INSTITUTE OF NATURAL AND APPLIED SCIENCES
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MASTER THESIS

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PURITY DETECTION OF SOME LIQUIDS BY USING TRANSMISSION LINE BASED METAMATERIAL

DEPARTMENT OF PHYSICS

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MSc THESIS

DEPARTMENT OF PHYSICS

We certify that the thesis titled above was reviewed and approved for the award of degree of the Master of Science by the board of jury on 23/07/2019.

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ABSTRACT

MSc. THESIS

PURITY DETECTION OF SOME LIQUIDS BY USING TRANSMISSION LINE BASED METAMATERIAL

Sanam MOVAZZAFGHAREHBAGH

ÇUKUROVA UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF PHYSICS

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The aim of this thesis is to design and fabricate two kind of metamaterial based sensor. One of them, determine purity of Methanol's and Ethanol's mixture in the water by using the octagonal form of resonator and the sample holder. Other one is designed by utilizing transmission line integrated hexagonal shaped metamaterial based sensor which can detect and determine some materials with each other for example determining of Ammoniac, Pure water, Iso Propyl Alcohol (IPA) and Propylene Ethylene Glycol (PEG).

First proposed structure has been employed in the 8-12 GHZ frequency band and the second structure can be used in the 1-8 GHZ frequency band. The important thing in the both of two work are 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 change in liner figure by considering the dielectric coefficient.

We use copper for metal layer and resonator and also use FR-4, Isola IS680 (3.2DK) (lossy) for substrate layer. We simulate one unit cell of these two kind of metamaterial sensor by CST microwave software and then achieve the results and evaluate them. Both the numerically and experimentally tests, give same outcomes and results and they will be in good agreement with each other.

These proposed structure can be used in many application where the purity and determining of some materials might be necessary.

Key Words: Metamaterial, Sensor, Purity, liquid samples

ÖZ

YÜKSEK LİSANS TEZİ

PURITY DETECTION OF SOME LIQUIDS BY USING TRANSMISSION LINE BASED METAMATERIAL

Sanam MOVAZZAFGHAREHBAGH

ÇUKUROVA ÜNİVERSİTESİ
FEN BİLİMLERİ ENSTİTÜSÜ
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Bu tezin amacı, iki tür metamalzeme tabanlı sensör tasarımı ve üretimidir. Sensörlerden biri, rezonatörün sekizgen formunu ve numune tutucuyu kullanarak sudaki Metanol veya Etanolün saflığını belirler. Diğeri, örneğin Amonyak, Aseton, Saf su, İzo Propil Alkol (IPA) ve Propilen Etilen Glikol (PEG) gibi sıvıları birbirinden ayırmaya yarayan ve farklı malzemeleri belirleyebilen iletim hattı bütünleşik altıgen şekilli rezonatör formu kullanan sensör tasarlanmıştır.

Önerilen ilk yapı 8-12 GHZ frekans bandında kullanılmıştır ve ikinci yapı 1-8 GHZ frekans bandında kullanılabilir. Her iki çalışmada da önemli olan şey, dalga şeklinin rezonans frekansındaki değişimleridir. Malzemelerin çıkış dalga formu (S_{11} veya S_{12}) dielektrik geçirgenliği göz önünde bulundurularak liner şekilinde değişmelidir.

Metal tabaka ve rezonatör için bakır ayrıca alt tabaka için FR-4, Isola IS680 (3.2DK) (kayıplı) kullanıldı. Hem sayısal hem de deneysel testler için sonuçların uyum içinde olduğu gözlendi. Önerilen yapılar, bazı malzemelerin saflığını belirlemede ve bazı malzemelerin tespitinin gerekli olduğu birçok uygulamada kullanılabilir.

Anahtar Kelimeler: Meta malzeme, Sensör, Saflık, Sıvı numuneler

EXTENDED SUMMARY

The aim of this thesis is to design and manufacture two types of sensor with metamaterial. Due to the high potential of metamaterials, they have many applications and in technological research, sensor applications have always been the focus of interest.

Metamaterials are non-natural materials with different electromagnetic behavior and exhibit specific electromagnetic (EM) properties that cannot be found inherently in nature. The metamaterial is generally applied in a periodic structure. Metamaterials are artificially designed structures. They have negative dielectric constant and magnetic permeability. The left handed materials with unusual electromagnetic properties (MTMs) theoretically proposed by the Russian physicist Viktor Veselago in 1968. In this study, Veselago also mentioned events such as inverse refraction law and inverse Doppler Effect.

Metamaterials are used in many applications such as antennas, filters, polarization converters, optics, and sensor applications.

Dielectric constant and magnetic permeability must be determined during sensor operation. The dielectric constant is the coefficient for measuring the effect of electric field in the medium. There are many ways to measure the dielectric constant value. One of them is using the probe kit that immersed in liquid.

There are different methods for obtaining parameters of dielectric constant and magnetic permeability. Each method has several advantages and disadvantages. However, the most advantageous method for calculating the parameters is the S-parameters.

In summary, the metamaterial structures and working processes used in the thesis are explained.

In this study, we designed and researched two different structures. One of them is the Octagonal Shaped Resonator Structure,based purity of the liquid and the other one is the Hexagonal Shaped Resonator Structure. Both of them are made according to the measurement conditions.

We used chiral method (reflection coefficient-S_{11}) and transmission line method (S_{12}) to obtain results. These two structures are simulated by using the CST Microwave Studio program. CST is a software that can be used to analyze structures in the laboratory, obtain electromagnetic parameters and simulate models. The CST Microwave Studio program uses Finite Integration technique to perform its own operations. The finite integration technique was first developed by Thomas Weiland in 1977. This method allows and makes easier to analyze Maxwell's integral equations in integral form by converting them to linear form. This formulation process allows for easier analysis ın the complex electromagnetic structures created with the computer.

In the octagonal structure, Isola IS680 (3.2DK) (lossy) material is used for substrate. Copper resonators are made with 0.035 mm thickness. To reduce losses in the selected structure, Isola IS680 (3.2DK) (lossy) material is particularly preferred.

The hexagonal shape is designed for sensor application. This structure consists of a transmission line and a Hexagon location. The back of the structure is different from the front structure. This difference is designed to achieve a strong electromagnetic coupling. FR-4 (Lossy) was selected as substrate. Resonators are made of copper with a thickness of 0.035 mm.

The sensor location in the Octogonal-Shaped Resonator has a thickness of 10 mm and in this study we examine the methanol's solution after placing the ethanol mixture with water in the sensor layer to determine the purity of the ethanol and methanol. These measurements are designed in the CST Microwave Studio program based on the FIT method in the 8 GHz -12 GHz frequency band range. We used the waveguide port for this model. The produced elements are fully inserted into the waveguide. When the boundary condition is applied and the samples are placed, the reflection coefficients of the structure are obtained. The solution of ethanol and the solution of methanol are placed, for example, in the sensor layer. By keeping the thickness of the sensor layer constant, we obtain the reflection coefficients parameter (S_{11}). When the reflection coefficient is checked and examined, resonance is observed in the Octagonal-shaped resonator structure at GHz levels to determine the purity of ethanol and methanol.

Resonance is the tendency of a system (usually a linear system) to oscillate larger at some frequencies than others. Even small periodic forces at these frequencies can produce very large amplitudes. In short, the resonance frequency can be said as the frequency at which a system operates.

If we compare the changes in resonance frequency (S_{11}) with the dielectric constant of the samples, it is seen that these changes are in a linear form by looking at the amount of Ethanol solution or Methanol solution.

When the dielectric constant of the sensor layer changes, the resonance frequency of the entire system will change.

Linearity can be explained with relation between dielectric constant and resonance frequency in sensor studies. In other words, the dielectric constant which changes due to increasing or decreasing of capacitance or inductance effect, causes continuous increase or decrease in resonance frequency.

Our study contain two different shaped sensor application mainly, first part is octoganal shaped metamaterial based sensor application for purity detection, second part is the transmition line integrated hexagonal shaped metamaterial based sensor application for differentiate liquids.

For the first part, different materials can be placed in the sensor layer for determine the purity, in this study sensor applications are examined in detail for two types of samples (thanolEthanol's solution and methanol solution). Also the reflection coefficients of the structure have been obtained numerically and these results have been proved by comparing them with experimental results. After measurement and simulation, it is seen that experimental and numerical results are compatible with each other and there is little difference. These differences are due to production, calibration and material. The purpose of selecting this structure is easy to produce and can be easily used in many areas, such as determining the purity of some liquids.

For the second part, the hexagonal-sensor structure was investigated. This structure consists of transmission line, resonator and sensor location. The sensor is located approximately between the structure and it is like a pool. Some materials such as Iso Propyl Alcohol, Propylene Ethylene Glycol (PEG), Water and Ammonia have spilled in the sensor layer to differentiate and determine their purity. The hexagonal shaped sensor layer has a thickness of 1,635 mm. Back side of the structure is different from infront of the structure. This difference is designed to achieve a strong electromagnetic coupling. FR-4 (Lossy) is selected as the substrate material. Resonators are made of copper with a thickness of 0.035 mm. The structure is designed in the CST Microwave Studio program based on the FIT method and frequency band is proposed in 1GHZ-8GHZ. In order to differentiate fluids, the hexagonal structure is analyzed numerically and the effect of the transmission coefficient parameters is observed. In the hexagonal sensor-based transmission line structure, it can be seen that it has a resonance point with the selected materials.

Changing the dielectric coefficient, changes the resonance frequency of the whole system. Furthermore, if we pour the iso Propyl Alcohol (IPA) solution in the sensor layer, it can be seen that there is regularity between the transmission-resonance frequency and the dielectric constant. As a sensor, this structure can be used to differentiate liquids or to determine the purity of certain substances.

After obtaining the results of the experimental and simulation studies, we have seen that the two sensors that we successfully designed and perform in real time, fast and accurate in measurements.

Consequently, in the Octogonal-Shaped Resonator structure, the values of the reflection coefficient (parameter S_{11}) can be used to determine the purity of ethanol and methanol samples according to the results.

In the hexagonal sensor-based transmission line structure, according to the results, the values of the transmission coefficient (parameter S_{12}) can be used to detect four types of samples (Iso Propyl Alcohol, Propylene Ethylene Glycol (PEG), Water and Ammonia) or to determine the, purity of IPA solution.

Both the Octagonal Shaped Resonator and the Hexagonal Shaped Sensor-Based Transmission Line have low costs. We can measure and examine them with a small amount of sample. In this study, both sensors show positive results in test processes. The difficulty in differentiating of fluids from each other or determining the purity of the fluid is that dielectric coefficients might be close to each other.

GENİŞLETİLMİŞ ÖZET

Bu tezin amacı, metamalzeme tabanlı iki farklı geometride sensör tasarımı ve üretilmesidir. Çünkü metamalzemeler sahip oldukları farklı özelliklerle birçok uygulama alanına sahiptir. Sensör uygulamaları da her zaman teknolojik araştırmalarda ilgi odağı olmuştur.

Metamalzemeler, farklı elektromanyetik davranışlara sahip, doğal olmayan malzemelerdir ve kendiliğinden doğada bulunamayan özgün elektromanyetik özellikler gösterirler. Metamalzeme genellikle periyodik bir yapıda uygulanır. Metamalzemeler yapay olarak tasarlanmış yapılardır. Negatif dielektrik sabiti ve magnetik geçirgenliğe sahiptirler. 1967 yılında Veselago tarafından ortaya atılan bir hipotezde değerlerin negatif olabileceği teorik hesaplamalarla ortaya konulmuştur. Veselago bu çalışmasında ayrıca ters kırılma kanunu, ters Doppler etkisi gibi olaylardan bahsetmiştir.

Metamalzeme antenler, filtreler, polarizasyon konvertörleri, sensör uygulamaları gibi birçok uygulamada kullanılmaktadır. Metamalzemeler yardımıyla sensörlerin hassasiyetini ve çözünürlüğünü artırabiliriz. Metamalzeme tabanlı sensörler tarım ve biyomedikal gibi birçok alanda kullanılmaktadır. Kısacası, metamalzemeler, çeşitli uygulamalar için tasarlanıp analiz edilebilirler.

Sensör çalışmalarında dielektrik sabiti ve manyetik geçirgenliğin belirlenmesi gereklidir. Dielektrik sabiti, bir malzemenin üzerinde yük depolayabilme yeteneğini ölçmeye yarayan katsayıdır. Dielektrik sabiti değerini ölçmenin birçok yolu vardır. Bunlardan biride sıvı içerisine daldırılan prob kittir.

Dielektrik sabiti ve manyetik geçirgenlik parametrelerini elde etmek için farklı yöntemler vardır. Her yöntemin birkaç avantajı ve dezavantajı vardır. Ancak, parametreleri hesaplamak için en avantajlı yöntem, s-parametreleridir.

Özet olarak, tezde kullanılan metamalzemelerin yapıları ve çalışma süreçleri açıklanmıştır.

Bu çalışmada iki farklı yapı tasarladık ve araştırdık. Bunlardan biri, sekizgen şekilli rezonatör yapısı diğeri ise altıgen şekilli rezonatör yapısıdır. Her ikisi de ölçüm şartlarına göre tasarlanmıştır.

Sonuç elde etmek için kiral metod (yansıma katsayısı-S_{11}) ve iletim hattı yöntemini (S_{12}) kullandık. Bu iki yapı CST Microwave Studio programı kullanılarak simüle edilmiştir. CST, laboratuvarda yapıları analiz etmek, elektromanyetik parametreleri elde etmek ve modellerin simülasyonunu yapmak için kullanılabilecek bir yazılımdır. CST Microwave Studio programı kendi işlemlerini yaparken sonlu iterasyon tekniğini kullanır. Sonlu iterasyon tekniği ilk defa 1977 yılında Thomas Weiland tarafından geliştirilmiştir. Bu yöntem Maxwell denklemlerinin bilgisayarlar için uygun olan bütünleşik formlarında yeniden formüle edilmesini sağlar ve gerçek dünyadaki elektromanyetik alan problemlerinin çözülmesine olanak tanır.

Sekizgen şekilli yapıda, yüzey için Isola IS680 (3.2DK) (kayıplı) malzeme kullanılmıştır. Bakır rezonatör 0,035 mm kalınlığında kullanıldı. Seçilen yapıdaki kayıpları azaltmak için, Isola IS680 (3.2DK) (kayıplı) malzemesi özellikle tercih edildi.

Altıgen şekilli yapı, sensör uygulaması için tasarlanmıştır. Bu yapı, bir iletim hattından ve bir Altıgen bölümünden oluşur. Güçlü bir elektromanyetik kuplaj elde etmek için yapının arka kısmı ön kısmına göre farklı olarak tasarlanmıştır. FR-4 (Kayıplı), alt taban olarak seçilmiştir. Rezonatörler 0,035 mm kalınlığında bakırdan yapılmıştır.

Sekizgen şekilli yapıdaki sensör 10 mm kalınlığa sahiptir ve bu çalışmada ilk önce etanolun saflığını belirlemek için, etanol-su karışımını, sensör tabakasına yerleştirdikten sonra etanolün çözünmesini inceliyoruz. Bu ölçümler, 8 GHz -12 GHz frekans bandı aralığında önerilen FIT metoduna dayanan CST Mikrodalga Stüdyosu programında tasarlanmıştır. Bu model için dalga kılavuz portunu kullandık. Üretilen yapılar tam olarak dalga kılavuzunun içine yerleştirilmiştir. Sınır koşulu uygulanıp, numuneler yerleştirildiğinde, yapının yansıma katsayıları elde edilir. Etanol çözeltisi ve metanol çözeltisi, örnek olarak sensör katmanına yerleştirilir. Sensör katmanının kalınlığını sabit tutarak yansıma katsayıları parametresini (S_{11}) elde ederiz. Yansıma katsayısı kontrol edildiğinde ve incelendiğinde, etanol ve metanolün saflığını belirlemek için sekizgen şekilli rezonatörde GHz seviyelerinde, rezonans olduğu gözlenmiştir.

Rezonans bir sistemin (genellikle doğrusal bir sistemin) bazı frekanslarda diğerlerine nazaran daha büyük genliklerde salınması eğilimidir. Bu frekanslarda küçük periyodik kuvvetler bile çok büyük genlikler üretebilir. Yani kısaca rezonans frekansı bir sistemin çalıştığı frekans olarak söylenebilir.

Rezonans frekansındaki değişiklikleri (S_{11}), örneklerin dielektrik sabiti ile karşılaştırırsak, Etanol çözeltisi veya metanol çözeltisi miktarına bakılarak bu değişikliklerin, doğrusal bir biçimde olduğu görülür.

Sensör katmanının dielektrik sabiti değiştiğinde tüm sistemin rezonans frekansı değişecektir.

Sensör çalışmalarında lineerlik, dielektrik sabiti ile rezonans frekansı arasındaki ilişkiyle açıklanabilir. Artan yada azalan kapasitif veya endüktif etkiye bağlı olarak bağlı dielektrik sabitindeki artma veya azalma rezonans frekansında sürekli olarak artma yada azalmaya neden olabilir.

Sensör uygulamalarında, sensör katmanına farklı malzemeler yerleştirilebilir, bu çalışmada saflık sensörü uygulamaları için iki farklı numune detaylı olarak incelenmiştir (Etanol ve metanol çözeltisi).

Bu çalışmada, yapının yansıma katsayıları sayısal olarak geliştirilmiş ve elde edilmiştir. Bu sonuçlar üretim sonucu yapılan deneysel sonuçlarla karşılaştırılarak doğrulanmıştır. Ölçüm ve simülasyon yapıldıktan sonra deneysel ve sayısal sonuçların birbiriyle uyumlu olduğu ve farkın önemsenmeyecek düzyde olduğu görülmüştür. Farklılıklar üretim yöntemi, cihazların kalibrasyonu ve kullanılan malzemeden kaynaklanmış olabilir. Yapıları seçmemizin sebebi, kolay üretilir olması ve bazı sıvıların saflığının belirlenmesi, bileşenlerin tezpit edilmesi gibi birçok alanda kolayca kullanılabilir olmasıdır.

Bu tezin ikinci aşaması için, altıgen sensör yapısı araştırılmıştır. Bu yapı iletim hattı, rezonatör ve sensör bölümlerinden oluşur. Sensör katmanı, yaklaşık olarak, yapı arasına yerleştirilmiş ve havuz gibidir. İzo propil alkol, propilen etilen glikol (PEG), su ve amonyak gibi bazı malzemeleri, birbirinden ayırt etmek için ve saflığını belirlemek için sensör alanına malzemeleri döktük. Sensör katmanı, 1.635 mm kalınlığa sahiptir.

Arkadaki yapı, öndeki yapıdan farklıdır. Bu fark, güçlü bir elektromanyetik kuplaj elde etmek için tasarlanmıştır. Alt taban olarak FR-4 (Kayıplı) malzeme seçildi. Rezonatörler 0,035 mm kalınlığında bakırdan yapılmıştır. Yapı, FIT metoduna dayalı CST Mikrodalga Stüdyosu programında tasarlanmış ve 1GHZ-8GHZ frekans bandı aralığında incelenmiştir. Sıvıları ayırt etmek için, altıgen şekilli yapı sayısal olarak analiz edilip iletim katsayısı parametrelerinin etkisi gözlendi.

Dielektrik katsayısının değişmesi tüm sistemin özelliğini değiştirir. Ayrıca, sensör katmanına izopropil alkol (IPA) çözeltisini dökersek, iletim-rezonans frekans grafiği ile dielektrik sabiti grafiği arasında düzenlilik olduğu görülebilir. Sensör olarak bu yapı, sıvıları ayırt etmek için veya bazı maddelerin saflığını belirlemek için kullanılabilir.

Sıvı saflığını belirleyen sekizgen şekilli rezonatör yapının ve sıvıları birbirden ayırt etmek için altıgen şekilli sensör bazlı iletim hatlı yapının sonuçları ayrı ayrı incelenmiştir.

Deney ve simülasyon çalışmalarının sonuçlarını inceledikten sonra, başarılı bir şekilde tasarladığımız iki sensörün, hızlı ve doğru performans gösterdiği tespit edildi.

Sonuç olarak, sekizgen şekilli rezonatör yapısında, yansıma katsayısının değerleri (S_{11}), etanol ve metanol örneklerinin saflığını belirlemek için kullanılabilir.

Altıgen şekilli iletim hatı tabanlı sensör yapısında, elde edilen sonuçlara göre, iletim katsayısının değerleri (S_{12}), dört çeşit numuneyi (İzopropil Alkol, Propilen Etilen Glikol (PEG), Su ve Amonyak) birbirinden ayırmak için ayrıca IPA'nın saflığını belirlemek için kullanılabilir.

Hem sekizgen şekilli rezonatör, hem de altıgen şekilli iletim hattı tabanlı sensör, düşük maliyetlidir. Her ikisinde de az miktarda örnek kullanarak ölçüm yapıp sonuçlara ulşabiliriz. Bu çalışmada kullanılan her iki sensör de test süreçlerinde olumlu sonuçlar göstermiştir. Bu önemli avantajlarının yanısıra kullanılan sıvıların dielektrik katsayıların birbirine yakın olmasından dolayı malzemelerin saflığını belirlemede zorluklar yaşanmıştır.

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ABBREVIATIONS AND SYMBOLS WITH DESCRIPTIONS

MM	: Metamaterial
RH	: Right-Handed
IPA	: Izo Propyl Alcohol
SRR	: Split-ring resonator
TE	: Transverse electric
TEM	: Transverse electric-magnetic
LH	: Left-Handed
TL	: Transmission line
TLM	: Transmission line method
TM	: Transverse magnetic
TMM	: Transmission matrix method
CMM	: Chiral Metamaterial
CMS	: Chiral Metamaterial Sensor
EM	: Electromagnetic
RHM	: Right handed material
LHM	: Left handed material
λg	: Wavelengths
p	: Unit cell dimensions
ε	: Dielectric constant
μ	: Magnetic permeability
$\vec{E}$	: Electric field vector
$\vec{B}$	: Magnetic field vector
$\vec{W}$	: Wave vector
NIM	: Negativ refractive index material
DNM	: Double negativ material
MNZ	: μ'near to zero material

ENZ	: ε near to zero material
THZ	: Terahertz
PEG	: Propylene Ethylene Glycol
MWS	: CST Microwave Studio
FDTD	: Finite Difference Method in Time Domain
FIT	: Finite Integration Technique
FEM	: Finite Element Method
α	: Angle of incidence
X	: Magnetic electric parameter
ω	: Angular velocity
c	: Light velocity
n	: Refractive index
2D	: Two dimensional
3D	: Three dimensional
Q_e	: charge density
J_s	: electric current density

1. INTRODUCTION

1.1. Metamaterial

Metamaterials are unnatural materials that have different electromagnetic behaviors and show specific electromagnetic (EM) properties that cannot be found inherently in the nature. The mentioned differences are negative refraction index, negative reflection, negative Doppler Effect, negative permittivity and negative permeability. Metamaterials are usually applied in a periodic constructions. It is good way to design and fabricate by repeating structure with the unit cells. A unit cell is a combination of SRR and wire structure. An array of unit cells may be used to get this structure. The split ring resonator (SRR) is shown in figure 1.1. (Pendry and Holden, 1999)

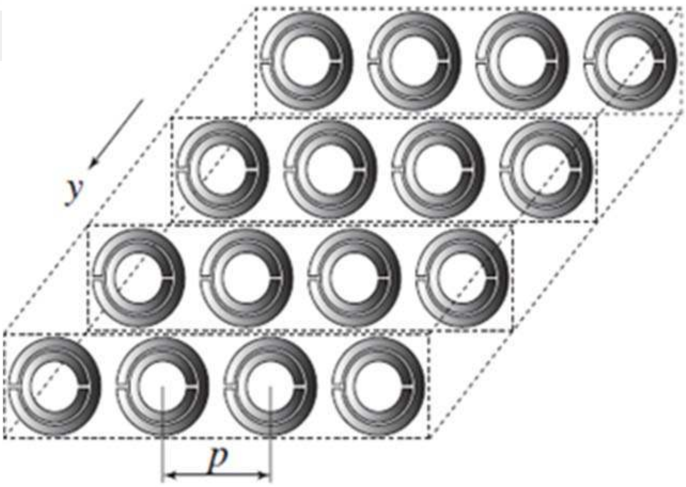


Figure 1.1. Split-ring resonator (SRR) structure (Pendry and Holden, 1999)

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 which provide extraordinary features such as backward propagation, negative permittivity and/or permeability.

1.2. Left Handed Metamaterial (LF) and Right Handed Metamaterial (RH)

In the wave function $e^{-j\beta r}$ or $e^{+j\beta r}$ the propagation constant β is considered by the $\beta = k_n = nk_0 = n\omega/c$ (k_n= wave number in the medium, $k_0 = \omega/c$: free space wavenumber, ω: angular frequency, c: speed of light) (John Wiley & Sons, 2004)

So the constitutive parameters are the permittivity ε and the permeability μ, which are related to the refractive index n by the below equation:

$$n=\sqrt{\varepsilon_r}\mu_r \tag{1.1}$$

where ε_r and μ_r are the relative permittivity and permeability related to the free space permittivity and permeability by $\varepsilon_0 = \varepsilon/\varepsilon_r = 8.854 \cdot 10^{-12}$ and $\mu_0 = \mu/\mu_r = 4\pi \cdot 10^{-7}$, respectively. We can see four kind of sign combinations for (ε, μ) in the equation but if the sign combinations in the pair (ε, μ) be [(−,−)], with simultaneously negative permittivity and permeability, corresponds to the new group of materials called left-handed (LH) materials.

1.3. Reversall Snell's Law

Negative refractive index (NRI) is the property of left hand media and the Reversal Snell's Law (negative refractive) is described at the interface of the left hand medium and right hand medium or at the at the boundary between two media. If θ_i be considered as incident angel, θ_r *as* reflected angel and θ_t *as* refracted or transmitted angle, the SNELL'S LAW can be shown by the below relations (C. Caloz, 2004),

$k_i \ sin \ \theta_i = k_t \ sin \ \theta_t$ (1.2)

$n_1 \ sin \ \theta_1 = n_2 \ sin \ \theta_2$ (1.3)

In the Figure1.2. Reversal Snell's Law is illustrated:

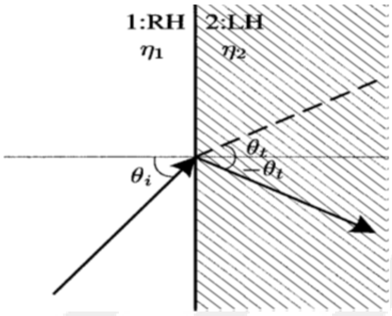


Figure 1.2. Interface RH/LH with a negative angle of refraction (Caloz, 2004)

1.4. Classic Field of Electromagnetic Theory

The manner of specific substances under the influence of the electromagnetic field is expressed by the H, J, D components and relation between them, which H, is defined as a magnetizing field, J as current density and D as displacement field. These are determined often through a simple linear relation.

1.4.1. Maxwell's Equations

In a LH (left hand) material that double negative nature of the constitutive parameters, ε and μ results in the propagation of electromagnetic waves, exhibiting antiparallel phase and group velocities or LH waves. At the first we should know Maxwell's Equations. Metamaterial can be characterized by using Maxwell equations that these equations obtained from the classical laws of electricity and magnetism. In presence of matter, Maxwell's equations written as (Weiland, 1977; Taylor, 2010):

$$\nabla \times E = -\partial B/\partial t - M_s \qquad \text{(Faraday's law)} \tag{1.4}$$

$$\nabla \times H = \partial D/\partial t + J_s \qquad \text{(Ampere's law)} \tag{1.5}$$

$$\nabla \cdot D = Q_e \qquad \text{(electric Gauss' law)} \tag{1.6}$$

$$\nabla \cdot B = Q_m, \qquad \text{(magnetic Gauss' law)} \tag{1.7}$$

where E (V/m) is the electric field intensity, H (A/m) is the magnetic field intensity, D (C/m2) is the electric flux density, B (W/m2) is the magnetic flux density, M_s (V/m2) is the magnetic current density, J_s (A/m2) is the electric current density, Q_e (C/m3) is the electric charge density, and Q_m (C/m3) is the magnetic charge density. Maxwell equation related to time can be written (Greengard,1987; Clemens, Thoma, Weiland, 1995)

$$\nabla \times E = -j\omega\mu H - M_s, \tag{1.8}$$

$$\nabla \times H = j\omega\varepsilon E + J_s, \tag{1.9}$$

$$\nabla \cdot D = \rho_e\ , \tag{1.10}$$

$$\nabla \cdot B = \rho_m\ , \text{ and} \tag{1.11}$$

$$D = \varepsilon E,\ B = \mu H \tag{1.12}$$

2. PREVIOUS STUDIES

2.1. Metamaterials from Historical Perspective

The left handed materials with unusual electromagnetic properties (MTMs) 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" that is shown in the fourth quadrant of Figure 2.1. 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, 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, Padilla, 2000) San Diego (UCSD) 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 (Pendry, Holden, Robbins and Stewart, 1998), was to exploit the inductive response from structured nonmagnetic materials to obtain high-frequency magnetism. This concept has found successful implementations through the use of arrays of copper SRRs which generate an effective magnetic response at frequencies up to hundreds of terahertz. In this range of frequencies, SRRs combined with wires have been used as the constituent particles of artificial media in which NRI (Negative refraction index) can be observed for plane waves with fixed polarization impinging at certain angles.

During these years of infancy for metamaterials (MTMs), which emerged from the first experimental demonstration of a left-handed (LH) structure in 2000, the vast majority of the groups involved in research on MTMs had been focusing on investigating from a physics point of view the fundamental properties of MTMs and their applications.

2.2. Speculation of Veselago about Classification of Materials

Viktor Veselago speculate and classificate metamaterial theoretically as the below figure 2.1.

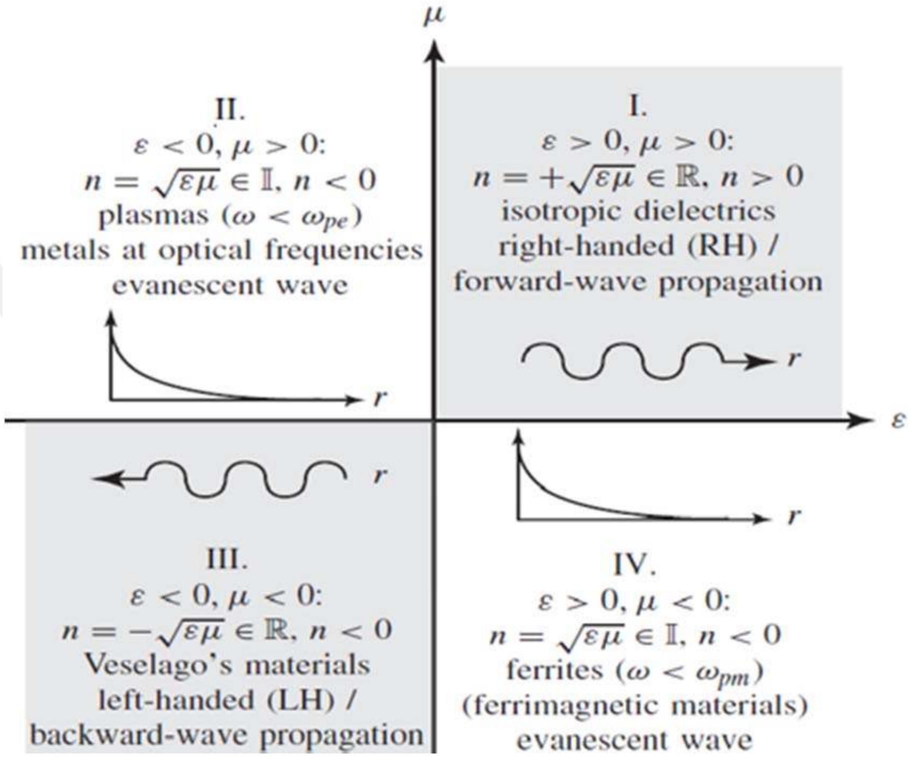


Figure 2.1. Permittivity-permeability ($\varepsilon - \mu$) and refractive index (n) diagram (Caloz 2004, Itoh 2004)

2.3. Review of Previous Fabrication Metamaterial Sensors

In the previous studies, for example, Transmission Line Integrated Metamaterial Based Liquid Sensor (Karadag, Karaaslan, and etc, 2018), and Chiral Metamaterial Sensor (CMS), Octagonal Shaped Metamaterial Absorber Based Energy (Karadag, Karaaslan, Dalgac and etc, 2018), have been designed, simulate and fabricate.

In the experimental studies, for all kind of these metamaterials, at the first, the proposed structure is fabricated and then samples are adjusted into the sensing layer of structure. After these processes, the resonance frequency of the proposed sensor structure is measured by using a device that its name is, vector network analyzer. Finally, the numerical and experimental results must be compared to each other.

In Transmission Line Integrated Metamaterial Based Liquid Sensor (Karadag, Karaaslan, and etc, 2018), main resonators consist of metallic open loop and dielectric gap, which achieve strong resonance. They can be couple with electric and magnetic waves due to their geometrical size and orientation. This structure could be used to differentiate and determine the authentic and inauthentic gasoline samples, or fabricated structure can be used as a liquid detector. One kind of chiral metamaterial based sensor is improved by Mr. Karaaslan and Bakir. We can use, this model sensor as pressure, density and temperature sensor in X band frequency regime.

Chiral Metamaterial Sensor (CMS) (Karadag, Karaaslan, Dalgac and etc, 2018), which is designed with four rectangular shaped Split Ring Resonators (SRR) and reveal two different types of sensor applications by experimentally and numerically. After designing chiral metamaterials, sensor layer which is placed behind the back side of the resonators, has been deployed. Vibration and motion of metallic loop and limited electric field in the dielectric gap and capacitive sensing gaps would be happen at the resonance frequency. This resonance is very sensitive depending on the dielectric inclusions in the subwavelength gap area. Chiral metamaterial sensor structure is used for substance purity. Front and back side resonators have been placed with 180◦ angle difference with each other to increase mutual capacitance and mutual inductance effects. Chiral Metamaterial Sensor (CMS) material has been specifically chosen due to its limited loss of value in increasing the sensitivity of the sensor. The split ring resonator forms can be explained in a series of a RLC resonant circuit. The resonant frequency

$$f_0 = \frac{1}{2\pi\sqrt{LC}} \tag{2.1}$$

After preparing samples, we have placed them in the sensor layer and measured the reflection coefficient (S11) for different solutions that at first evaluated and presented with simulation study results.

In many industries such as petrol industry, Petrol adulteration and purity determination is an important problem and Kerosene is one of the adulterant that it causes to increase illegal profit and it isn't good for economy of countries, so the main approach of metamaterial based liquid detector is to solve these problems.

Octagonal Shaped Metamaterial Absorber Based Energy generally consists of three layers which are metal back plate, substrate layer and resonator layer. The resonators are also chosen as copper (Karadag, Karaaslan, Dalgac and etc, 2018). Octagonal shape metamaterial absorber is investigated in TE, TM and TEM modes.

Perfect absorption can be completed by arranging the periodic structures in a method by switching of complex permittivity and permeability for well absorb electromagnetic energy. In the future, this design can be developed for better performance in all application modes as well as sensor applications may be offered.

3. APPLICATION OF METAMATERIAL

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, Luukkonen, Jylhä, Venermo, Tretyakov, 2007), antennas (Metamaterial can increase the gain and reduce the return loss and disadvantage of a patch antenna) (Zhu1, Lin, 2005), filters, polarization converters, optics, cloaking (Alitalo, Luukkonen, Jylhä, Venermo, Tretyakov, 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 sensors are placed on resonant material and employ SRR to enhance the sensitivity for better result in agriculture), metamaterial based harvesters and absorbers (In 2008 landy employed two metallic layers and dielectric as a first Metamaterial based absorber) and chiral metamaterial and etc. These applications can be grouped according to the geometry of the metamaterial structures. In brief, varied kinds of metamaterials with many applications are analyzed for various applications.

4. MATERIALS AND METHODS

4.1. Obtaining Parameters

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 metods.

There are different methods for obtaining these parameters. Each method has several advantages and disadvantages. However, there is 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 medium. Numerical and experimental results are used, to design new metamaterials, the researchers can compare, and the numerical results of simulation program with the obtaining parameters of experimental method for propose structure.

4.2. Methods for Measuring S-Parameters

A number of domains have been developed for measuring the dielectric properties of materials, such as time domain, frequency domain,

Each method includes limitations or specific constraints. By considering of these domains, measurments 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

Here, the most advantageous method for obtaing parameters, such as the refractive index, effective dielectric permittivity, 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, effective magnetic permeability are obtained. And another reason, these methods aren't time consuming and don't need lot of laboratory equipments.

In this study, we have designed two structures, for one of them chiral metod and for other one transmission line method are chosen and structures are made accordingly in terms of measurement conditions.

The resonators at the front and back side of the structure have symmetry and they could be placed with different angle to each other, in the chiral method (reflection method). There is a loop as resonator with the gap in the Transmission line method to get strong resonance.

4.3. Numerical Methods Used in Electromagnetic Wave Propagation

Finite difference method in time domain (FDTD), finite integration technique (FIT) and finite element method (FEM), which are commonly used methods in the solution of electromagnetic problems.

4.3.1. Finite Difference Method in Time Domain (FDTD)

The finite difference method in time domain was created by Kane Yee in 1966 (Yee & Chen, 1997). It has been developed by researchers in the following years and is a method used of electromagnetism, frequently. Nowadays, its use is very common. The FDTD method is a method used to solve Maxwell's differentially shaped curl equations. It represents the spatial and temporal derivatives of Maxwell's equations.

This expression is used because it represents the spatial and temporal derivatives of Maxwell's equations.

The space point specified in the below equation

$$(i, j, k) = (i\Delta x, j\Delta y, k\Delta z) \tag{4.1}$$

A function of location and time for this situation in space;

$$u(i\Delta x, j\Delta y, k\Delta z) = u_{i,j,k}^{n} \tag{4.2}$$

4.3.2. Finite Element Method (FEM)

The FEM method, which is a numerical technique, is a suitable method for solving boundary value problems. The FEM method was first presented by Courant in the 1940s (Courant, 1943). The method used in mechanical structure problems and in different fields in the following years.

The FEM method allows the mathematical expression of complex equations or physical expressions of precision partial difference equations in the time domain. Because it is based on matrix equations, it provides easy analysis with the necessary algorithm methods and provides a fast result (Lyer et al, 2003). The FEM technique is also an appropriate method for the creation of dielectric structures. The accuracy of calculations in the FDTD and FEM methods is very high. Due to these properties they produce results that are close to actual values.

4.3.3. Finite Integration Technique (FIT)

It was first studied by Weiland in 1977 (Weiland, 1977). In the following years, different electromagnetic waves have been used to solve problems. The finite integration technique (FIT), which is an iterative or repetitive technique, makes it easier to analyze Maxwell's integral equations in integral form by converting them into linear form. This formulation process allows for easier analysis ın the complex electromagnetic structures created with the computer (Clemens and Weiland, 2001).

For homogeneous situation, the FIT and FDTD methods used are two methods that show similarities. It is a technique that addresses the relationship between interfaces and different environments more precisely. Finite integration method is widely used, due to its high flexibility in geometric modeling, for curved borders and complex shapes also it gives true and more accurate results (Rahimi, 2011).

4.4. Simulation Method by CST

CST Microwave Studio (CST MWS) and CST Electro Magnetic (EM) are used for analyzing the structures. In this thesis, CST Microwave Studio which is applied effectively by scientists, have been used for obtaining electromagnetic parameters and simulation of models. CST is a software that can be used in the laboratory. CST Microwave Studio (MWS) is an environment where low wavelength and high frequency designs are studied.

CST is a software that uses FDTD and FIT methods. The finite integration method is used to solve Electro Magnetic (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 in Maxwell's equations.

4.5. Structures

In this section, the metamaterial structures and the processes of works which are used in the study are described below.These two structures are simulated by using CST Microwave Studio program.

We have investigated two different structure and two different designs have been realized for metamaterial electomagnetic characterization. One of them is, Octagonal Shaped Resonators Structure Based purity of liquid and other one is Hexagonal Shaped resonator structure as below.

Relative dielectric constant and thickness, Isola IS680 (3.2DK) (lossy) material has 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. First structure in this thesis and each unit has seen in Figure 4.1.

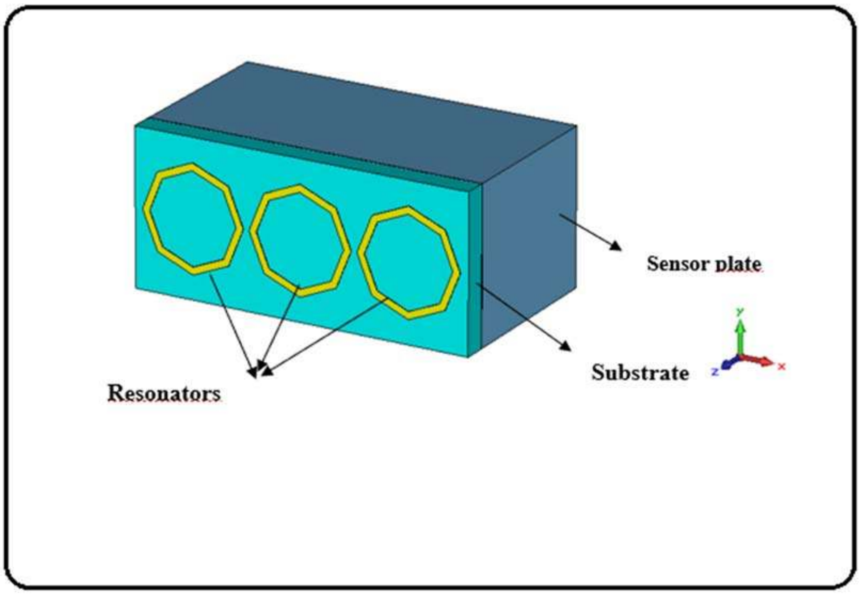


Figure 4.1. Octogonal shape resonator for determine purity of liquid

The structure has designed for the application of sensor and consists of an outer line and a Hexagon place at the upper to lower layer. The structure on the back is different from the structure on the front. This difference is intended to achieve a strong electromagnetic coupling. FR-4 (Lossy), material has been selected as substrate. Resonators are made of copper with the thickness of 0.035 mm.

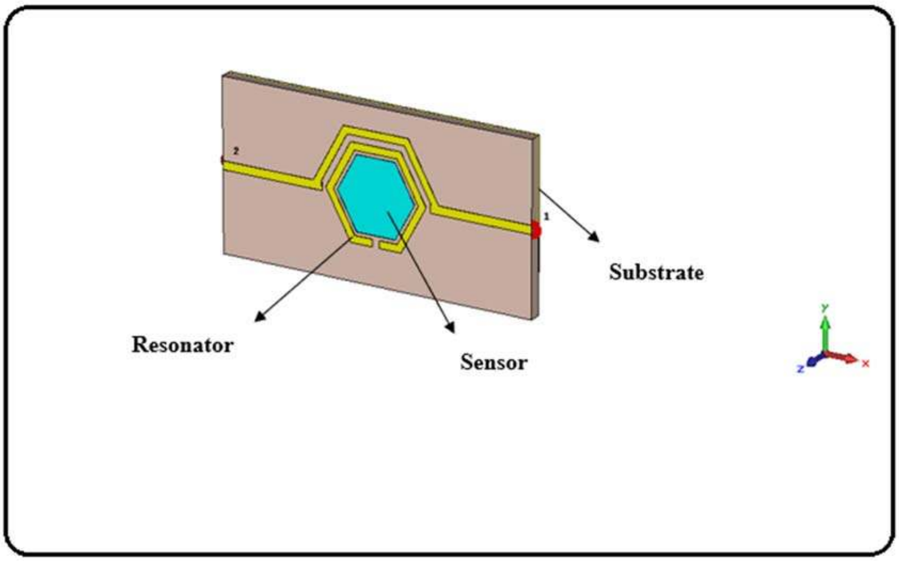


Figure 4.2. Hexagonal Shaped Sensor based Transmission Line

5. RESEARCH FINDINGS AND DISCUSSION

In this section, for the applications of the structures, the reflection coefficient (S_{11}), transmission coefficient (S_{12}) and EM properties of these structures are discussed with obtained findings in numerical and experimental working.

5.1. Octagonal Shaped Resonators Based purity of liquid Structure

5.1.1. Design and Dimension of Octagonal Shaped Resonators Based purity of liquid Structure

Octogonal shaped structure-based liquid's purity, consists of three discrete octagon resonators at the front and three octogonal resonators at the back of substrate and sensor plate.

In this study, the use of Octogonal-Shaped Resonator Based purity of liquid, is described in a unit cell for sensor application. In Figure 5.1, 5.2 and Table 5.1, type of materials and details on dimension of Octogonal-Shaped resnator Based purity of liquid, are presented. In the octagonal-shaped structure, Isola IS680 (3.2DK) (lossy) that shown in Figure 5.1, have placed on the substrate part by considering dielectric coefficient and loss tangent value of this material relatively. Resonators are manufactured with copper, have a specific conductivity and 0.035 mm thickness. This type of resonator is suitable due to their narrow bandwidth. The sensor plate, in the Octogonal-Shaped Resonator Based purity of liquid' structure has 10 mm thickness and in this study, at first we placed ethanol's mixture with water in sensor layer for determine the purity of it, then examin metanol'solution.

These measurements are designed in CST Microwave Studio program based on FIT numerical metod which have been proposed in 8 GHz -12 GHz frequency band range. The produced structure is shown in Figure 5.1.

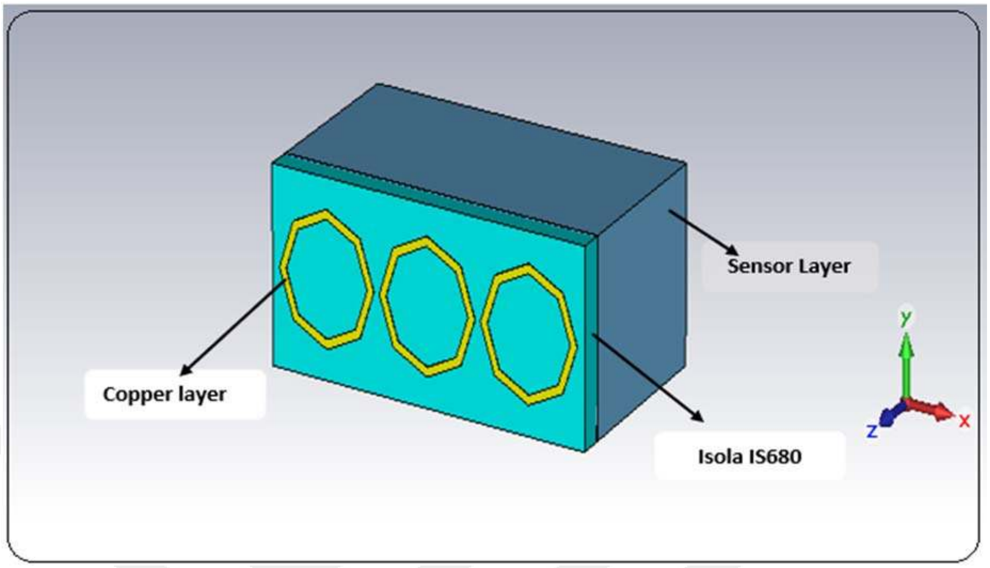


Figure 5.1. Type of materials use in Octogonal-Shaped Resonator Based purity of liquid

The technical details and specifications for the mentioned structures are given in the following section and shown in Fİgure 5.3.

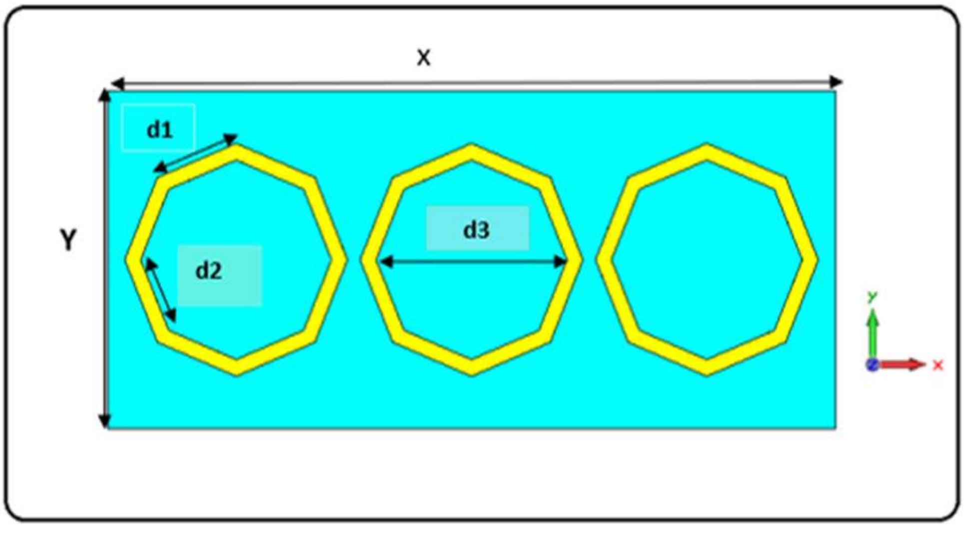


Figure 5.2. Dimension of Octogonal Shaped Resonators to determine purity of liquid

Table 5.1. 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

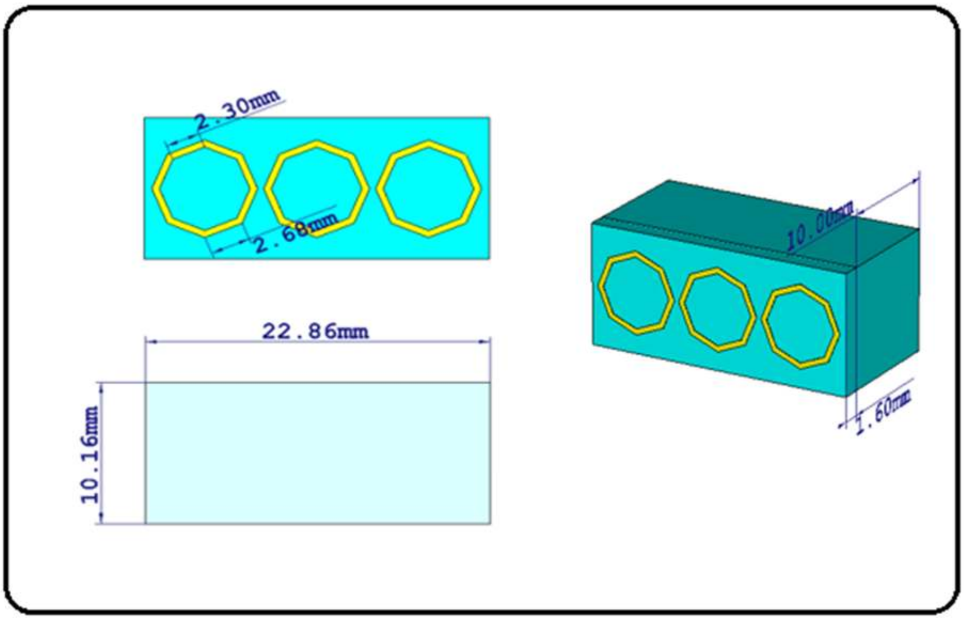


Figure 5.3. Unit Cell's Fabrication, Front View, Side and Back View for Octogonal-Shaped Resonator Based Purity of Liquid

5.1.2. Defining Ports and Boundary Conditions

We have used waveguide port for this model. Boundary Conditions of unit cell, for the Octogonal Shaped Resonators 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 Figure 5.5. Axes and values are entered in the simulation program, for the characterization of the waveguide. The produced elements are located exactly inside the waveguide.

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 Figure 5.4, is 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 5.2. The boundary condition of the x and y axes is the same as with each other. In the figure 5.5 has shown design of structure with the boundry condition.

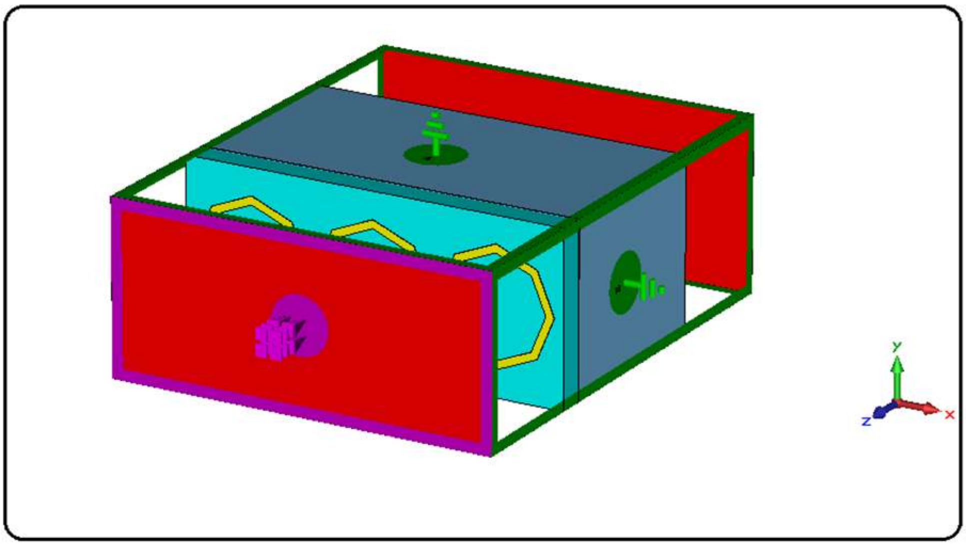


Figure 5.4. Perspective View of Boundary conditions applied for octogonal-shaped resonator

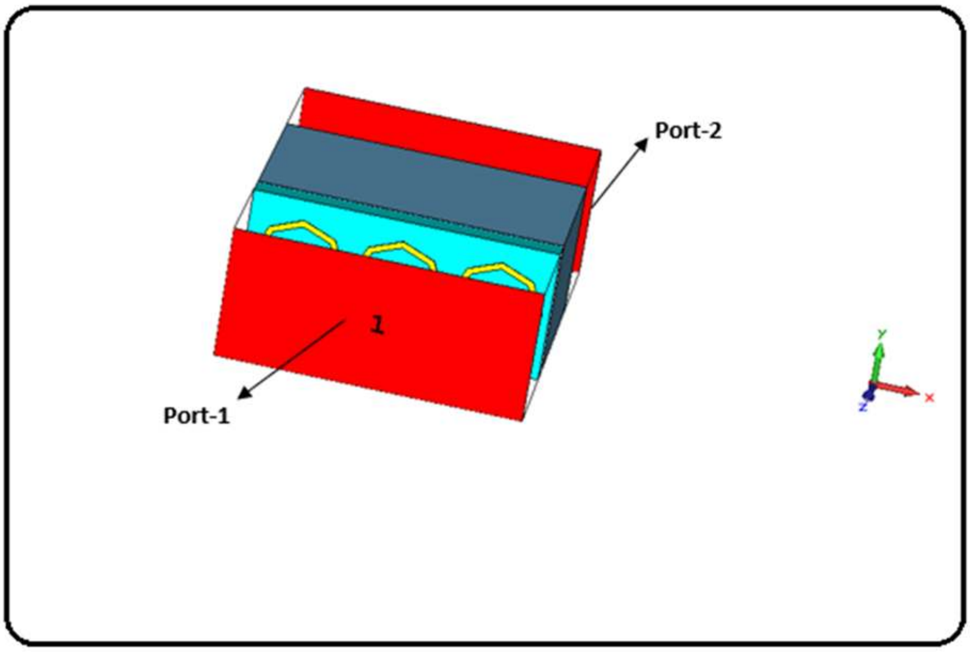


Figure 5.5. Defining of Ports for Octogonal-Shaped Resonator to determine purity of liquid structure

Table 5.2. Boundary conditions applied for octogonal shape resonator for determine purity of liquid

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

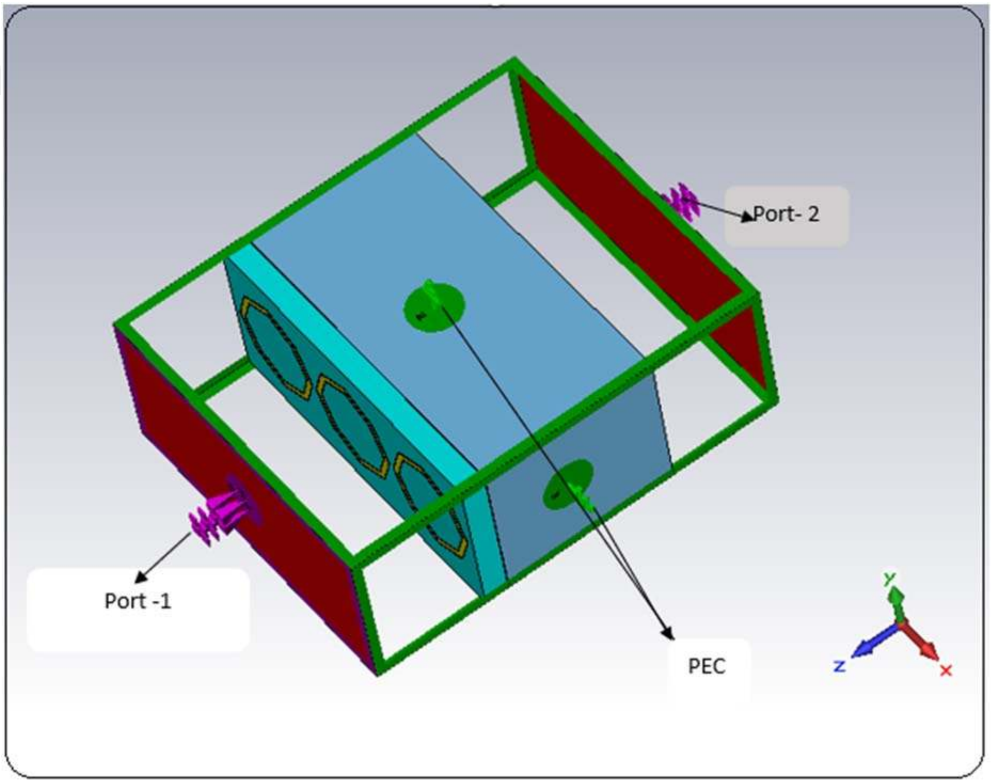


Figure 5.6. Boundry Condition for Octogonal-Shaped Resonator to determine purity of liquid structure

When boundary conditions are applied to Octogonal-Shaped resonator Based purity of liquid structure, the resonance frequencies of selected water as a sample, for reflection coefficients and transmission coefficient are determined as the below figure:

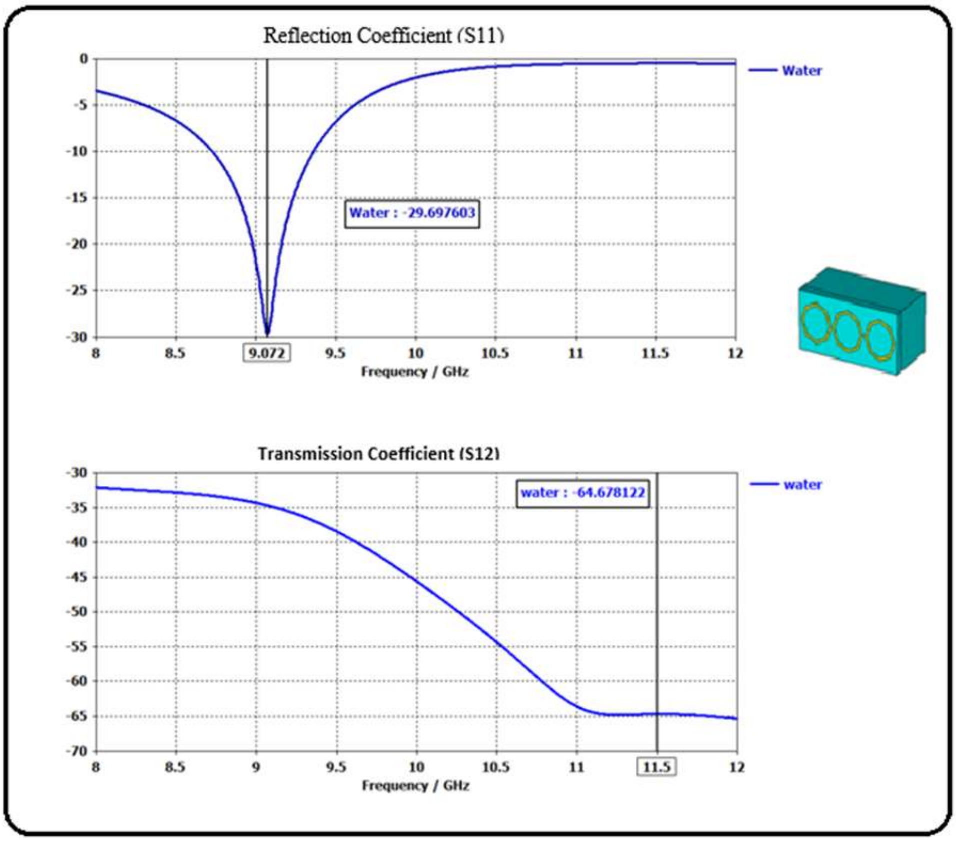


Figure 5.7. Value of Reflection and transmission Coefficient in Octogonal-Shaped Resonator Based Purity of liquid Structures with Water as Sensor

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

When the boundary condition is applied and samples are placed, the reflection and transmission coefficients of structure are presented in Figures 5.7. and 5.8. 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.

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. How ever, 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. Figures 5.7. and 5.8. shows that the transmission coefficient is unchanged while the reflection coefficient is shifted backwards.

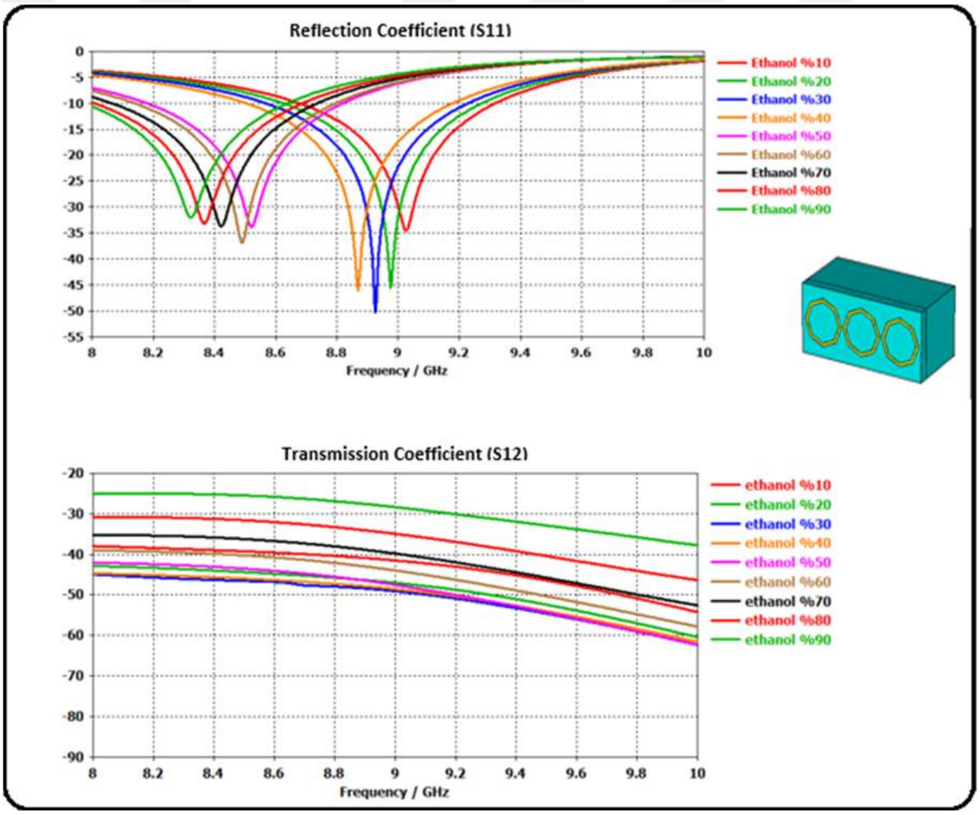


Figure 5.8. (a) Reflection Coefficient of Ethanol's Solution, (b) Transmission Coefficient of Ethanol's Solution.

Table 5.3. Resonance Frequency of Ethanol's solution in the Octogonal-Shaped 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

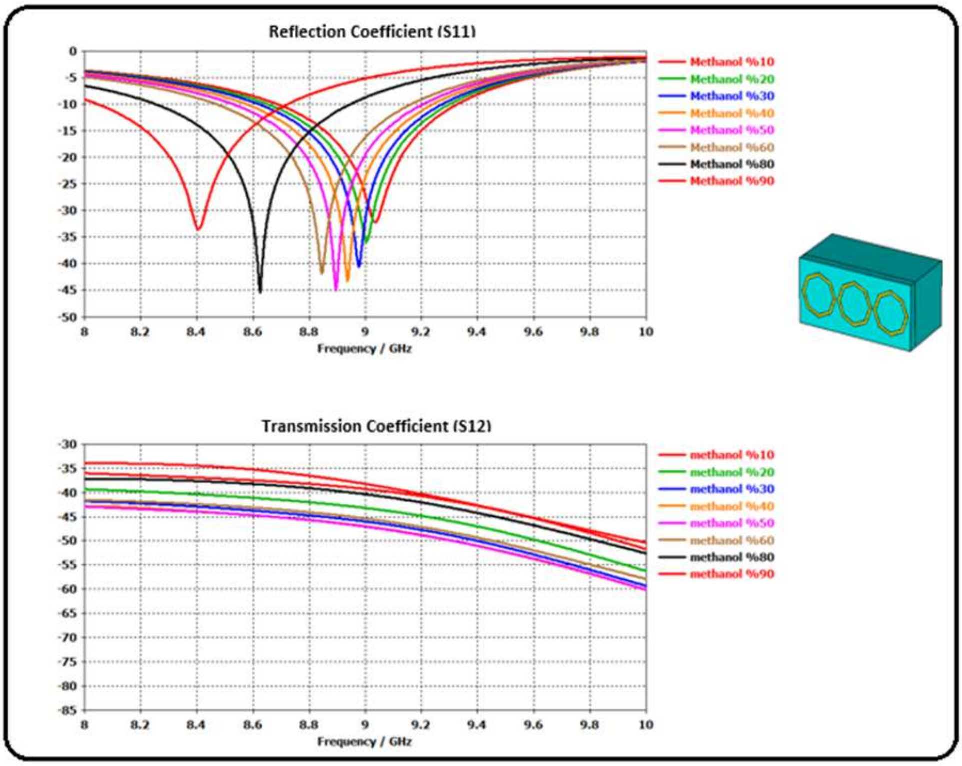


Figure 5.9. (a) Reflection Coefficient of Methanol's Solution, (b) Transmission Coefficient of Methanol's Solution.

Table 5.4. Resonance Frequency of Methanol's Solution in the Octogonal-Shaped 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

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

The changes of dielectric coefficient, 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. The dielectric constant varies according to environmental factors such as temperature, humidity or pressure. Electric Dispersion values are presented in Table 5.5.and 5.6. According to the applying voltage, the values of the reflection coefficient (S11) have been changed. As seen in Figure 5.9. 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 placed 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.

Diectric coefficient for different materials placed on the sensor layer and measurements of the designed structures, can be easily carried out by a network analyzer. Figure 5.9. and 5.10. 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.

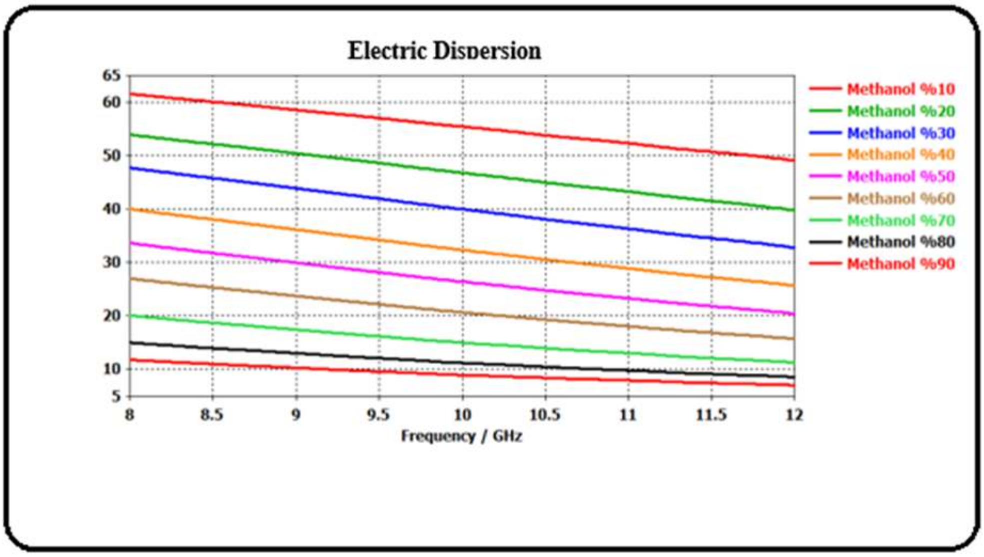


Figure 5.10. Frequency Value and Electric Dispersion of Methanol in the Octogonal-Shaped Resonator Based Purity of Liquid Structure

Table 5.5. Electric Dispersion of Methanol in Specific Frequency (10 GHZ) in the Octogonal-Shaped Resonator Based Purity of Liquid 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

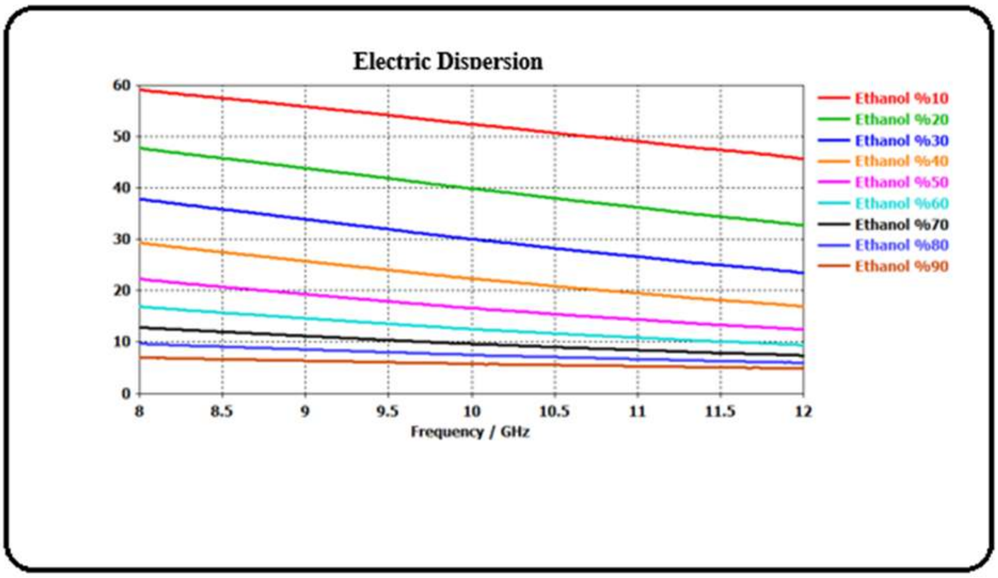


Figure 5.11. Frequency Value and Electric Dispersion of Ethanol in the Octogonal-Shaped Resonator Based Purity of Liquid Structure

Table 5.6. Electric Dispersion of Ethanol in Specific Frequency (10 GHZ) in the Octogonal-Shaped Resonator Based Purity of Liquid 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

5.1.5. 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 program should be in good agreement with the experimental study results. The purpose of selecting this structure is that it is easy to produce and can easily used in many fields such as determination of purity some liquid. The operating frequency is in the 8GHz-12GHz range. Figure 5.11. shows the details of the experimental study.

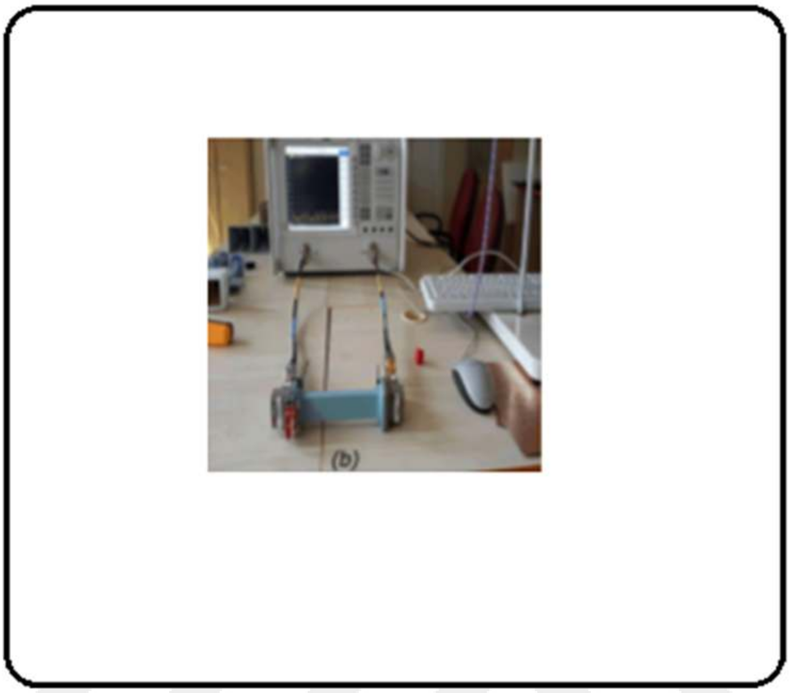


Figure 5.12. Experimental Study

The experimental analysis results are presented in Figure 5.13. As you see in the figure we don't test all the percentages of methanol and ethanol' solution. Because we didn't have enough sampls in the lab.

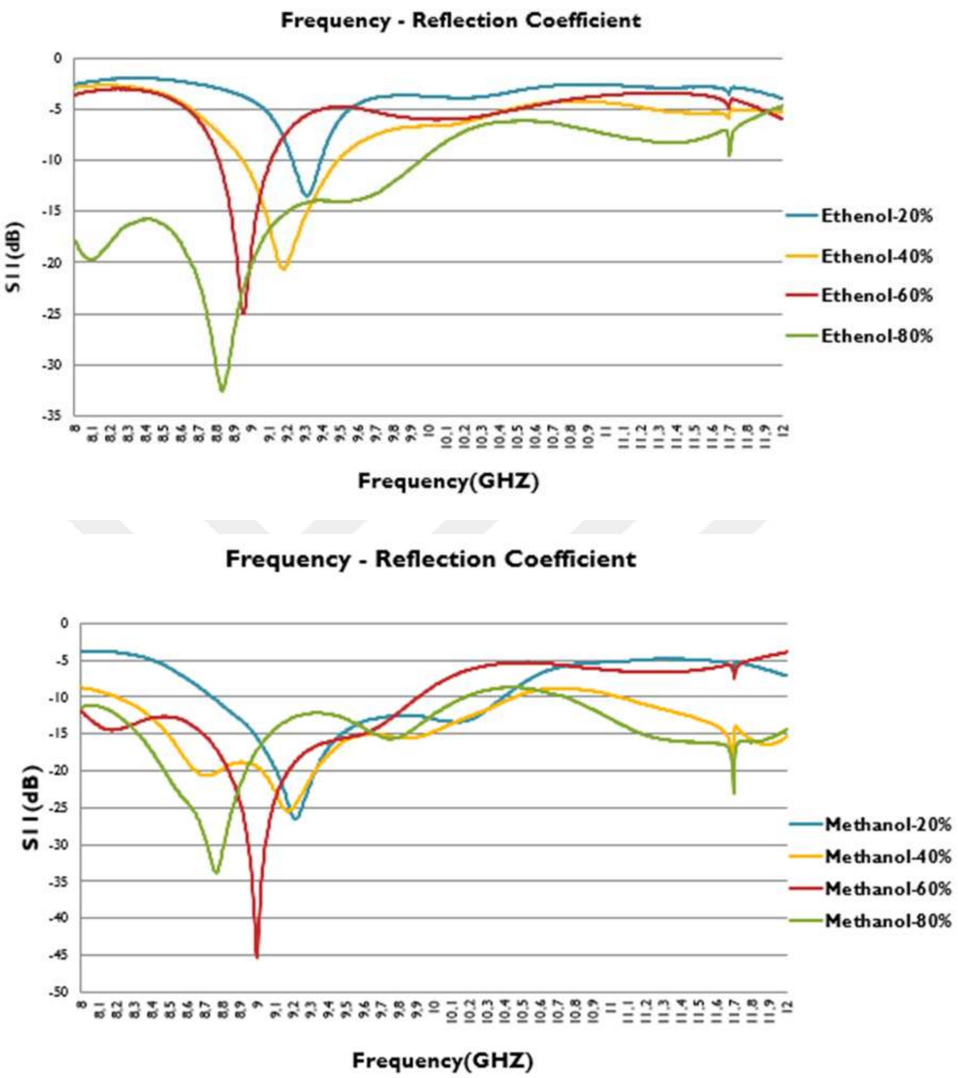


Figure 5.13. Experimental Study Results for Two Sample

5.2. Hexagonal Shaped Sensor based Transmission Line for determination of liquid with each other

Second structure that we have investigated in this study, proposed as below specifications.

5.2.1. Design and Dimension of Hexagonal Shaped Sensor based Transmission Line Structure for Differentiate liquid

Hexagonal-sensor structure consists of transmission line resonator and sensor laver. The structure are designed for the application of sensor and consists of an outer line and a Hexagon at the upper to lower layer. The sensor approximately has placed between the structure like laver (pool) and diffrent materials are placed on this place for measuring the purity of them. The sensor layer, in the Hexagonal sensor shaped based transmission line' structure has 1.635 mm thickness.

The structure on the back is different from the structure on the front. This difference is intended to achieve a strong electromagnetic coupling. FR-4 (Lossy), material has been selected as substrate. Resonators are made of copper with 0.035 mm thickness. The structure is designed in CST Microwave Studio program based FIT metod. The produced structure has shown in Figure 5.12, 5.13, while the structure is designed, the present studies have been reviewed to adjuste resonator and substrate dimensions according to the working frequency. The best dimensions have been determined where the sensor capability is in good situation and therefore the production and testing steps have been made.

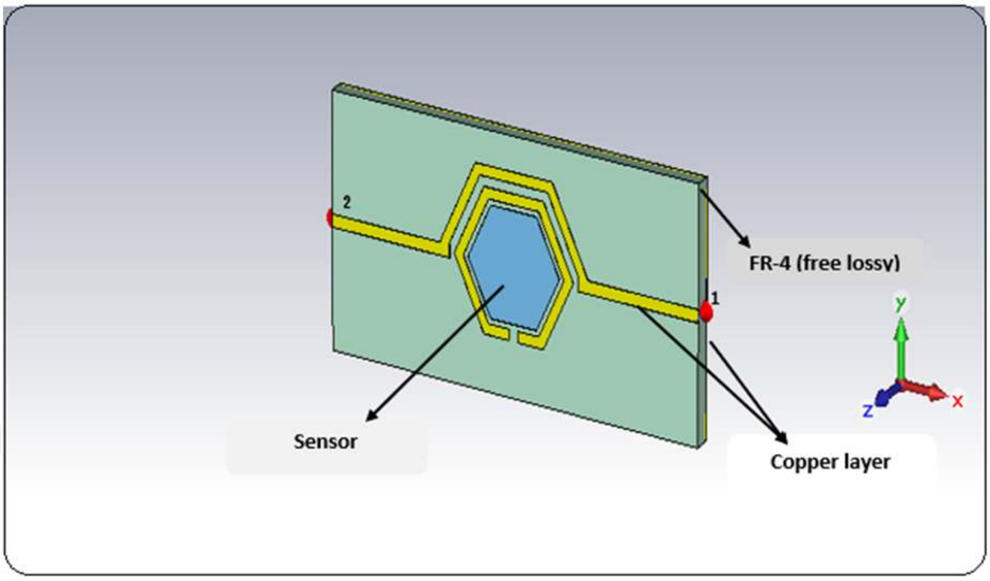
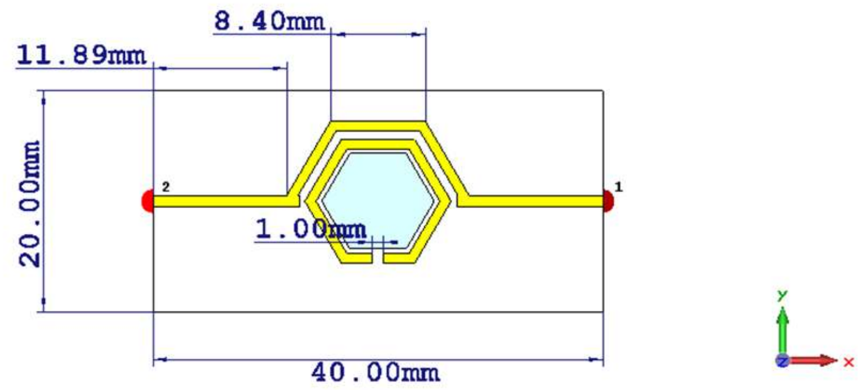
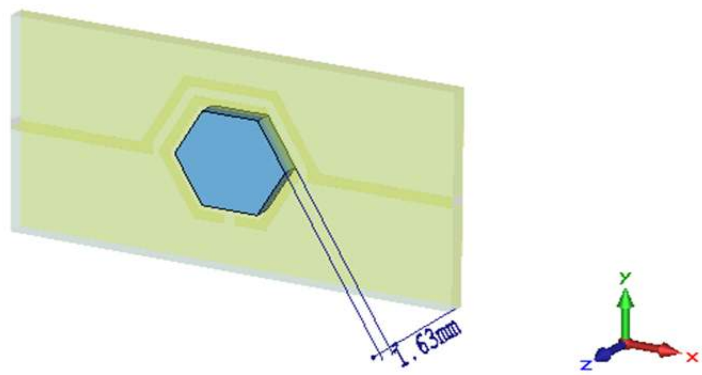


Figure 5.14. Type of Materials use in Hexagonal Shaped Sensor based Transmission Line

In this study, the Hexagonal design based transmission line, have been proposed in the 1GHZ-8GHZ frequency band. We adjusted some marterials like Izo Propyl Alcohol, Propylene Ethylene Glycol (PEG), Water and Ammoniac in sensor location for differentiating and determining mentiond materials from each other. The technical details and specifications for the specified structures are given in the following section.



a)



b)

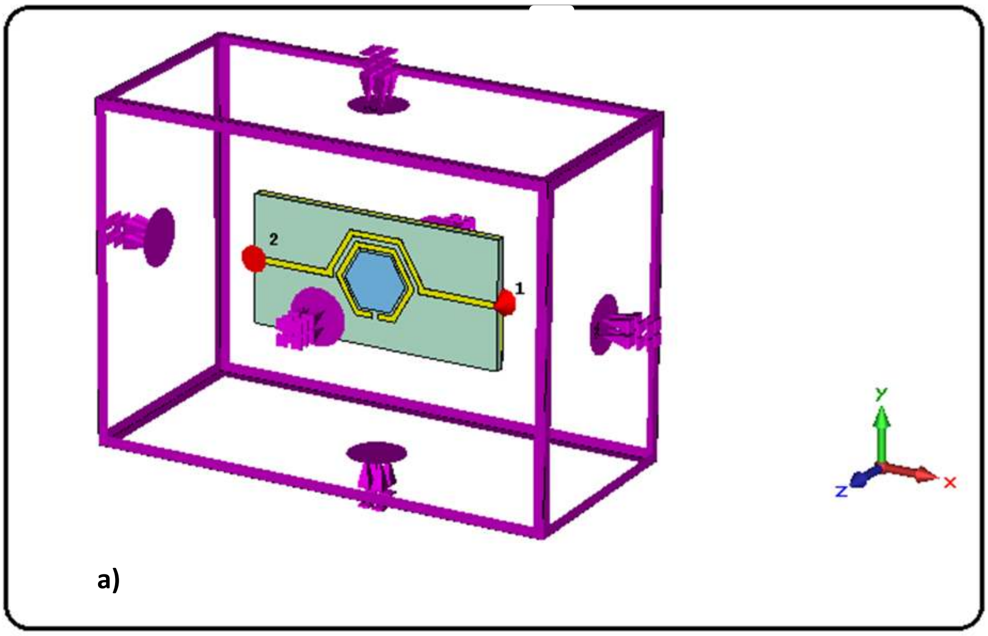
Figure 5.15. Dimension of Hexagonal Shaped Sensor Based Transmission Line (a) Measurement Values, (b) Place of Sensor and its Thikness

The back of the substrate section has covered completely with the copper-plated with the 0.035 mm to provide a strong signal feature that shown in Figure 5.14 .Firstly, the expected outputs of this study are presented When designing this model, and then the dimensions of the mentioned structure are determined in the CST microwave studio program at working frequency band.After determining these dimensions, resonator geometry is determined and then after determining the geometry, the design is completed by determining which results are near the desired results by using CST microwave studio program.

5.2.2. Defining Ports and Boundary Conditions for Hexagonal Shaped Sensor

The boundary conditions (open add apace-electric Et=0) are studied for metamaterial characterization in case of Wave applied to periodic structures. Simulation of this boundary condition is possible by entering the axis (x) and axis (y) values in the simulation program. In other words, open add space boundary condition is applied to the lower and upper walls and side walls of the unit cell. Thus, the reflection and transmission parameters obtained when these boundary conditions are applied.

For the Hexagonal Shaped Sensor Based Transmission Line structure, in the X / Y / Z axes, are perposed, Open Add Space / Open Add Space / Open Add Space boundary conditions respectively. As shown in Figure 5.14, we use discrete port for this structure.



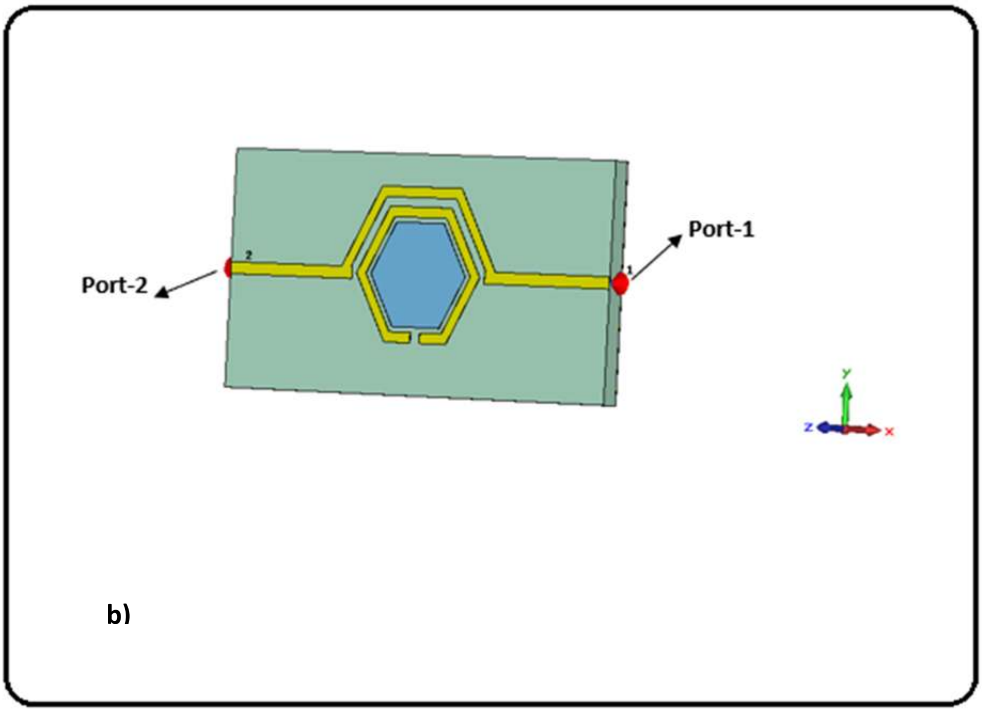


Figure 5.16. a) Boundary Conditions, b) Defining Port for Hexagonal Shaped Sensor Based Transmission Line structure

This section describes the characterization of using unit cell boundary condition. Unit cell boundary condition is selected for simulation of unit cells and simulation of axes. The boundary conditions of Unit Cell are generated by taking a small area (unit cell) to simulate the infinite structure.When boundary conditions are applied to Hexagonal shaped sensor based transmission line, the resonance frequencies of selected vaccum material as a sensor, for transmission and reflection coefficient have determined as the below figure:

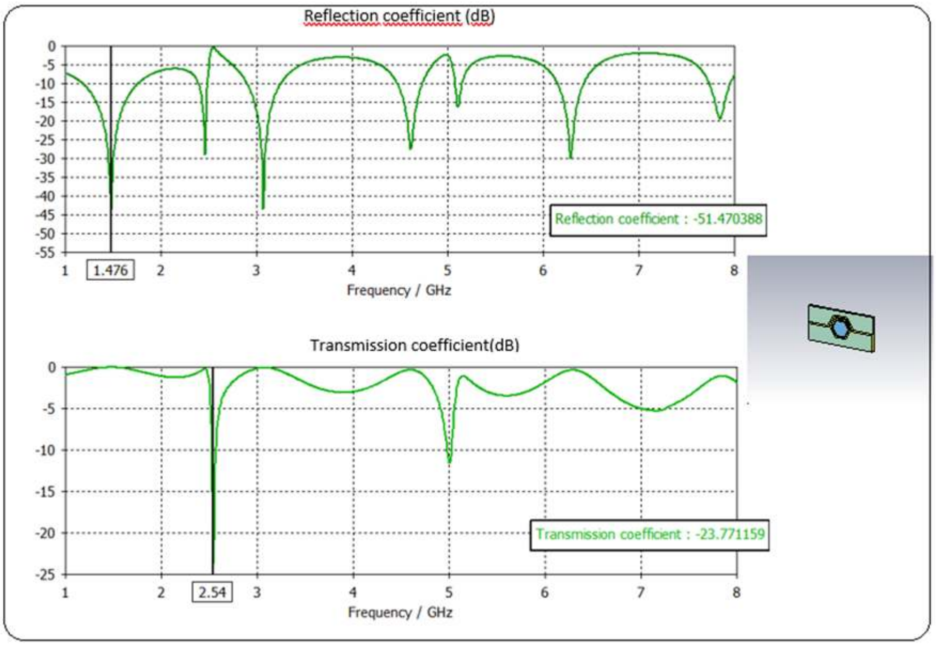


Figure 5.17. Value of Reflection and Transmission Coefficient in Hexagonal Shaped Sensor with the Vaccum Sensor

5.2.3. Placed of Samples (Izo Propyl Alcohol, Propylene Ethylene Glycol [PEG]), Water and Ammoniac in Sensor Layer

In this study, Hexagonal sensor shaped based transmission line is designed and then a sensor layer is placed between the copper part of the structure and the substrate part. The sensor layer, in the Hexagonal sensor shaped based transmission line' structure has 1.6355 mm thickness.

In this study, Hexagonal shaped sensor based transmission line for determination of liquid are analyzed numerically in unit cell boundary conditions by filling Izo Propyl Alcohol, Propylene Ethylene Glycol (PEG), Water and Ammoniac at the sensor plate in order to investigate the effect of parameters on the transmission coefficient. The numerical analysis results are presented in Figure 5.16. It can be seen that the Hexagonal shaped sensor based transmission line structure has resonance point with the selected materials.

The changes in the dielectric coefficient in the sensor layer change the characteristic of the whole system, so the proposed structure can be develop and can be used as a sensor in some applications.

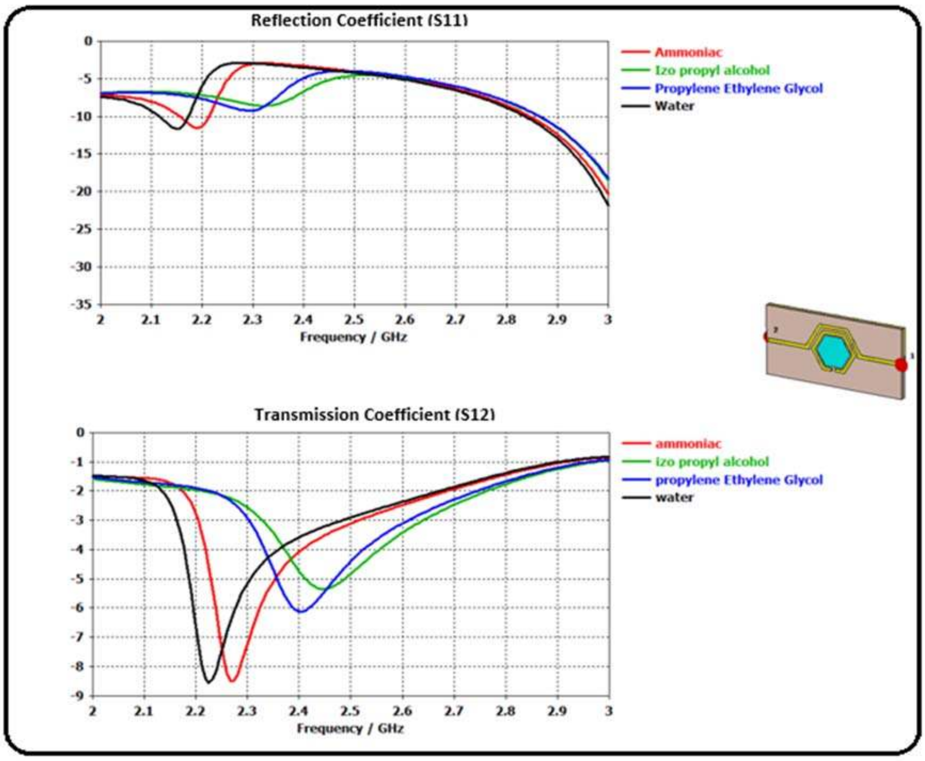


Figure 5.18. (a) Reflection Coefficient, (b) Transmission Coefficient for Differentiating of four kind of Liquid, in the Hexagonal Shaped Sensor based Transmission line structure

Table 5.7. Resonance Frequency of Mentioned Materials in Hexagonal Sensor Shaped Based Transmission Line Structure

Material	**Resonance Frequency (GHZ) according to (S12)**	
Water	2.225	
Ammoniac	2.267	
Propylene Ethylene Glycol (PEG)	2.40	
Izo Propyl Alcohol	2.449	

5.2.4. Dielectric Constant of Samples (Izo Propyl Alcohol, Propylene Ethylene (PEG), Water, Acetone and Ammoniac Glycol)

It can be seen that there is regularity between transmission-resonance frequency graph and dielectric coefficient graph. This structure as a detector or purity sensor can be used to detect different liquid or detect some parameters like purity. The reduction of the capacitance value, will cause to increase the resonance frequency of the resonator structures. By using this, it is possible to develop a sensor for situations in which the changes of resonance frequency depending on the dielectric coefficient and environmental condition. In addition, this proposed study can be improved in sensor applications. If there is a need for adjustment, it is also possible to benefit from other things. The parameters of the material could change the resonance frequency. The increase or decrease ratio in the resonance frequency is entirely related to the voltage-dependent capacitance value. The results, obtained from the simulation studies have evaluated and discussed with the experimental results for characterization of metamaterial structure.

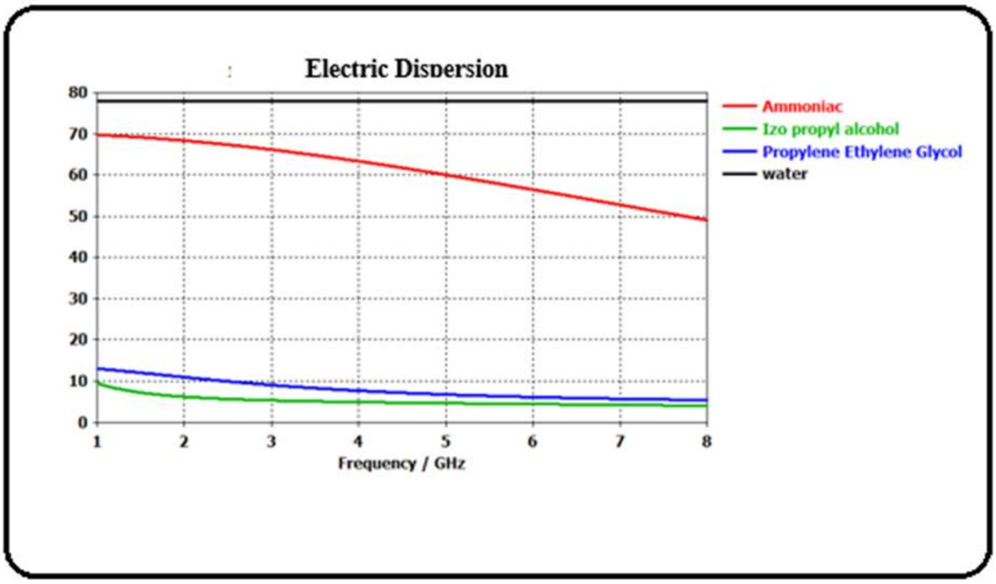


Figure 5.19. Frequency Value and Dielectric Coefficient of Mentioned Materials in the Hexagonal Sensor Shaped Based Transmission Line Structure

Table 5.8. Dielectric Coefficient of Mentioned Materials in Specific Frequency (3 GHZ) in Hexagonal Sensor Shaped Based Transmission Line Structure

Frequency (GHZ)	Material	Dielectric coefficient	
3 GHZ	Water	78	↑
3 GHZ	Ammoniac	66.16	
3 GHZ	Propylene Ethylene Glycol (PEG)	9.04	
3 GHZ	Izo Propyl Alcohol	5.31	

5.2.5. Placed of Samples (Izo Propyl Alcohol Mixture with Water), in Sensor Layer of Hexagonal Shaped Sensor based Transmission Line

There is regularity and linear array between transmission-resonance frequency graph and dielectric coefficient graph when we pour izo Propyl Alcohol (IPA) solution in sensor place that shown in Figure 5.18.

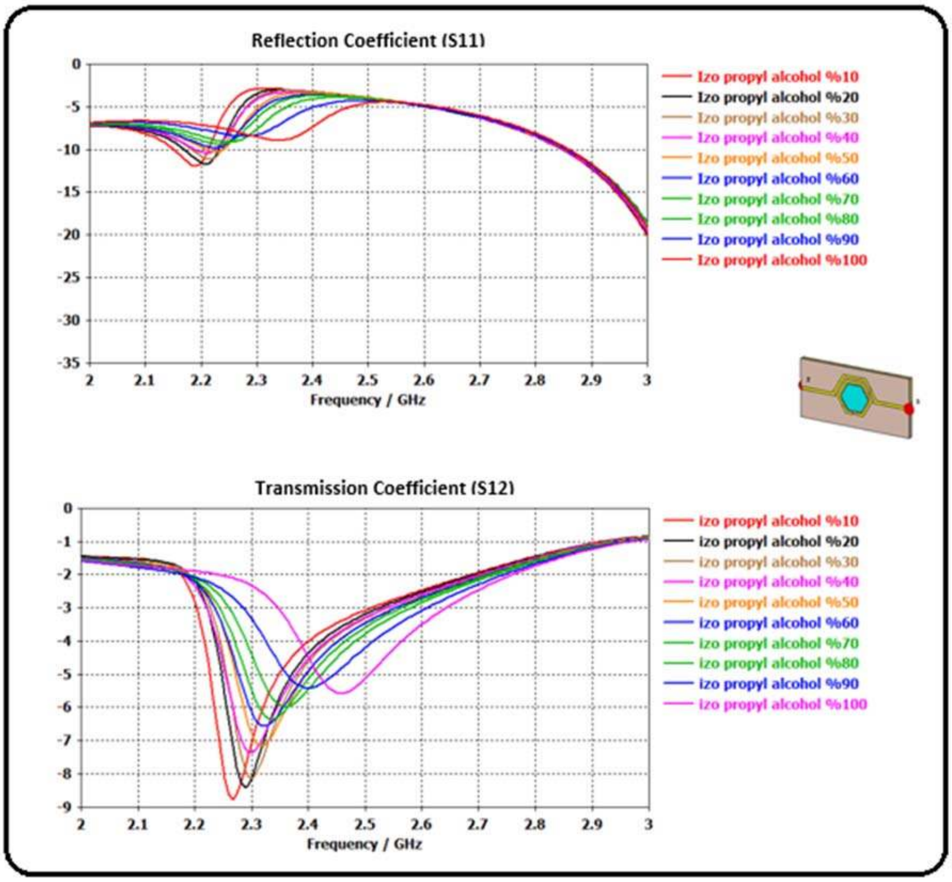


Figure 5.20. (a) Reflection Coefficient, (b) Transmission Coefficient of Hexagonal shaped sensor based Transmission line for Determination Purity of Izo Propyl Alcohol Mixture

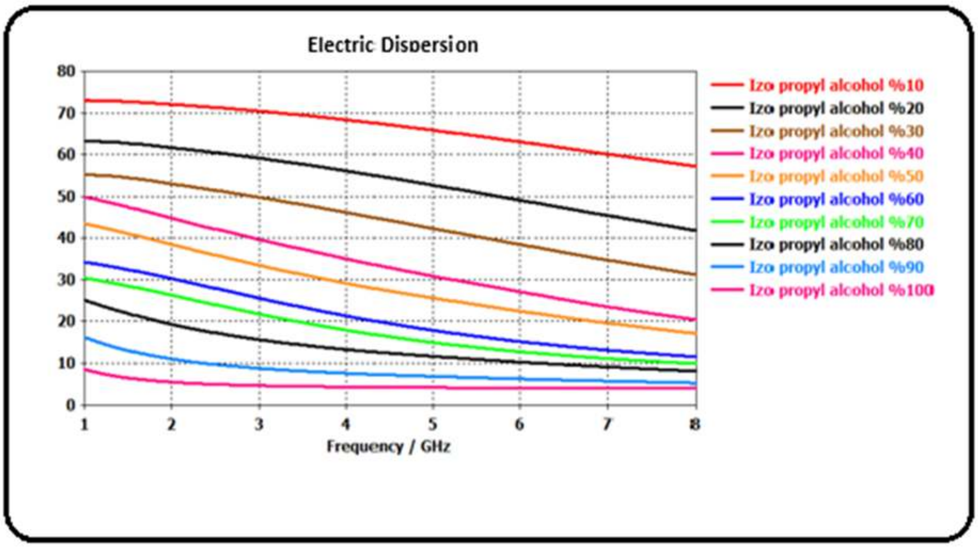


Figure 5.21. Frequency Value and Dielectric Coefficient of IPA'Solution in the Hexagonal Sensor Shaped Based Transmission Line Structure

5.2.6. Exprimental Study of Hexagonal Shaped Resonator Structure

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. The experimental analysis results are presented in Figure 5.21.

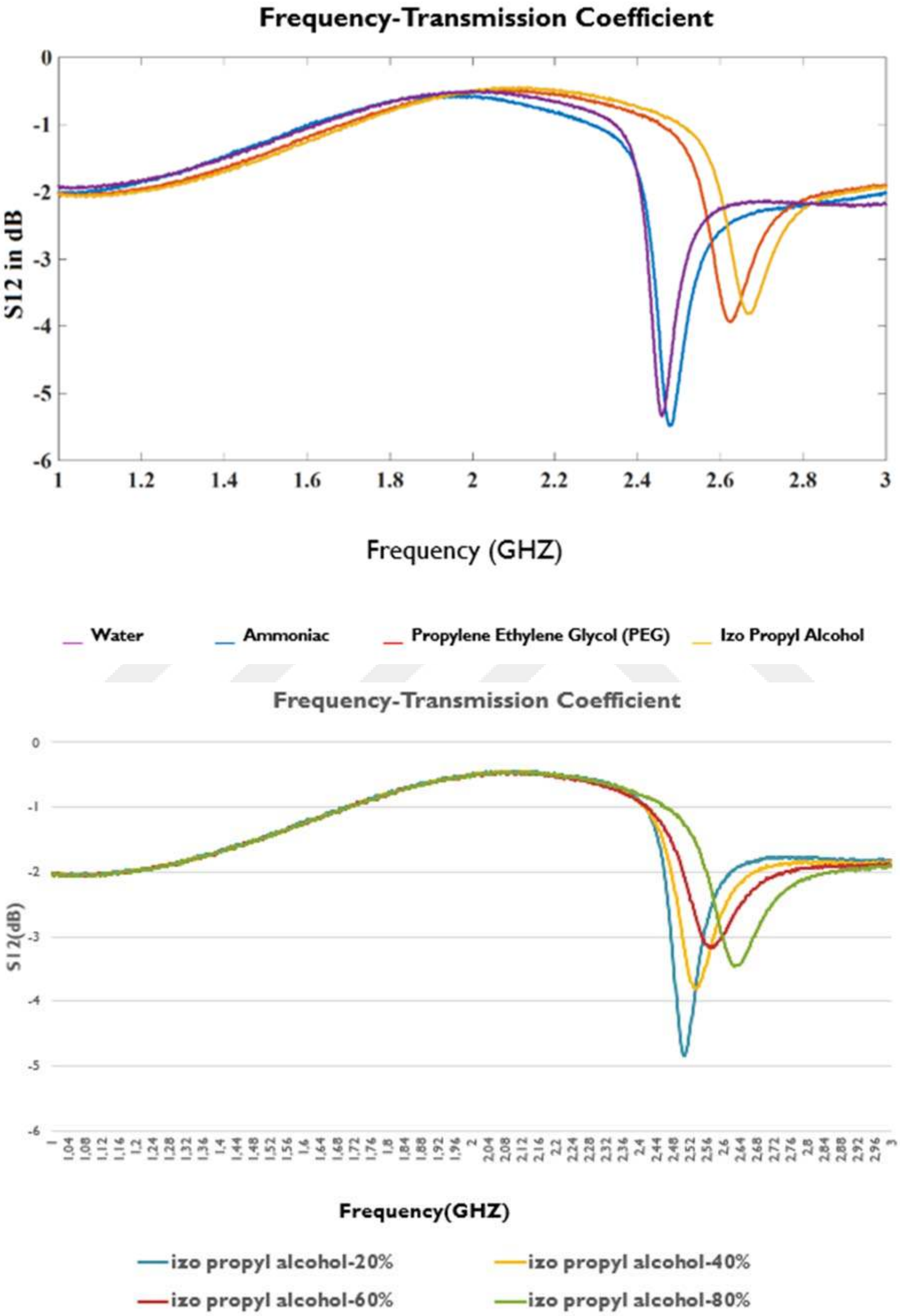


Figure 5.22. Experimental Study Results for Hexagonal Structure

6. MEASURING DEVICE IN EXPERIMENTAL STUDIES

A great leadership of experimental studies is supported, from other universities, to experiments that could not be carried out. There is a network analyzer, in addition, there are waveguides and calibration kits, to use of these network analyzers.

Network analyzer is a tool that measures the values and one of the most important tools used in laboratories that can be seen in figure 6.1. Nowadays, the network analyzers used generally measure the s-parameter values of the circuits; so with the help of this device the reflection values and transmission value at the input and output of the networks are easy to measure at high frequency values. Network analyzers are typically used in 2-port circuits, such as amplifiers and filters. The Vector Network Analyzer measures the transmission and reflection values of the network and the scalar network analyzer measures only the magnitude. Vector Network Analyzer consist of oscillator scanner, 2 port test set, control panel, information display and RF cable. Other options in the network analyzers include a computer and a voltage and current controller for controlling and storing the data. According to the user's request, network analyzers can be measured at the desired frequency values. Before starting measurements with the vector network analyzer, the user has to calibrate the network analyzer. There are various calibration techniques and many calibration standards. The user can optionally calibrate only the transmission and reflection, and has the option to calibrate 2 ports one by one or both. In general, users need to calibrate both the transmission and reflection ports in order to perform 2-port s-parameter measurements.

Figure 6.1. Vector Network Analyzers

7. METAMATERIAL CHARACTERIZATION

Electromagnetic characterization is very important for different applications of proposed structures. 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 for two structures are investigated and examined and also sensor applications are described. 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.

8. CONCLUSION

The results of the Octogonal-Shaped Resnator Based purity of liquid and Hexagonal Shaped Sensor based Transmission Line for determination of liquid structure are investigated. In order to examine the simulation study results, we can see that the two sensors 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 Resnator Based purity of liquid. It is observed that the Changes in the amount of ethanol and methanol samples in the water, will cause linear changes in the resonance frequency.

Also the values of the transmission coefficient (S12 parameter), according to the results can be used to detect and determine purity of four samples (Izo Propyl Alcohol, Propylene Ethylene Glycol (PEG), Water, Acetone and Ammoniac) with each other in Hexagonal Sensor Shaped Based Transmission Line Structure. When the results of the Hexagonal Shaped Sensor based Transmission Line structure were examined, it is observed that the resonance frequency change in a linear way compared to the selected samples. It is observed that the resonance frequency changed linearly according to the changes of dielectic constant of the samples. We can say that this change can be used for sensor detection. Four different samples, will cause linear changes in the resonance frequency.

Both Octogonal-Shaped Resnator Based purity of liquid and Hexagonal Shaped Sensor based Transmission Line for determination of liquid structures have 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.

We can see that the structures we have designed successfully, accomplish the determination purity and detection process in real time, fast and accurately as a sensor in the simulation studies and experimental studies. In the literature, there are studies to determine the purity of liquid and detect liquid. Both 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.

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