogonal-shaped resonator to determine purity of liquid structure.

The waveguide design, has a number of specification such as small construction, easy production and low cost. Waveguide dimensions are more important for operating frequency. In addition to the unit cell's boundary conditions, the reflection and transmission values are obtained by using the waveguide. Measurements are performed in TE wave mode using a network analyzer. As known, TEM wave cannot advance in waveguides. After measurement and simulation, it can be seen that experimental and numerical results are compatible with each other and there are very few differences. These differences are due to production, calibration and material. In Figures 5 and 6 are shown that the Electric (Et = 0) boundary conditions are on the side and top walls. The resonators are arranged vertical to the axis, so that the direction of the magnetic field, as described in Faraday's law, is perpendicular to the resonators. All of these units are obtained by CST Microwave Studio program, which is an electromagnetic analysis program based on finite integral method. The Octogonal Shape Resonators are presented with different boundary conditions shown in Table 2. The boundary condition of the x and y axes are the same as with each other.

Figure 4 shows the design of the structure with boundary conditions.

Table 2. Boundary conditions applied for octogonal shape resonator for determine purity of liquid.

Boundary conditions	min	max
x	Electric (Et=0)	Electric (Et=0)
y	Electric (Et=0)	Electric (Et=0)
z	Open (add space)	Open (add space)

3. Results

3.1. Placed of Samples (Ethanol and Methanol's solution) in Sensor Layer

The reflection and transmission coefficients of the structure when the boundary condition is applied and the samples are placed are presented in Figures 7 and 8. These graphs are obtained in the case where the parameter is used in mm and Ethanol's solution as a sample placed in the sensor layer. The sensor layer, in Octogonal-Shaped Resonator Based purity of liquid, has 10 mm thickness and it is located just behind the Isola-is680 layer (substrate layer). By keeping the thickness of the sensor layer constant, the material of sensor, are modeled to be variable. Thus, parameters such as, dielectric constant can be detected.

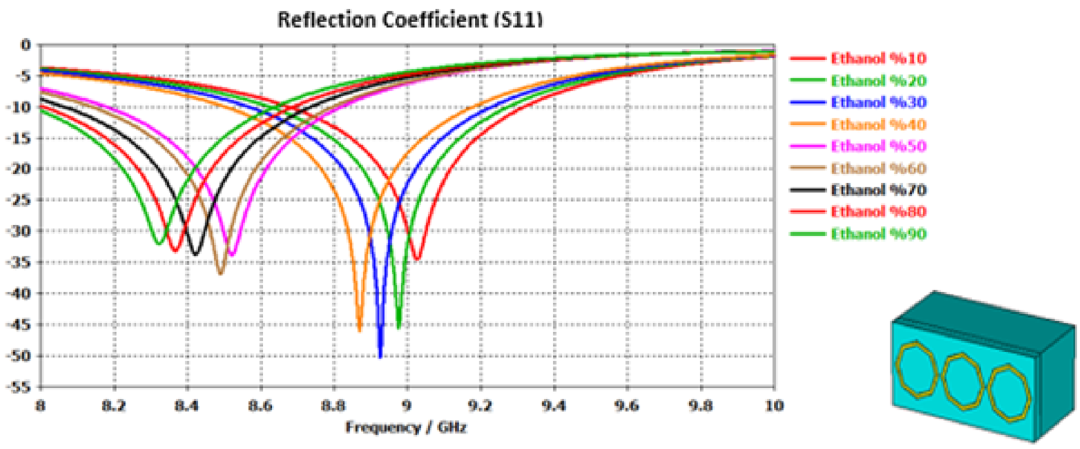

Figure 7. Reflection coefficient of ethanol's solution.

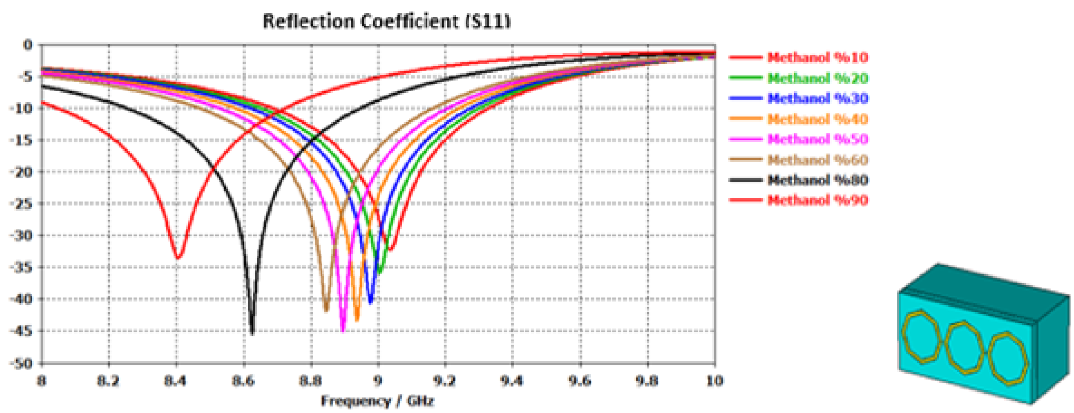

Figure 8. Reflection coefficient of methanol's solution.

When the reflection coefficient has checked and investigated, it has seen that there is a resonance at GHz levels in Octogonal-Shaped resonator Based purity of ethanol and methanol. Resonance Frequency of ethanol and methanol's solution in the Octogonal Resonator Based purity of liquid structure are given in Tables 3 and 4. However, when the transmission coefficients are examined, it has seen that there is no resonance for the Octogonal-Shaped resonator structure. This is due to the fact that the capacitance cannot pull the resonance frequency to the selected band. Resonance values of Ethanol's solution are seen at different frequencies. In Figures

7 and 8, the transmission coefficient is unchanged while the reflection coefficient is shifted backwards.

Table 3. Resonance frequency of ethanol's solution in the octogonal resonator based purity of liquid structure.

Ratio of Ethanol Mixture with Water	Resonance Frequency (GHZ)
Ethanol %10	9.024
Ethanol %20	8.976
Ethanol %30	8.924
Ethanol %40	8.868
Ethanol %50	8.520
Ethanol %60	8.488
Ethanol %70	8.420
Ethanol %80	8.368
Ethanol %90	8.324

Table 4. Resonance frequency of methanol's solution in the octogonal resonator based purity of liquid structure.

Ratio of Methanol Mixture with Water	Resonance Frequency (GHZ)
Methanol %10	9.036
Methanol %20	9.004
Methanol %30	8.976
Methanol %40	8.936
Methanol %50	8.896
Methanol %60	8.844
Methanol %70	8.755
Methanol %80	8.624
Methanol %90	8.408

3.2. Dielectric Constant of Samples (Ethanol and Methanol's Solution in Water)

The change of dielectric coefficients, with the values of the frequency, has been discussed in this section. The resonance frequency of the whole system will change when the dielectric constant of the sensor layer changes (Chieh-Sen & Yang, 2014). The dielectric constant varies according to environmental factors such as temperature, humidity or pressure. Electric Dispersion values are presented in Tables 5 and 6. According to the applying voltage, the values of the reflection coefficient (S11) have been changed. As seen in Figures 9 and 10 the dielectric coefficient affects the resonance frequency. When the temperature is increased, the resonance frequency of the reflection coefficient is linearly increased. This increase of value can be easily monitored by a network analyzer. In sensor application, for the Octogonal-Shaped Resonator Based purity of liquid, the sensor plate is placed behind and back of the structure. Different materials could place on this sensor layer, but in this study, the applications of purity sensor will be investigated and explained in detail for two kind of sample. In addition, the sensor based Metamaterial structure can be used in other sensor applications if different materials are placed in the sensor layer. Material can be selected according to sensor parameters. Since the sensor parameter and selected samples changes the dielectric coefficient, the resonance frequency of the system will change. Dielectric coefficient for different ratio of materials placed on the sensor layer and measurements of the designed structure can be easily carried out by a network analyzer. Figures 9 and 10, shows the frequency value and electric dispersion of two samples. If we compare the changes of reflection coefficient (S11) with the dielectric coefficient of samples, it is seen that these changes are in a liner form according to ratio of Methanol solution.

Table 5. Electric dispersion of methanol in specific frequency (10 GHZ) in the structure.

Frequency (GHZ)	Ratio of Material	Dielectric Coefficient
10 GHZ	Methanol %10	55.46
10 GHZ	Methanol %20	46.80
10 GHZ	Methanol %30	40
10 GHZ	Methanol %40	32.34
10 GHZ	Methanol %50	26.41
10 GHZ	Methanol %60	20.67
10 GHZ	Methanol %70	14.98
10 GHZ	Methanol %80	11.19
10 GHZ	Methanol %90	8.93

Table 6. Electric dispersion of ethanol in specific frequency (10 GHZ) in the structure.

Frequency (GHZ)	Ratio of Material	Dielectric Coefficient
10 GHZ	Ethanol %10	52.45
10 GHZ	Ethanol %20	39.91
10 GHZ	Ethanol %30	30.04
10 GHZ	Ethanol %40	22.37
10 GHZ	Ethanol %50	16.61
10 GHZ	Ethanol %60	12.54
10 GHZ	Ethanol %70	9.64
10 GHZ	Ethanol %80	7.50
10 GHZ	Ethanol %90	5.75

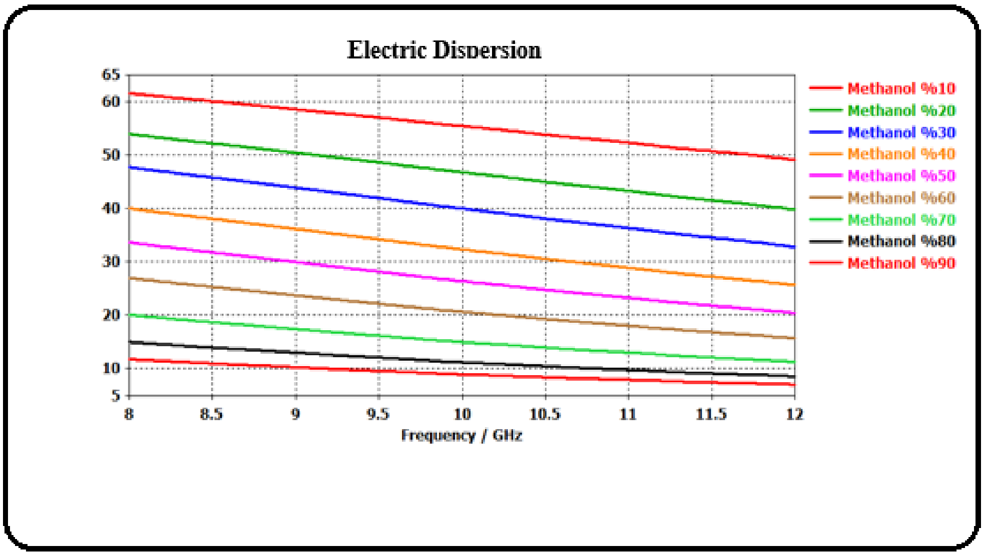

Figure 9. Frequency value and electric dispersion of methanol in the octogonal resonator based purity of liquid structure.

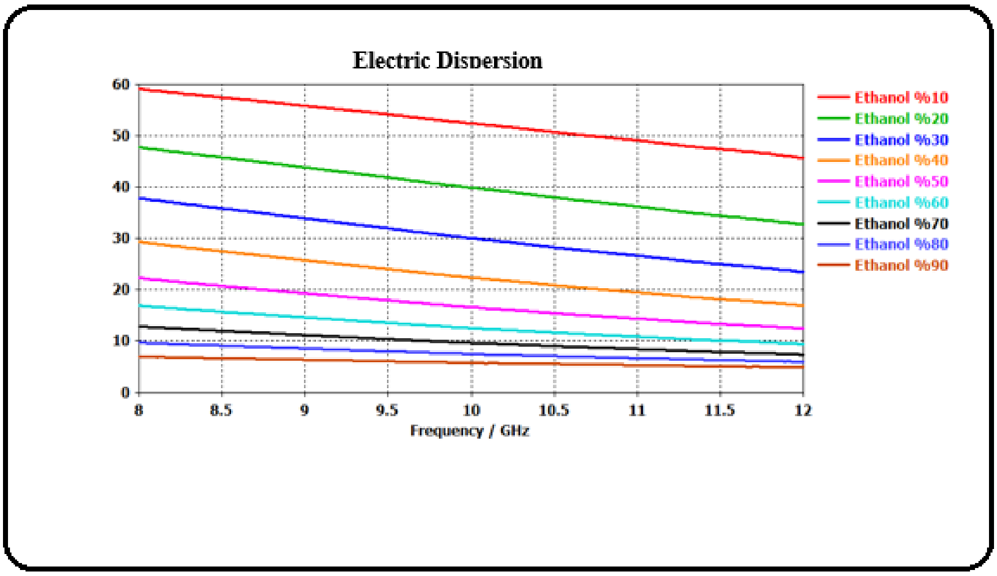

Figure 10. Frequency value and electric dispersion of ethanol in the octogonal resonator based purity of liquid structure.

3.3. Experimental Study of Octogonal-Shaped Resonator Based Purity of liquid Structure

In this study, reflection coefficients for the structure have been developed and obtained numerically and these results are proved by comparing them with experimental results. After performing numerical and experimental studies, the numerical results obtained by CST Microsoft program should be in good agreement with the experimental study results (Bakır, 2017). The purpose of selecting this structure is that it is easy to produce and can easily use in many fields such as determination of purity some liquid. The operating frequency is in the 8GHz-12GHz range. Figure 11 shows the details of the experimental study for Ethanol's solution. The experimental analysis results are presented in Figures 11 and 12.

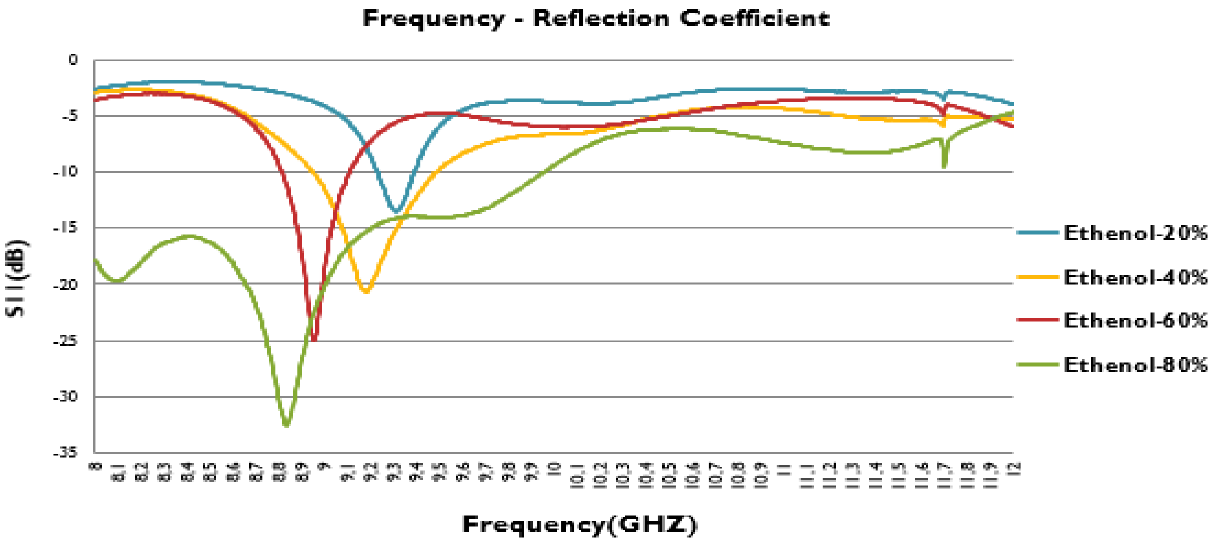

Figure 11. Experimental study results for ethanol's solution.

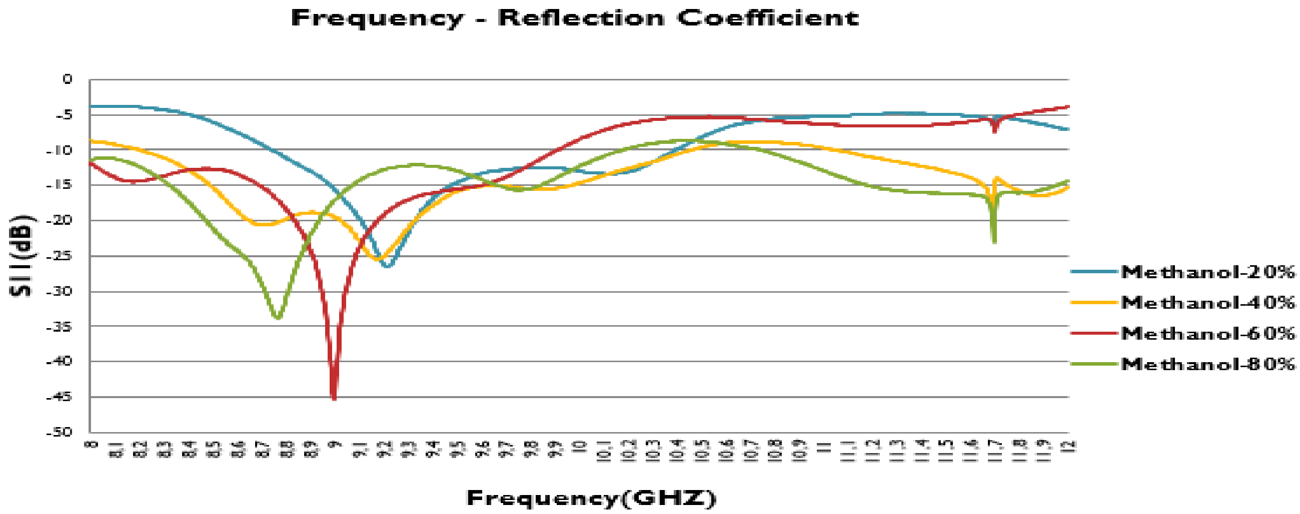

Figure 12. Experimental study results for methanol's solution.

4. Discussion

The results, obtained from the simulation studies have evaluated and discussed with the experimental results for characterization of metamaterial structure. After measurement and simulation, it can be seen that experimental and numerical results are compatible with each other and there are very few differences. These differences are due to production, calibration and material. Electromagnetic characterization is very important for different applications of proposed structure. When electric and magnetic fields are focused in a certain direction, improved electrical and magnetic permeability occurs. Strong magnetic resonance is caused by inductance and capacitance effects between resonators. This indicates that the resonance is stimulated by the magnetic field. In this study, resonance frequencies for the periodic unit cell, electric field and surface current distributions is investigated and examined. If applications are related to the purity of liquid and determination of liquid, they are carried out both experimentally and numerically. Reflection and transmission parameters (S-parameters) are both obtained with the CST Microwave Studio software based FIT method, as well as experimentally researched.

5. Conclusion

The result of the Octogonal-Shaped Resonator Based purity of liquid for determination of liquid is investigated. In order to examine the simulation study results, we can see that the sensor we have designed successfully, perform real-time, fast, quick and accurate in the measurements as liquid detection sensors. It is observed that the resonance frequency changes in a linear way compared to the samples that we are examined. As a result of this linearity it is seen that there is a detection band width. In addition to these changes, it is proved that the values of the reflection coefficient (S11 parameter), according to results, can be used to determine the purity of ethanol and methanol samples in the Octogonal-Shaped Resonator Based purity of liquid. It is observed that changing amount of ethanol and methanol will cause linear changes in the resonance frequency. Octogonal-Shaped Resonator Based purity of liquid sensor has low costs. We can measure and examine them with small amount of samples. When the results are examined, it could be seen that they give very sensitive results. The sensor in this study showed positive results in the processes of test.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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