SEPTEMBER 2019 M. Sc. in Electrical and Electronics Engineering EMİNE KILINÇ

REPUBLIC OF TURKEY

GAZİANTEP UNIVERSITY

GRADUATE SCHOOL OF NATURAL & APPLIED SCIENCES

FREQUENCY-SELECTIVE PERMITTIVITY DETERMINATION OF SOLID DIELECTRIC MATERIALS BACKED BY A CONDUCTOR

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EMİNE KILINÇ

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Supervisor

Prof. Dr. Uğur Cem HASAR

by

Emine KILINÇ

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Emine KILINÇ

ABSTRACT

FREQUENCY-SELECTIVE PERMITTIVITY DETERMINATION OF SOLID DIELECTRIC MATERIALS BACKED BY A CONDUCTOR

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We have presented a method for complex permittivity detection with short-circuit termination of low-loss materials based solely on amplitude reflectance measurements. This method has advantages and disadvantages. The first advantage is that we can obtain max and min frequencies and make derivation easier because a certain frequency is observed. The second advantage is that it does not require calculation. The disadvantage of this method is that it requires us to use a wide bandwidth and is more suitable for materials with a high dielectric constant. In this method, which we use the Reflection Method, complex and only amplitude scatter parameter measurements of a low loss material (silicon) placed in the section of a waveguide are calculated and supported by numerical analysis. Like other non-resonance methods, the method may be a coarse indicator of the imaginary portion of permeability for low loss samples.

Key Words: Reflection Method, Non-resonans, Numerical Analysis

ÖZET

İLETKEN TARAFINDAN GERÇEKLEŞTİRİLEN KATI DİELEKTRİK MALZEMELERİN BELİRLİ FREKANSLARDA DİELECTRİC SABİTİNİN BELİRLENMESİ

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Düşük kayıplı malzemelerin kısa devre sonlandırması ile karmaşık geçirgelik tespiti için sadece genlik yansıma ölçümlerine dayanan bir yöntem sunduk. Önerdiğimiz bu yöntemin avantajları ve dejavantajları mevcuttur. İlk avantajı, belirli bir frekansa bakıldığı için max ve min frekansları elde edip daha kolay derivasyon yapabiliriz. İkinci avantajı ise hesaplama gerektirmemesidir. Önerilen bu yöntemin dejavantajı ise geniş bant aralığı kullanmamızı gerektirmesi ve yüksek dielektirik sabitine sahip malzemelere daha uygun bir yöntem olmasıdır. Reflektif Method'tan yararlandığımız bu yöntemde, bir dalga kılavuzun bölümüne yerleştirilmiş düşük kayıplı bir malzemenin (silikon) X_bandında karmaşık ve sadece genlik saçılma parametresi ölçümleri hesaplanıp numerik analiz ile desteklenmiştir. Diğer rezonans olmayan yöntemler gibi yöntem, düşük kayıplı numuneler için geçirgenliğin hayali kısmının kaba bir göstergesi olabilir.

Anahtar Kelimeler: Reflektif Method, Rezonas, Numerik Analiz

"to my family"

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TABLE OF CONTENS

Page

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOLS

ε	Electric Permittivity
μ	Magnetic Permeability
E	Electric Field Intensity
H	Magnetic Field Intensity
D	Electric Flux Density
B	Magnetic Flux Density
J	Current Density
F	Potential Vector
A	Magnetic Vector
P	Electric Dipole
c	Speed of Light in Vacuum
M	Equivalent Sources
k	Wavenumber
ω	Angular Frequency
S_{11}	Forward Reflection Coefficient
χ_e	Polarizable a Material
χ_m	Magnetic Susceptibility
k	Wave Propagation Vector
ς, ζ	Cross Coupling Terms
Γ	Reflection Coefficient
T	Propagation Factor
Z_0 Z	the impedances of the air-filled/ the sample-filled
q_{ev}	Electric Charge Velocity
q_{mv}	Magnetic Charge Velocity
β	Phase Constant

LIST OF ABBREVIATIONS

MM	Metamaterial
TR	Transmission / Reflection
SCL	Short Circuit Line
ANA	Automatic Network Analyzer
RM	Reflection Method
PVC	Polyvinyl Chloride
M1/M2/M3	Metamaterial 1/2/3
RCM	Reflection Coefficient Method
S-	Scattering

CHAPTER 1

INTRODUCTION

For many years, knowledge about the characterization and electromagnetic parameters of materials has an important place in many fields and we can see this more clearly especially in the studies in the field of industry. At the same time, characterization of the material is very important problem in many materials manufacture; like as agricultural processing and administration; food engineering, medical practice, bio-engineering [1,2,3,4,5,7]. However, all of our applications on dielectrics can be fully utilized in scientific intents, e.g. in connection with the examine of loosening phenomena, on the other hand they are nowadays of increasing significance in the design and characteristic of circuit components and in telecommunication and quasi-optical elements. Especially with the development of technology, different fields have emerged, such as mobile telecommunication tools or high-speed digital circuits, printed circuit boards, ferrites, noise-canceling composite materials, filters, dielectrics, and the like [6]. In addition, microwave engineering, port security, military, industrial and civilian lifestyle have previously played important roles, about clear information about the electromagnetic properties of materials at microwave frequencies. There is increasing demand among manufacturers for the identification of materials.

In the beginning, the studies to determine the electromagnetic properties of the existing materials continue to develop and increase by finding new methods with the increasing demand with the developments of the age. Because of all of these causes, different techniques which have each with its specific properties, advantages and restriction, have been presented for characterizing the materials properties. We can list the most efficient and useful of these techniques developed in order to characterize the properties of materials that will facilitate our work in many areas. Because the method can be understood by everyone as

easy to include accurate and accurate information, easy to apply, does not create problems in repetition of the important elements for the techniques. But first of all, if we give explanations on the topics that we define as electromagnetic properties that we aim to find as a result of these techniques, our studies will be more efficient. We can classify them into various roofs, such as material types, whether they are dielectric materials. But we need to focus on the dielectric devices that are necessary for us.

Before we provide the information that I deem necessary, we can provide a short description of what we will talk about. First of all, what we need to know is what is called dielectric material and what are its properties and we will focus on its building block E and M. We will then explain what methods are used to determine these properties and what we should pay attention to when applying these methods. After explaining these, we will talk about wave guides which have an important place in the measurements we have used. As a result of this information, we will give more detailed information about the type of polymers that we will use and we will also mention the silicones that are in this class of materials.

1.1 Proporties of Dielectric Metarials

If, when we apply an external electric field at the material, it is capable of storing energy; we decided to the material is a ‘dielectric’. We say that the general properties of typical electromagnetic materials are including dielectric materials, semiconductors, conductors, magnetic materials, and artifical materials. The general properties of the electromagnetic materials are came together for understanding results of measurement and correcting the possible mistakes on many meet in materials characterization [2]. For this firstly, if we look at the artificial materials from this group of materials, as a beginning study by Kock in this field, a dielectric lens composed of a variety of small metal particles responds to electromagnetic waves similar to the molecules of a natural dielectric [8]. If we talk about dielectric properties, the dielectric constant (permittivity or electrical permeability) indicates how much energy is stored in the external electric zone under the influence of an area and how much energy is lost in the material. The dielectric constant of the material is an amount that reduces the

electrostatic force between two electrical charges [9,10]. Materials with dielectric properties don't connection electricity, but they are affected by the applied electric field. Under the influence of the electric field, electrons and atoms are exchanged. As a result of these situations, the electrical charge centers shift and electrical polarization occurs. The resulting electrical dipoles allow the accumulation of electrical charge on the surface of the dielectric material. For these reasons, they are used in the construction of capacitors. The reason they are used as insulators is that they prevent load transfer in the electric circuit [9,11]. If we say dielectric material, we should know very well the basic building blocks Permittivity (ε' and ε'') and permeability (μ' and μ''). It is very important to know the quality and properties of materials used in the microwave region. The properties that determine the media can be listed as magnetic permeability (μ), electrical permeability (ε) and conductivity (σ). If we look these pepar [12,2], permittivity is complex number and permeability is also same like this and the imaginary part of permittivity give us information about the conductivity of the material.

1.1.1 Permittivity (ε)

First of all, let's focus on permittivity (ε) which is important for us; if we want to learn how polarized a medium; enought to look properties of permittivity of electric field. If we examine the unit of dielectric constant; In SI units, ε is in Farad / meter, whereas in cgs units, the unit is unitless. This difference illustrates the main differences between the two transmittance measurements in differences unit systems. In SI units which we will use, ε_0 is the permeability of the free space and has a value of

$$\varepsilon_0 \approx 1.85 \times 10 \text{ -12 Farads / meter.}$$

On the other hand if we look other materials, specifically dielectrics metarials, we see that a metarials which in electric field have a permittivity that interrelated to their electric susceptibility, (χ_e), which is a calculate result of how polarizable a material. The relationship is given by

$$\mathbf{P} = \chi_e \mathbf{E}$$

where **P** is per unit volume of the dielectric which the electric dipole moment and **E** represent the electric field intensity. if we want to reach permittivity as a result of these;

$$\varepsilon = \varepsilon_0 (1 + \chi_e) \quad \textbf{SI}$$

$$\varepsilon = (1 + 4\pi\chi_e) \quad \textbf{cgs or Gaussian}$$

In SI units, the number $(1 + \chi_e)$ is also called the relative permittivity,(ε_r). A rate called the dielectric constant is described as;

$$k = \varepsilon_r = \varepsilon/\varepsilon_0 . E$$

On the other hand, the relative permissions of the dielectric plates are generally complex;

$$\varepsilon = \varepsilon \text{ '- j } \varepsilon'',$$

ε' is the relative dielectric constant, while ε" is considered as the missing factor. We should also add that ε'' is much smaller than ε' for lowloss material. In addition, ε' is the main cause of signal phase change and ε'' is the main cause of signal attenuation when passing through the material [13].

1.1.2 Permeability (μ)

According to the definition of electromagnetism, permeability refers to the measure of the ability of a dielectric material to produce a magnetic field within itself. For these reasons, it is also the degree of magnetization a dielectric material obtains in response to an applied magnetic field. In SI units, permeability is measured in henry per meter (H / m or H · m - 1) or in newtons per square ampere (N · A - 2). The permeability constant (μ_0), also known as the permeability of the magnetic constant or free space, is a measure of the amount of resistance encountered when creating a magnetic field in a conventional vacuum. The magnetic constant has an absolute (defined) value

$$\mu_0 = 4- \times 10-7 \text{ H} \cdot \text{m} \approx 1 \approx 12.57 \times 10-7 \text{ H} \cdot \text{m or 1 or N} \cdot \text{A} - 2$$

From [14]; where χ_m is known the magnetic susceptibility (dimensionless quantity). Therefore we can define

$$\mu_r = \mu_0 (1 + \chi_m)$$

1.2 Methods for Characterization

We have already said that there are a number of methods and techniques for determining the characterization of materials. We will come to the methods and techniques that we shouldn't be considering later, but now we can talk about the starting points that will enable us to use all these methods in a healthy and beneficial way.

First we should know the result of swept-frequency measurement of complex permittivity and complex permeability of materials in microwave frequencies, and because of this reason we have improved transmission-line-based methods for years of research. If you look at this researchs, they incorporate basic or specific measurement techniques [6,15–16], calculation algorithms for material parameters or tensor permittivity and permeability measurement [6,16].

The effective and useful method for calculating the electromagnetic properties of materials is the simulation and measurement of scattering (S-) parameters. [17, 18,19,20,21,22,23,24] Since the type of material we focus on is complex materials (eg polymeric), if we use methods such as qualitatively effective media method [25], the method that uses the average of others [26] and the homogenization method [27], this type of complex material cannot be properly applied to both structures and numerical analysis and not suitable for measurements [28].

A method commonly used for (ε) and (μ) measurement consists of measuring the complex reflection coefficients of short circuit and open circuit (quarter wavelength short circuit line) metarials [29]. Using this method, measurements are not easy to make and the open circuit sample must be determined at all measurement frequency. Article [29] have used a research for determining (ε) and (μ) from the transmission and reflection coefficients of a planar sample. This research is particularly proper for fast, ordinary and broadband measurement of (ε) and (μ) values of high loss materials. For samples with a dielectric (or magnetic) loss tangent of less than 0.1, in transmission and reflection coefficients measurements loss factor measurements were establish to be incorrect due to mistakes. The dielectric constant and loss tangent of low-loss materials can be

measured more exactly and reliably using different free-space research, which requires measuring the reflection coefficient of a metal-supported material [29]. In the method of article [29], the free-field reflection and transmission coefficients S11 and S12 of a planar material are measured for a normal event plane wave. The complex structural parameters (ε) and (μ) are determined from the resuts S11 and for samples of resilient and slim magnetic materials, are poor due to the measuring accuracy of S11 and prolapsing of the materials when assemble on the sample holder. The material was therefore compressed in the middle of two combined quartz plates of half wavelength in the middle band. The real reflection and transmission coefficients of the material, S11 and S12, are determined from the results of S11 and S12 of the quartz plate-sample-quartz plate mountined using complex electrical permeability and thickness information of the quartz plates. In Article [29], the finding are recorded in the frequency between 8.6-13.4 GHz for Teflon, sodium borosilicate glass, Eccogel 1365-90 (epoxy resin) and microwave absorbent samples. As a result of these measurements, another important point determined by the article in [29] is that two-port TRL calibration methods with time-space transients should be applied to eliminate the effects of multiple reflections. Especially recently, the TRL calibration mehod has been shown to be superior to the conventional open, short, paired termination calibration method for a coaxial line [29]. At the microwave frequencies, TRL calibration can manufacture the highest possible quality calibration (effective directivity up to 60 dB and welding impedance) [29].

At high frequencies, the magnetic properties of materials differ slightly from free space. On the other hand, the electrical properties have a wide range of variation with respect to the frequency range studied [9,10]. In a general case, research like this have been found at fixed frequencies in the frequency domain helping from slotted-line and impedance-bridge configurations [30]. In these days, a technique which after the measuring the [30] scattering parameters of the broad-band microwave constituent that to achieve the reflected and transmitted transient responses of the constituent to an incident subnanosecond risetime pulse and after those exhibition discrete Fourier transforms on the 3 waveforms. The frequency resolution we obtained as a result of this method could not reach an approach that can be obtained by narrowband frequency-domain methods.

However, we can say that this is the most appropriate method now, and even a bandwidth of up to two or three years can be handled by a single transient measurement method. The best application of this property has been demonstrated to be material solutions; A system in the range of 0.4-GHz to 0.4-10 GHz has been developed. At rewive [30] a description of this system and how to improve the frequency range and accuracy is given. If we want to give some information about X-band which we used in our study, it is the defination of a band of frequencies in the microwave radio domain of the electromagnetic spectrum. Although the frequency range of the X band is not certain, it is accepted as 7.0-11.2 GHz with the help of some engineering fields. But this range is assumed to be 8.0 - 12.0.

In addition, the dielectric properties of the samples in the time-dependent areas may not correspond to their properties in fixed areas. For this reason, time or frequency dependent permeability is highly necessary for the improvement of high frequency instrument [7]. Furthermore, the frequency dependence of the permeability reflects the limited time required by the particles (molecules, ions, atomic nuclei, electrons, colloidal particles, etc.) that make up the materials to form a balance polarization [7].

On the other hand, the presence of final sampling oscilloscopes that allow the display of frequency constituent of waveforms until 12 GHz suggests that, for example, an alternative tecnique for obtaining the transmission scattering coefficient of a consutient may be a individual measurement, a transient response to an impulse or step waveform, then using appropriate fourier analysis techniques to convert to system function. However, we should not ignore that the measurement of the reflected response can likewise cause a reflection coefficient rising of the wide frequency range. Referring to article, we will see that various analogue methods [31] are provided for low-frequency spectral examination handling shifted oscillators or delay line, unfortunately they are not suitable for presenting the probable suppleness and certainty of a digital tecnique, if appropriate for display.

Returning to the methods used to determine characterization, if we use the information in [2], we will see that there are methods like;

- Transmission / Reflection Methods,
- Resonator Methods,
- Reflection Methods,

Before we give some information about some methods used for dielectric materials, we can say that there are two main problems of methods based on complex scattering (S-) parameter analysis for determining complex permibilitty (ε) of medium and low loss materials. First of all, these analyzes lead to multiple solutions. If we want to eliminate these solutions, we can succeed by selecting a material thickness less than a quarter wavelength [38]. On the other hand, the fine materials used can result in altering and winding theoretical simulations [29,38], reducing the applicability and reproducibility of the measurements. As for the second question, the values of the complex S parameters obtained from the reflection measurements of low-loss materials are much delayed by the phase uncertainty at frequencies corresponding to the multiple-half wavelength. [38].

1.2.1 Transmission / Reflection Method

First of all, Transmission / Reflection methods (TR) and short circuit line (SCL) methods are frequently used in many places these days. The most important reason for this is that they are relatively simple. Furthermore, in these methods, the material we use is placed on the appropriate waveguide to coincide with a portion of the coaxial line. Then, the scattering parameters of the material are obtained using an automatic network analyzer [ANA]. The corresponding scattering values refer to the permeability and permittivity of the material to the measured scattering parameters. In the TR measurement method, the system of values is variable permeability and permittivity, the two determine plane positions, and in some applications we may encounter sample length is variable. SCL measurements in the TR procedure are available in all four scattering parameters, as we have more datas. The system of equations is usually predetermined. However, there is no comprehensive summary of uncertainties regarding TR and SCL methods in the literature [34].

Another case for transmission line techniques is one of the simplest techniques for electromagnetic properties at broadband frequencies. However, If we say what they are, we can talk about certain lines that are not long (single-port measurement) and transmission/reflection lines (twoport measurements). To found the transmission/reflection method (TR), the measuring part comprises a coaxial line or part of a rectangular waveguide, characterized in that the sample is fiiled with the sample to be measured [40 In this method we can obtain frequencies corresponding to the full multiples of the half-wavelength as a result of the measurement, but it is generally accepted that we can see these frequencies mostly using low-loss materials. So many researchers have offered different perspectives to eliminate this disorder.

1) by reducing the length of the sample under the half-wavelength and trying to reduce the damage to accuracy;

2) using a highly recommended iteration procedure in recent times for permeability measurements [40,41]. Despite all this to eliminate the iterative character, we must first make a proper permittivity estimation, then get a mathematical result, and now we can starting to calculate. [40].

1.2.2 Resonator Method

As for the resonator method, which is another method, measurement fixtures for the characterization of materials, resonators are generally protected by conductors. For the founding properties of dielectric materials, we assume that we are familiar with surface impedance protective conductors, which are usually metal. If we are familiar with the properties of dielectric sample, the impedance of the protective conductors can be derived from the resonance properties of the resonator. Furthermore, we can generally use the dielectric resonator method to determine the properties of low-loss materials. However if we want to find the dielectric properties of the material by means of dielectric resonator method, the structure of the material to be used and the metal clapper should be prepared. We need different algorithms for all these techniques. Because the dielectric material and metal shield we use have different structures. [2].

After obtaining general information about the commonly used methods, we can focus on the more important reflection method. But it would be more accurate to consider it under one heading.

1.2.3 Reflection Method

After sharing general information about a few of the most commonly used methods today, we can talk about Reflection Method (RM) in a little more detail, which we will focus on the original.

In a RM, the characterisation of a material are found from reflection for the impedance discontinuity resulting from the demeanor, construction and existence of the material in a transmission structure. After the general RM definition, it is also useful to know that the RM is a variety of nonresonant technique [2]. In adition RM is a very good technique for obtaining the dielectric parameters and its characterisation [13].

In addition to this information, we can say that RM has a method to determine material properties that can be applied as open circuit reflection and short circuit reflection.

1.2.3.1 Open-Circuited Reflection Method

First of all, we can say that the open-ended reflection method means the obtaining of the reflection coefficient at the between the two dielectric samples, at the open end of the line (as a detector) and on the sample that used [42].

The reflection method on an open-ended technique is the most appropriate method if it is not desired to have destructive and invasive effects- In this method, it is essential that an open-ended coaxial line is present and therefore the reflection coefficient is measured [42]. In addition, this method is widely used to determine the characterization of dielectric materials. [42,43].

Furthermore, the material we use must be in perfect association with the probe. As well, we should adjust the thickness of the material to be more than twice the penetration depth of the electromagnetic wave d. [42]. As a result, the

approximate waves of reflections from the interface of this distant material are approx. -35 dB, ensuring that the does not have much importance on the result of the obtained reflection coefficient. [42,43].

1.2.3.2 Short-Circuited Reflection Method

This method is more capable of measuring a complex parameter, either permittivity or permeability. As shown in Figure 1.1, a general short circuit reflection is given. For this method, a sample piece is first placed on a portion of the short-circuit transmission line; for example, the end face is located 1 distance from the short distance. In this method we must make some assumptions; for example, there is a single main mode, then the material is homogeneous and isotopic, and we assume that only the transverse electric field is present in the transmission line. [2].

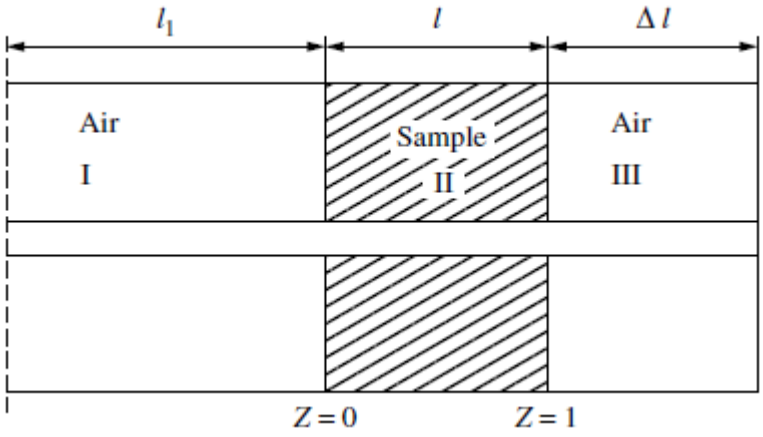

Figure 1. 1 A sample is inserted in a short-circuit transmission line

On the other hand, for Figure 1.1, in the short circuit model, the calibration plane and static waves can be observed on the surface contacted by the material. This allows accurate measurement of permittivity at certain frequencies and accurate measurement of permittivity at other frequencies, cleaving on material lenght and other lengths. By the way, we put the material according to which feature we want to find. Further, the short circuit position has a low electric field and creates a high magnetic field zone. However, the λ / 4 position away from the short-circuit position has a high electric field and a low magnetic field zone. For this reason, the material remove from the short circuit position for permeability

measurements, and the material move close to the short termination for permittivity measurements.

1.3 Wave Guide and Field Solution

Waveguides are structures used to transmit high powers at GHz frequencies. It is possible to mention three basic types of waveguides that can be used for the specific problem to be solved [44]. These,

- Parallel Plate Waveguide
- Circular Wave Guide
- Rectangular Waveguide

Since rectangular waveguides are used in this study, only details of this type of structures are given and other types are not considered. Rectangular waveguides are the oldest transmission media used for transmitting microwave signals and are already preferred in many applications. It has many equipment with different standards between approximately 1 - 220 GHz. Given the current technology, it is clear that in many applications planar transmission lines (such as microstrip lines) are used rather than waveguides. However, in some cases (high power systems, millimeter wave practices, planet systems, sensitivity test practices, etc..), the need for rectangular waveguides remains. Rectangular waveguides are capable of emitting TE and TM modes, and there are cut-off frequencies against which transmission is not possible [44].

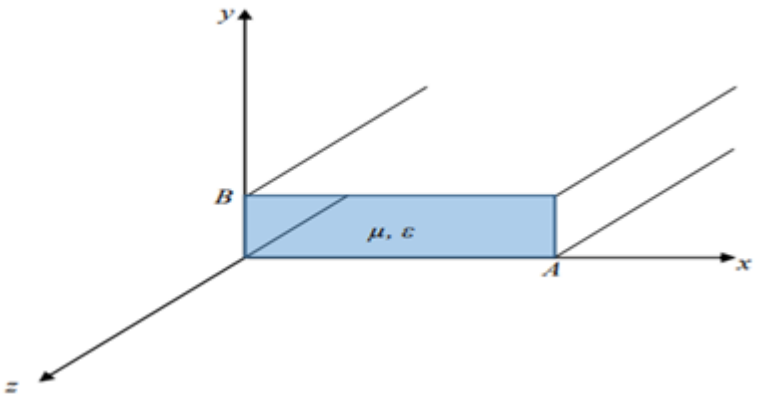

Figure 1. 2 Rectangular waveguide fitted to the z-axis

Figüre 1.2, the dielectric constant ε, magnetic permeability constant filled with the material and the rectangular waveguide along the z-axis is seen.

For TE Modes

It is assumed here that the width of the guide on the x-axis is longer than the length on the y-axis ($A > B$). TE modes can be characterized as $Ez = 0$, $Hz \neq 0$.

For TM Modes

TM modes are characterized by the fact that they meet Hz = 0 and Ez $\neq$ 0 as opposed to TE modes.

1.4 Polymers and Dielectric Properties

Polymer molecules are formed by covalent bonds between a plurality of groups which are identical in composition and structure. Polymers are sometimes called "high-molecular compounds" or "macromolecules [9,45].

Polymers are formed by the addition of monomers (addition polymers) or by the separation of a small molecule (condensation polymers) during the interaction of the monomers. Condensation polymers are polymeric substances obtained by condensation polymerization. The addition polymers are formed by chain reactions by the introduction of monomers directly into the polymer molecules. Ethylene polymerizes with a polymerization initiator catalyst to form polyethylene; polyethylene is an addition polymer. The addition polymer prepared from vinyl chloride is polyvinyl chloride (PVC). Silicone polymers, which form an important class of polymers, contain silicon. Silicon is an element that can give ─Si─O─Si─O─Si─O─ chains [9].

Polymeric materials, which have an important place in industry and in the life of modern man, show very different structures and properties. The usefulness of some polymers depends on the electrical properties of these materials. Such polymers are used in parts of electrical insulators, dielectric capacitors or microwave devices. Polymeric materials are also used as heat insulators. In this case, thermal properties become important. Some polymers have superior optical

properties. These polymers are made of aircraft glazing, inner layers of safety glazing [9,45,46].

Dielectric studies on polymers started in 1958. A lot of applications have been carried out to investigate the dielectric properties of polymers in the electrical industry, molecular mobility and relaxation times [9].

In this study; the frequency changes of the dielectric properties of Silicon, which is selected as a polymer material, were investigated.

Silicone: Silicon polymers, which form an important class of polymers, contain silicon. Silicon is an element that can give -Si-O-Si-O-Si-O- chains as in silicates [9,46]. The electrical properties are just mediocre. It is used at both high and low temperatures [9].

In this study, we will talk about a microwave method which shows the dielectric properties of the material using only reflection scattering parameters (S-). The organization of the thesis is given as: First, in Section 2, we tell about a theoretical analysis. In this section, we find solutions for complex permittivity determination of low-loss materials are studied and obtained the equations which we will use in the other section. Next, in Section 3 which is a practical analysis, in the laboratory, we worked to extract new material and the method is measured by complex and amplitude-base S-parameter values of a low-loss (silicon) sample that putting into a waveguide. Finaly in section 4, we used the Matlab which is numeric analysis to examine the performance of the investigated method.

CHAPTER 2
THEORETICAL ANALYSIS

2.1 Theoretical Analysis for the First Proposed Technique (Reference-Plane-Invariant Effective Thickness and Electromagnetic Parameters Retrieval of Low-Loss Materials Comprising Boundary Effects)

In theoretical analysis, we applied the beam tracing approach [14] as it provides a more informative and near-field surface effect in a simpler way. For this purpose, the sample I used was placed in a short-terminated waveguide, as shown in Figure 2.1. We will examine a typical case for the waveguide properties of the reflection S-parameter of a dielectric plate with the thickness (d) of this sample supported by short-circuit termination [1].

Auxiliary vector potentials used to obtain solutions for electrical (E) and magnetic (H) fields are frequently used in the analysis of electromagnetic limit values problems. The most known vector potential functions are A, magnetic vector potential and F is electrical vector potential. The Hertz vector potentials form another pair of Πe and Πh. The Hertz vector potential is Πe similar to A, and Πh is similar to F. In solving a problem, only one set, A and F or e and h are required. We will prefer A and F, and we can started by analyzing them by explaining them [14].

In a homogeneous medium, any formulas for the electric and magnetic fields must found from Maxwell's equations;

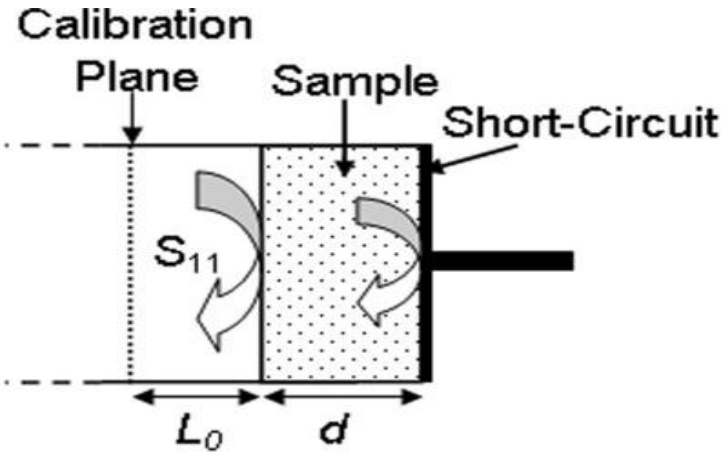

Figure 2. 1 Adapted draft to obtain scattering parameters of the sample placed within the waveguide

$$\nabla \times E = -M - j\omega\mu H \tag{2.1a}$$

$$\nabla \times H = J + j\omega\varepsilon E \tag{2.1b}$$

$$\nabla \bullet E = q_{ev}\ \varepsilon \tag{2.1c}$$

$$\nabla \bullet H = q_{mv}\ \mu \tag{2.1d}$$

or the vector wave equations;

$$\nabla^2 E + \beta^2 E = \nabla \times M + j\omega\mu J + \frac{1}{\epsilon}\nabla q_{ev} \tag{2.2a}$$

$$\nabla^2 H + \beta^2 H = -\nabla \times J + j\omega\varepsilon M + \frac{1}{\mu}\nabla q_{mv} \tag{2.2b}$$

where

$$\beta^2 = \omega^2\mu\varepsilon \tag{2.2c}$$

In regions where there are no sources, J = M = q_{ev} = q_{mv} = 0. In these regions, the preceding equations are of simpler form. J, which we call electric current density, is described as real sources or equivalent sources, whereas M, which we call magnetic current density, is represented only as equivalent sources. Although all of these equations will still be satisfiednew perspectives were developed by using A and F auxiliary vectors for obtaining electrical and magnetic currents.

2.1.1 For the vector potential A;

$$\nabla \bullet (\nabla \times A) = 0 \tag{2.3a}$$

where A is an arbitrary vector. Thus, we define

$$B_A = \mu H_A = \nabla \times A \tag{2.3b}$$

So;

$$H_A = \frac{1}{\mu} \nabla \times A \tag{2.3c}$$

The subscript we encounter refers to the fields caused by the A potential. Substituting (2-3c) into Maxwell's curl equation

$$\nabla \times E_A = - j\omega\mu H_A \tag{2.4a}$$

$$\nabla \times E_A = - j\omega\mu H_A = -j\omega \nabla \times A \tag{2.4b}$$

$$\nabla \times \nabla \times A = \nabla(\nabla \bullet A) - \nabla^2 A \tag{2.4c}$$

Equating Maxwell's equation

$$\nabla \times H_A = J + j\omega\varepsilon E_A \tag{2.5}$$

2.1.2 For the vector potential F;

$$\nabla \bullet (-\nabla \times F) = 0 \tag{2.6a}$$

where F is an arbitrary vector. Thus we can obtain D_F by

$$D_F = -\nabla \times F \tag{2.6b}$$

So

$$E_F = -\frac{1}{\varepsilon} \nabla \times F \tag{2.6c}$$

The subscript we encounter refers to the fields caused by the F potential. Substituting (2.6c) into Maxwell's curl equation

$$\nabla \times H_F = j\omega\varepsilon E_F \tag{2.7a}$$

$$\nabla \times (H_F + j\omega F) = 0 \tag{2.7b}$$

$$\nabla \times E_F = -\frac{1}{\epsilon} \nabla \times \nabla \times \mathrm{F} = -\frac{1}{\epsilon} [\nabla(\nabla \bullet \mathrm{F}) - \nabla^2 \mathrm{F}] \quad (2.7c)$$

and equating it to Maxwell's equation

$$\nabla \times E_F = -\mathrm{M} - \mathrm{j}\omega\mu H_F \quad (2.8)$$

2.1.3 The vector potential A and F;

In the previous two sections, we tried to find the fields valid for E and H in terms of potential vectors A. (E_A, H_A) and F (E_F, H_F). In addition, Appropriate expressions that could replace A and F were determined. The result of the sum of E and H is obtained by the method of superimposing individual areas connected to A and F.

$$\nabla^2 \mathrm{A} + \beta^2 \mathrm{A} = -\mu \mathrm{J} \quad (2.9)$$

$$\nabla^2 \mathrm{F} + \beta^2 \mathrm{F} = -\varepsilon M \quad (2.10)$$

where ; $\beta^2 = \omega^2 \mu \varepsilon$

Then we find E_A and H_A using above equations and the other equation in [14]

$$H_A = \frac{1}{\mu} \nabla \times \mathrm{A} \quad (2.11a)$$

$$E_A = -j\omega A - j \frac{1}{\omega \mu \varepsilon} \nabla (\nabla . \mathrm{A}) \quad (2.11b)$$

$$E_A = \frac{1}{j\omega\varepsilon} \nabla \times H_A \quad (2.11c)$$

Then we find E_F and H_F using above equations and the other equation in [14]

$$E_F = -\frac{1}{\varepsilon} \nabla \times F \quad (2.12a)$$

$$H_F = -j\omega F - j\frac{1}{\omega\mu\varepsilon}\nabla(\nabla \cdot F) \tag{2.12b}$$

$$H_F = -\frac{1}{j\omega\mu}\nabla \times E_F \tag{2.12c}$$

Then we found

$$E = E_A + E_F = -j\omega A - j\frac{1}{j\mu\varepsilon}\nabla(\nabla \cdot A) - \frac{1}{\varepsilon}\nabla \times F \tag{2.13}$$

$$H = H_A + H_F = \frac{1}{\mu}\nabla \times A - j\omega F - j\frac{1}{\omega\mu\varepsilon}\nabla(\nabla \cdot F) \tag{2.14}$$

And the we finaly found;

$$\vec{E} = -j\omega\left[\vec{A} + \frac{1}{\omega^2\mu\epsilon}\nabla\left(\nabla.\vec{A}\right)\right] - \frac{1}{\epsilon}\nabla \times \vec{F} \tag{2.15}$$

$$\vec{H} = \left\{j\omega\left[\vec{F} + \frac{1}{\omega^2\mu\epsilon}\nabla(\nabla \cdot \vec{F})\right] - \frac{1}{\mu}\nabla \times \vec{A}\right\} \tag{2.16}$$

In this thesis, let's starts by thinking that the waveguide we used is in dominant mode. (TE_{10}). Therefore, we have $\vec{A} = 0$ and $\frac{\partial F_z}{\partial y} = 0$ [14]. Then, the vector electric potentials can be obtained as air-filled region with length L_0 (region I) and sample-filled region with length d (region II) as

$$\mathrm{F_z}^{(\mathrm{I})}(\mathrm{x},\mathrm{z}) = \cos\left(\frac{2\pi}{\lambda_c}\mathrm{x}\right)\left[\mathrm{C_1}e^{-\gamma_0 \mathrm{z}} + \mathrm{C_2}e^{\gamma_0 \mathrm{z}}\right] \tag{2.17}$$

$$\mathrm{F_z}^{(\mathrm{II})}(\mathrm{x},\mathrm{z}) = \cos\left(\frac{2\pi}{\lambda_c}\mathrm{x}\right)\left[\mathrm{C_3}e^{-\gamma_0 \mathrm{z}} + \mathrm{C_4}e^{\gamma_0 \mathrm{z}}\right] \tag{2.18}$$

Where

$$\left.\begin{aligned}\gamma_0 &= j2\pi / \lambda_0\sqrt{1-{\lambda_0}^2/{\lambda_c}^2}\\ \gamma &= j2\pi / \lambda_0\sqrt{\varepsilon_r-{\lambda_0}^2/{\lambda_c}^2}\end{aligned}\right\} \quad (2.19)$$

If we explain the parameter $C_1 : C_4$ are the complex or real values; $\lambda_0 = c/f$ and $\lambda_c = c/f_c$ correspond tothe free-space and cut-off wavelengths; and f, f_c , and c are the operating and cut-off frequencies and the speed of light in vacuum, in order of; and $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ is the relative complex permittivity of the sample [1].

If we use the vector electric potentials in (2.17), (2.18), fields of electric and magnetic can be expressed using (2.15) and (2.16). The boundary conditions for the tangential electric and magnetic fields on the materials face and the disappearance of the tangential electric fields in the ending plane of Figure 2.1 are found as the reflection of the S-parameter.

$$S_{11} = {R_1}^2 \frac{\Gamma+T^2\Gamma_s}{1+T^2\Gamma\Gamma_s} \quad (2.20)$$

Where

$$\Gamma = \frac{Z-Z_0}{Z+Z_0} \ , \quad T = \exp(-\gamma d) \quad , \quad R_1 = \exp(-\gamma L_0) \quad (2.21)$$

$$Z = j\omega\mu_0/\gamma \ , \qquad Z_0 = j\omega\mu_0/\gamma_0 \quad (2.22)$$

If we examine [60], we can see that the Lorentz reciprocity theorem for validating derived electrical and magnetic field expressions can be applied by a according to a welded rectangular closed surface within the waveguide section [1].

2.2 Amplitude of the reflection S-parameter

We can see that C and T from (2.19) to (2.22) can be called $\varepsilon_r - (\lambda_0 / \lambda_c)^2$ for a d and f. In addition, it will guide us to find the custom to get the value of the expression. For this purpose we have defined a new set of variables for this purpose [1,33,35,38].

$$\left.\begin{aligned} \chi - j\xi &= \sqrt{\varepsilon_r - (\lambda_0/\lambda_c)^2} \\ B &= \exp(-4\pi\xi d/\lambda_0) \end{aligned}\right\} \quad (2.23)$$

$$A = 4\pi\varepsilon\chi d/\lambda_0 \ , \qquad \kappa = \sqrt{1 - (\lambda_0/\lambda_c)^2} \ . \quad (2.24)$$

Introducing (2.23) and (2.24) into (2.20), the amplitude of S_{11} ($|S_{11}{}^s|$) is derived as

$$|S_{11}{}^s| = \left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right)^{1/2} \quad (2.25)$$

Where

$$\Lambda_1 = B_1(\Lambda_0 + 2\kappa^2) + 2\,\Lambda_0 \cos(A) \quad (2.26)$$

$$B_1 = B + 1/B,$$

$$\Lambda_0 = \chi^2 + \xi^2 + \kappa^2,$$

$$\Lambda_2 = 4\kappa\xi \sin(A) + 2\kappa\chi B_2 \quad (2.27)$$

In the derivative of (2.25), it is accepted that $\Gamma_s = -1$ (the surface of the termination becomes a very good conductor). It is correct that because the term

$1 - (\lambda_0/\lambda_c)^2$ in (2.19) is a real quantity for$\lambda_0 < \lambda_c$, R_1in (2.21) will behave like imaginary. Because of this, its absolute value will be unit.

If we put f which means frequency in to the λ and d/λ_0 equal to L which means lenght;

$$\chi - j\xi = \sqrt{\varepsilon_r - (f_c/f)^2},$$

$$B = \exp(-2k_0\xi L),$$

$$A = 2k_0\chi L,$$

$$\kappa = \sqrt{1 - (f_c/f)^2},$$

ε_r can be found using different frequency values with using only the $|S_{11}{}^s|$ parameter. For this, the variation of the S value with frequency should be analyzed:

$$\frac{\partial|S_{11}{}^s|}{\partial f_{min}} = \frac{\partial\left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right)^{1/2}}{\partial f}$$

We know

$$F(x) = \sqrt{g(x)} \qquad\qquad F'(x) = \frac{g'(x)}{2\sqrt{g(x)}}$$

So;

$$\frac{\partial|S_{11}{}^s|}{\partial f_{min}} = \frac{1}{2\left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right)^{1/2}}\frac{\partial\left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right)}{\partial f} = 0 \qquad (2.28)$$

$\left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right) \neq 0$ forwhy $\Lambda_1-\Lambda_2 \neq 0$ and because of these equation (2.28) can be provided as follow;

$$\frac{\partial\left(\frac{\Lambda_1+\Lambda_2}{\Lambda_1-\Lambda_2}\right)}{\partial f} = \frac{\left(\frac{\partial\Lambda_1}{\partial f}+\frac{\partial\Lambda_2}{\partial f}\right)(\Lambda_1-\Lambda_2)-\left(\frac{\partial\Lambda_1}{\partial f}-\frac{\partial\Lambda_2}{\partial f}\right)(\Lambda_1+\Lambda_2)}{(\Lambda_1-\Lambda_2)^2} = 0 \qquad (2.29)$$

$$\frac{\partial \Lambda_1}{\partial \mathrm{f}} \Lambda_1 + \frac{\partial \Lambda_2}{\partial \mathrm{f}} \Lambda_1 - \Lambda_2 \frac{\partial \Lambda_1}{\partial \mathrm{f}} - \Lambda_2 \frac{\partial \Lambda_2}{\partial \mathrm{f}} = \frac{\partial \Lambda_1}{\partial \mathrm{f}} \Lambda_1 - \frac{\partial \Lambda_2}{\partial \mathrm{f}} \Lambda_1 + \frac{\partial \Lambda_1}{\partial \mathrm{f}} \Lambda_2 - \frac{\partial \Lambda_2}{\partial \mathrm{f}} \Lambda_2 \tag{2.30}$$

$$\frac{\partial \Lambda_2}{\partial f} \Lambda_1 = \frac{\partial \Lambda_1}{\partial f} \Lambda_2 \tag{2.31}$$

$$\frac{\partial \Lambda_1}{\partial \mathrm{f}} = (\chi^2 + \xi^2 + \kappa^2) \frac{\partial (\mathrm{B}+1/\mathrm{B})}{\partial \mathrm{f}} + 2(\chi^2 + \xi^2 - \kappa^2) \frac{\partial \cos(\mathrm{A})}{\partial \mathrm{f}} \tag{2.32}$$

$$\frac{\partial \Lambda_2}{\partial \mathrm{f}} = 4\kappa\xi \frac{\partial \sin(\mathrm{A})}{\partial \mathrm{f}} + 2\kappa\chi \frac{\partial (\mathrm{B}-1/\mathrm{B})}{\partial \mathrm{f}} \tag{2.33}$$

$$\frac{\partial \mathrm{B}}{\partial \mathrm{f}} = (-2\mathrm{k}_0 \xi \mathrm{L}) \exp(-2\mathrm{k}_0 \xi \mathrm{L}) \qquad \mathrm{k}_0 = \frac{2\pi}{\lambda} = \frac{2\pi}{\mathrm{c}/\mathrm{f}} = \frac{2\pi \mathrm{f}}{\mathrm{c}}$$

$$\frac{1}{\mathrm{B}} = \frac{1}{\exp(-2\mathrm{k}_0 \xi \mathrm{L})} \qquad \frac{\partial (1/\mathrm{B})}{\partial \mathrm{f}} = -(-2\mathrm{k}_0 \xi \mathrm{L}) \frac{1}{\exp(-2\mathrm{k}_0 \xi \mathrm{L})}$$

So;

$$\frac{\partial \mathrm{B}}{\partial \mathrm{f}} = -\frac{4\pi\xi \mathrm{L}}{\mathrm{c}} \mathrm{B}, \qquad \frac{\partial (1/\mathrm{B})}{\partial \mathrm{f}} = \frac{4\pi\xi \mathrm{L}}{\mathrm{c}} \frac{1}{\mathrm{B}}, \tag{2.34}$$

$$\frac{\partial \sin(A)}{\partial f} = \cos(A) \frac{\partial A}{\partial f},$$

$$\frac{\partial \cos(A)}{\partial f} = -\sin(A) \frac{\partial A}{\partial f},$$

$$\left.\begin{aligned} \mathrm{A} = 2\mathrm{k}_0\chi\mathrm{L} = \frac{4\pi\mathrm{f}\chi\mathrm{L}}{\mathrm{c}}, \\ \frac{\partial \mathrm{A}}{\partial \mathrm{f}} = \frac{4\pi\chi\mathrm{L}}{\mathrm{c}}, \end{aligned}\right\} \tag{2.35}$$

$$\frac{\partial \sin(\mathrm{A})}{\partial \mathrm{f}} = \cos(\mathrm{A})\frac{4\pi\chi\mathrm{L}}{\mathrm{c}},$$
$$\frac{\partial \cos(\mathrm{A})}{\partial \mathrm{f}} = -\sin(\mathrm{A})\frac{4\pi\chi\mathrm{L}}{\mathrm{c}},$$

Using equations (2.29)-(2.35), the following metric function F(a) is obtained:

$$\left.\begin{aligned} &2\chi\xi(\chi^2+\xi^2+\kappa^2)\left(B+\frac{1}{B}\right)\cos(A) + 4\chi\xi\chi^2+\xi^2-\kappa^2\cos^2(A) - \\ &\chi\xi(\chi^2+\xi^2+\kappa^2)\left(B+\frac{1}{B}\right)^2 - 2\chi\xi(\chi^2+\xi^2-\kappa^2)\left(B+\frac{1}{B}\right)\cos(A) = \\ &-2\xi^2(\chi^2+\xi^2+\kappa^2)\left(B-\tfrac{1}{B}\right)\sin(A) - 4\chi\xi(\chi^2+\xi^2-\kappa^2)\sin^2(A) \\ &-\chi\xi(\chi^2+\xi^2+\kappa^2)\left(B-\frac{1}{B}\right)^2 - 2\chi^2(\chi^2+\xi^2-\kappa^2)\left(B-\frac{1}{B}\right)\sin(A) \end{aligned}\right\} \tag{2.36}$$

$$\left.\begin{aligned} &4\chi\xi\kappa^2\left(B+\tfrac{1}{B}\right)\cos(A) - 8\chi\xi\kappa^2 \\ &= -2\left(B-\tfrac{1}{B}\right)[(\chi^2+\xi^2)^2-(\chi^2-\xi^2)\kappa^2]\sin(A) \end{aligned}\right\} \tag{2.37}$$

$$\Lambda_A = 2\chi\xi\kappa^2\left(B + \frac{1}{B}\right),$$

$$\Lambda_B = -4\chi\xi\kappa^2,$$

$$\Lambda_c = \left(B - \frac{1}{B}\right)[(\chi^2 + \xi^2)^2 - (\chi^2 - \xi^2)\kappa^2],$$

With these findings, we define an F(A) function:

$$F(A) = \Lambda_A \cos(A) + \Lambda_B + \Lambda_c \sin(A)$$

(2.37)

As can be seen from equation (2,37), the value of ε_r can be calculated with the $|S_{11}{}^s|$ value at three different frequencies by eliminating the value of the multi-result generating value (considering that the material is not dispersive). In addition, the following approaches for low-loss materials.

$$B \to 1, \quad \Lambda_A = 4\chi\xi\kappa^2, \quad \Lambda_B = -4\chi\xi\kappa^2, \quad \Lambda_c = 0 \quad , \qquad (2.38)$$

F (A) simplifies as follows:

$$F(A) = 4\chi\xi\kappa^2 \cos(A) - 4\chi\xi\kappa^2 = 4\chi\xi\kappa^2(\cos(A) - 1) = 0$$

(2.39)

As can be seen from equation (2.39), the minimum $|S_{11}{}^s|$ value for low-loss materials occurs when $\cos(A) = 1$. We use this information and equations in numeriz analysis.

CHAPTER 3

PRACTICAL ANALYSIS

In this study, we have chosen the silicon material type because the materials with high dielectric constant will provide more efficient and clear results. For this, we used the raw form (which is in liquid form) instead of processed silicon which can be found everywhere in the market. Of course, we had to carry out some operations on this raw material to make it the shape we want. We had 3 silicone samples in liquid form containing different interaction materials and the catalysts required for each of these. After making the necessary interactions with these catalysts, we would have reached the desired solid state silicon with high dieletrical constant. Before describing all these steps one by one, we will describe the properties of the 3 types of silicone substances that we have selected. We will then tell you what kind of stages they have gone through to become solid and how they take the form we want. After passing all these steps, we will share with Kyside measuring device how and in which methods we have done in the laboratory and share the results.

3.1 Sample Which is Analysed On: Silicone

As we mentioned above, after using silicone as material, we used 3 types of silicone with different strengths. The reason why we use three types of silicone is to give silicone to which one we can give the shape we want more comfortably and therefore to obtain healthier, more reliable results. Now we can first focus on the properties of these silicone materials.

3.1.1 Sample 1: Silicone Rubber-1 for Electronic Potting & Encapsulation

Description: Condensation-curing, pourable two-component electronic potting silicone rubber that vulcanizes at room temperature.

Aplications:

Electronic Potting Silicone Rubber-1 is used for insulating and encapsulating optoelectronic devices, LED packaging and LED assembly materials. Typical application areas:

- Optoelectronic devices
- LED's, LED screens
- High powered electronics, wind power generators
- PCB substrates, -DC/DC modules and circuit boards which require heat dissipation and high temperature resistance

Key Features and Benefits:

- Optically high purity, good transparency
- High light transmittance
- Excellent flowability due to low viscosity (ideal for small smd packages, power packages, multi-chip cob packages)
- Excellent thermal resistance
- Enhanced weatherability performance
- Excellent UV resistance
- Long-term resistance to yellowing and delamination of encapsulant from the substrate
- Excellent shock resistance
- Adjustability of cure speed (curing time can be adjusted by changing the type or value of curing agent)
- Deepsection curability (curing reaction proceeds uniformly at the surface and internally)
- Good workability
- Adhesion to led package substrates

Table 3.1 Technical Properties

Appearance/ Color Flowable liquid/ Transparent	Appearance/ Color Flowable liquid/ Transparent
Mixing ratio (A:B) 10:1	Mixing ratio (A:B) 10:1
Operating time/Pot life, at 25°C 60-120 minutes	Operating time/Pot life, at 25°C 60-120 minutes
Curing & Demold time, at 25°C 12-24 hours	Curing & Demold time, at 25°C 12-24 hours
Hardness (Shore A) 20±3	Hardness (Shore A) 20±3
Viscosity (cst), at 25°C 2.000 (±500)	Viscosity (cst), at 25°C 2.000 (±500)
Shrinkage (%) ≤0.1	Shrinkage (%) ≤0.1

Product Usage:

Clean up the coating surface, remove the rust, dust, oil dirt. Silicone Rubber-1 for Electronic Potting & Encapsulation is a flowing liquid, and it consists of two components: part A (Base) is the flowable liquid silicone rubber, part B (Catalyst) is the curing agent (shown Figüre 3.1). Stir component A and component B with 10:1 mixing ratio evenly in a container, mix the catalyst and some until homogeneous. You can do this by hand or by mechanical mixing, but it should not be mixed into multiple phases because if the temperature exceeds 35°C, poor results may occur.

Figure 3. 1 Base and catalyst of sample M1

3.1.2 Sample 2: Silicone Rubber-2 for Electronic Potting & Encapsulation

Description: Pourabie, condensation-curing, two-component electronic potting silicone rubber that vulcanizes at room temperature.

Aplications:

Electronic Potting Silicone Rubber-2 is mainly applied surfaces of polycarbonate, PP, ABS, PVC and metal etc. which is very useful for the electronic moisture_proof and waterproof, fixed.

Typical aplication areas:

- Optoelectronic devices
- High powered electronics, wind power generators
- PCB substrates, DC/DC modules and circuit boards which require heat dissipation and high temperature resistance LED's, LED screens
- LED’s, LED screens

Key Features and Benefits:

- Translucent color
- Condensation-curing (tin cure) at room temperature
- Mixing ratio 10:1
- Low viscosity, ideal for small SMD packages, power packages, multi-chip COB packages
- Curing time can change with the quantity of the curing agent, or by heating
- Easy pouring operation
- Very good adhesion and bonding performance
- Heat-conducting
- Inherent flame resistance
- Enhanced weatherability performance
- Environmental, odorless and nontoxic
- Resistant to radiation and abrasion
- Reach the EU-ROHS requirements fully

Table 3. 2 Technical Properties

Appearance/ Color	Flowable liquid/ Translucent
Mixing ratio (A:B)	20:1
Operation time/Pot life, at 25^0C	60-120 minutes
Curing time, at 25^0C	60-70 minutes
Hardness (Shore A)	15
Density (g/cm^3)	0.96
Viscosity, at 25^0C (MPa•s)	3000
Tensile strength (MPa)	2.2
Elongation at break (%)	<300
Volume resistivity (Q•m)	1014
Thermal conductivity (W/(m•K))	0.3
Flame-retardant level (UL 94)	v-2
Shrinkage (%)	<0.2

These values are only intended as a guide and should not be used in preparing specifications.

Product Usage:

1.Preparation

Clean up the coating surface, remove the rust, dust, oil and dirt.

2.Pouring

This sample is a kind of flowing liquid, and it consists of two component: part A (Base) is flow-able liquid silicone rubber, part B (Tin Catalyst) is the curing agent as shown in Figure 3.2.

Figure 3. 2 Base and catalyst of sample M2

Stir part A and part B with 20:1 mixing ratio evenly in a clean container, then mix together until the curing agent is completely dispersed in the base. You can do this by hand or by mechanical mixing, but it should not be mixed into multiple phases because if the temperature exceeds 35°C, poor results may occur. Mix in small amounts in a controlled manner for a healthy cure of the base and catalyst.

It is recommended to use a vacuum to remove any air bubbles that may form in the mixture after mixing. However, do not keep the vacuuming time longer than 3-5 minutes because the silicone rubber may show a cross-linking reaction during vacuuming. As result, it will be a good work.

Pour onto the electronic component/surface after vacuum degassing. Room temperature cure or heat-up cure is both suitable. The mixed silicone rubber can be also injected by machine. Note: It should be use up after open the package, the material must be kept in a cool place sealed well, and it should avoid from contact with moisture in the air.

Reducing the hardnes

Electronic potting or encapsulating applications may need to have a specific hardness. To reduce the hardness, line silicone fluids in viscosities of 50cSt, IOOcSt or 350cSt can be added into the silicone rubber. Please note that the working and curing time is directly proportional to the amount of silicone fluid.

The ratio of base and catalyst is always taken as 10: 1 regardless of the amount of silicone. A number of faults can occur during these processes, the most important of which is the careful adjustment of the base and catalyst amounts.

Handling Precautions

These products are very sensitive and must be handled with care. Store in clean, dry steel crates. For specific precautions, please sellect to the instructions given in the corresponding Material Safety Data Sheet. If you intend to use other

materials with this product, action should be taken after taking precautions. Please read and understand this type of information carefully and take action.

Limitations, Health and Environmental Information

This product is not tested or represented as suitable for medical or pharmaceutical uses.

Shelf Life and Storage

When stored at room temperature 25 0C in the tightly closed its first containers, the product has a shelf life of 12 months from the date of production.

3.1.3 Sample 3: Silicone Rubber With Platinum Catalyzed

Description: Two-component (1: 1 mixing ratio) liquid silicone rubber which is cured at room temperature by addition-type cross-linking with platinum catalyst and suitable for direct contact with food and skin.

Aplications

Platinum catalyzed silicone rubber is used in the production of many products produced by silicone casting mold, especially in food contact products such as chocolate, sugar and cake.

Platinum-catalyzed silicone rubber cement, gypsum, wax, rubber, plastic, resin, polyester and polyurethane products due to their properties such as low shrinkage-after-curing rate, excellent tear and abrasion resistance, high resistance to acids and chemicals, and optimal flexibility, ideal for manufacture with.

Thanks to its high purity level, excellent flexibility and high oil acceptance properties, it is also used safely in the manufacturing of silicone rubber based external dentures, silicone rubber orthopedic products and silicone rubber foot health materials, especially in the platinum catalyst silicone rubber orthopedic shoe insole.

Key Features and Benefits:

- High degree of purity
- Suitable for direct contact with food and skin
- Suitable for use in highly fluid, manual pouring or automated systems
- Optimized application, casting and curing times
- Minimum air bubble formation after mixing of components
- Tensile-to-ice ratio after curing
- Excellent resistance to long-term and extreme temperatures (-6YC to 2500C)
- High chemical resistance to resins
- High resistance to abrasion
- Excellent tear and tear resistance (high number of molded documents)
- Excellent elongation and high elasticity
- Transparent, easy to color with silicone rubber paints

Table 3. 3 Technical Properties

View	Opaque transparent
Degree of hardness	40 Shore A (H)
Mixing ratio of components (by weight)	1: 1 (A: B)
Working time, 25 0C at room temperature	20-40 minutes
Vulcanization time, 25 0C at room temperature	3-5 hours
Density	1.08 g / cm3
Viscosity, dynamic	8000 ($\pm$3000) mPa.s
Tensile strength	$\geq$ 6.5 M.Pa
Tear strength	$\geq$16 kN / m
Elasticity	$\geq$ % 400
Linear shrinkage ratio (%)	$\leq$ 0.1

These values are only intended as a guide and should not be used in preparing specifications.

Product Usage:

Clean and polish the model to be taken with soap and water and dry. Then spray the entire surface of the model with a mold release agent (if you need to), fix the model by placing it on a smooth wooden board without blanks and form a mold frame (eg by gluing 4 wooden plates onto a wooden board with silicone sealant) and a vacuum pump into the tank (If the vacuum pump is used, a more durable and longer lasting silicone mold is obtained).

Determine the amount of liquid silicone rubber to be cast into the mold and mix components A and B (shown in Figure 3.3) in a balanced and homogeneous manner for several minutes, taking into account the mixing ratio (1: 1 by weight). Pour 1/3 of the evenly and evenly mixed silicone rubber mixture into the mold frame, slowly and smoothly mix the textured mixture to accelerate the release of air bubbles remaining in the mold. Put the remaining 2/3 of the silicone rubber mixture into the vacuum pump tank to allow air bubbles to escape, take it from the vacuum tank after 3-5 minutes and pour it into the mold frame.

After 3-4 hours, remove from the mold, the silicone rubber completely cured and then remove the mold frame, clean the silicone residue and eaves using a razor blade. After 24 hours, the silicone mold becomes ready to use, but it is recommended to wait at least 48 hours before the silicone mold can be used for a longer time.

Figure 3. 3 Base and catalyst of sample M3

Precautions During Use

Components A and B of the product should be stored in clean, dry and tightly closed steel containers or drums. Components A and B of the product must be kept in separate packages. Storage in a cool, dry place is recommended.

Since this product is cured with platinum catalyst, it should not come into contact with, and should not be used in the presence of, nitrogen, phosphorus, sulfur, tin, lead or metal organic acid-like chemicals or mixtures containing them. Otherwise, the platinum catalyst is poisoned and the silicone rubber cannot cure, vulcanize, cure and degrade sufficiently.

Limitations, Health and Environmental Information

This product has not been tested for medical and pharmaceutical use, no compliance has been reported.

Shelf Life and Storage

Shelf life of the product is 24 months under normal conditions when stored in tightly closed original containers in 5-35℃. Exceeding this period does not mean that the product cannot be used, but the suitability of use must be checked. It

should not be exposed to direct sunlight and frost, so precautions should be taken.

3.2 Experiments Which Obtained Solid Silicone Use Bases and Catalysts

3.2.1 Unsuccessful Experiments

First of all, we started with the first silicon (M1) sample with the lowest strength which we first found. Then we use second silicona sample (M2) which have medium strength. There were several important steps that were important when starting experiments. The first one is the container we will put in order to cure in order to get the shape we want easily. The second is the container to mix the base and the catalyst. The third is a precision balance, as mixtures require a very precise measurement.

Figure 3. 4 Precision scale

Figure 3.4 shows the precision scale that we will use in all experiments. Because it is affected by the vibration around it, it is necessary to work very carefully. Another important issue regarding the precision balance is to reset the mixture after taring the container.

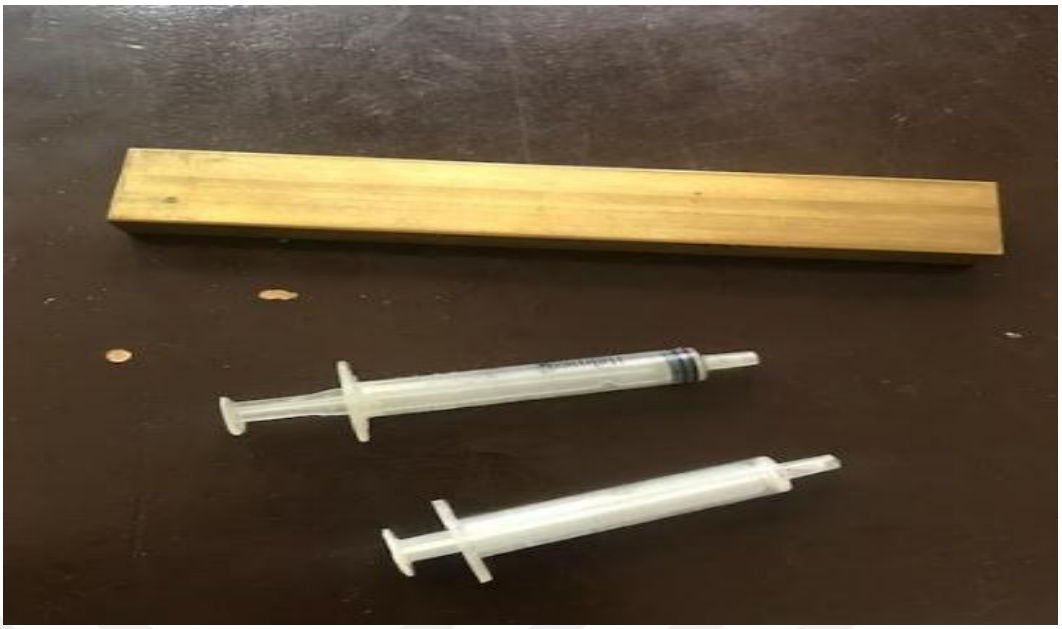

Figure 3. 5 Brass and injection

Experiment 1: As we can see in Figure 3. 5, we chose a brass which have 3:1 cm length and 4 cm in height that we can fill with M1 sample. Another reason for choosing the brass is that it has the same dimensions as the waveguide we will use. We also see a injection which we use for catalyzer in Figure 3. 4.

For first experiment Since we want to cure the M1 sample, we used the catalyst and base ratio of this sample which have 10:1 ratio. Baceuse of this we use 25 gr M1 base's and 2,5 M1 catalyst's as shown Figure 3.6. After stirring this mixture for 5 minutes, we let it settle for 10 minutes to remove air bubbles. We filled this rested mixture into the brass and let it cure for 24 hours in a dry environment. After hours our sample had cured but it would be very difficult to separate it from the brass because it was a material that dispersed very quickly. We tried air pumice for this but we failed and we got no results. A new experiment could have made our working easier.

Figure 3. 6 10% catalyst base mixture for M1

Experiment 2: Investigating our reasons for failure in the previous experiment and making corrections could lead us to the desired result. What was the main reason why we failed? Of course, it was the wrong curing vessel. We should have started here, and we should have chosen a container from which we could extract the sample more easily. For this, we preferred cardboard cups with slippery inner surface. Everything could have been easier since we would prepare the mixture for it.

Figure 3. 7 A sample of silicone that cured in cardboard

After applying the steps we made in the previous experiment one by one, we rest for 24 hours to cure our mixture to rest. As we expected, we had a sample of silicone that was easily separated from the cardboard cup as we can see in Figure 3.7. But we had another problem, that in any cutting process, due to its strength, it could dissipate very quickly. In this way, it was impossible for us to place it in the waveguide because the places we shaped continued to distribute.

Experiment 3: Because the cardboard cup we had chosen had eliminated the reason why the first experiment failed, and we could solve the second problem, for example, the dispersion problem with strength. It was during this time that we preferred a higher strength silicone sample which is Silicone Rubber for Electronic Potting & Encapsulation (M2).

After resetting the tared precision balance, we prepared the sample having a catalyst base ratio of 5%. We used 50 g base and 2,5 g catalyst as shown Figure 3.8 (M2 Base's and catalyst's).

Figure 3. 8 5% catalyst base mixture for M2

We mixed the catalyst and base for 5 minutes to homogeneously disperse. This sample does not require a rest because it does not make air bubbles. After 60-70 minutes, we noticed that it had cured and we could easily separate it from the cardboard cup and start shaping. Yes, it did not dissipate, but it was also very difficult to shape because there were roughness on the sample. These roughnesses can be clearly seen in Figure 3. 9.

Figure 3. 9 Rough form of sample M2 after shaping

As you can see, this experiment also failed. But the good news was our last failed experience.

3.2.2 Successful Experiment

At the end of many unsuccessful experiments, the best result is knowing what you should not do. We also knew what we shouldn't have done after all of failed experiences. First of all, we didn't leave it to chance and we got a third sample Silicone Rubber With Platinum Catalyzed which have high strength (M3). The second step was to design a container that had a full waveguide size and could be easily separated from silicon.

We chose colored blueprint cardboard to form the container. The reason we choose this cardboard is that it has a non-stick structure and has a thickness (0.5 mm) that can become a certain container. We have designed this to be the size of the waveguide we will use when it closes. You can see the designed open version in Figure 3.10.

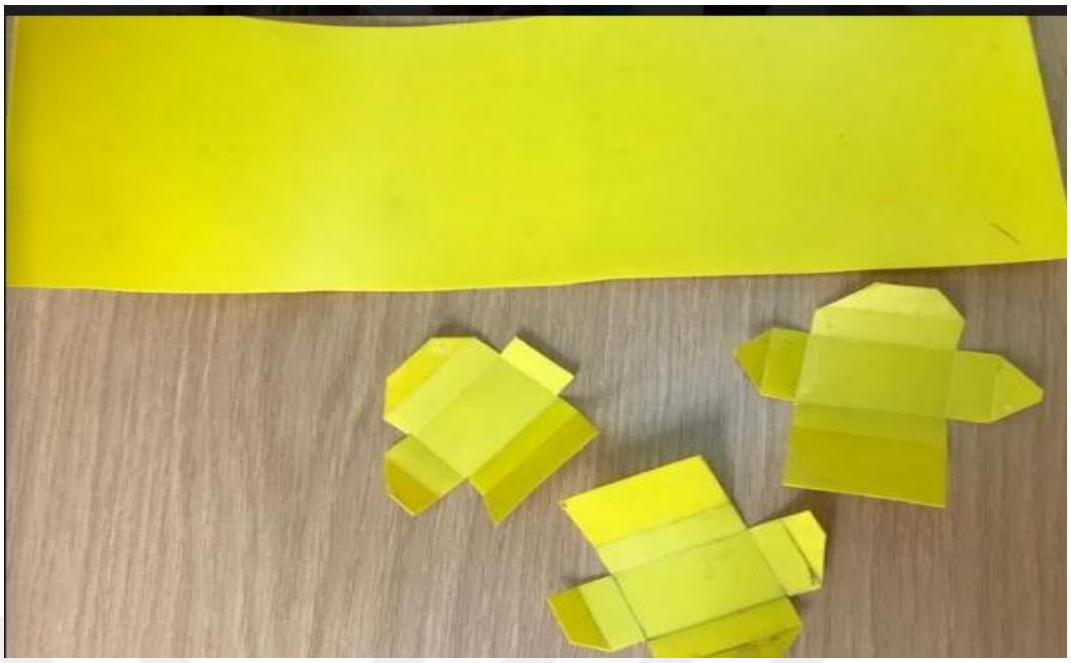

Figure 3. 10 Non-stick blueprint cardboard and open the boxes we cut for samples

We knew the catalyst and base ratio of M1 and M2, so we just need to make the necessary explanation for M3. A 1: 1 ratio is required for this example, due to this we mixed 50 g of 3340 A, 50 g of 3340 B (shown in Figure.11). We mixed for 10 minutes for homogeneous dispersion and let the air bubbles settle. After 5 hours, we observed that it cured. We obtained a mixture of M1 and M2 in the required proportions and observed that they cured. you can see these examples during curing in Figure 3.12.

Figure 3. 11 50% catalyst base mixture for M3

Figure 3. 12 M1, M2 and M3 samples which are kept in a cool environment for curing after mixing separately to certain sizes.

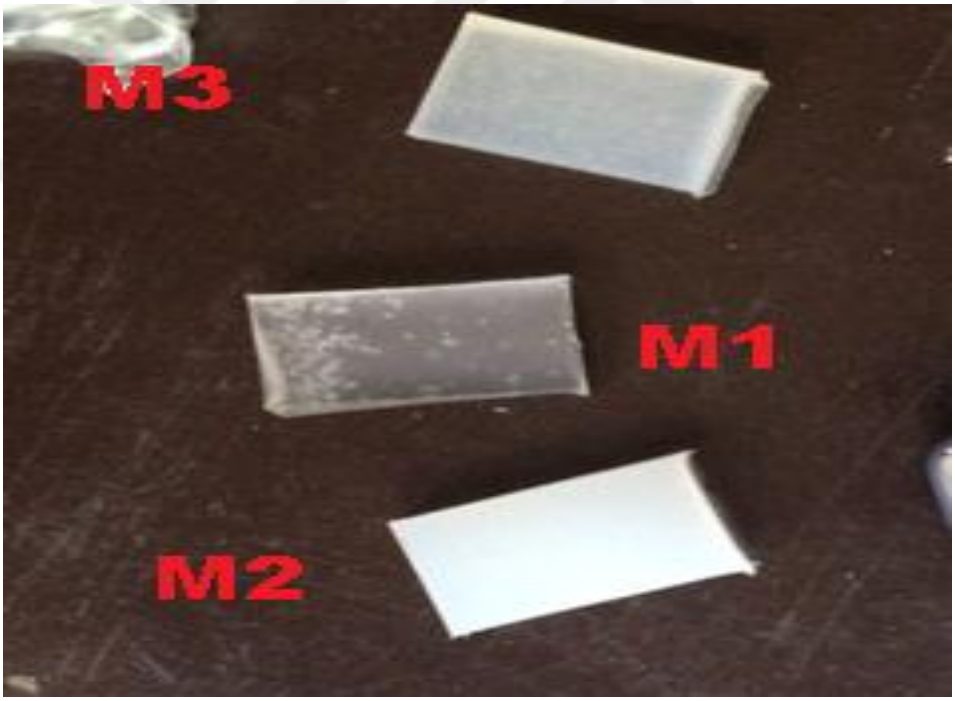

Figure 3. 13 M1, M2 and M3 curing ready-made silicone form in the desired size.

3.3 The Measurement of Scattering Parameters of The Samples Obtained in The Experiment in The Laboratory

3.3.1 Measuring Device For Obtained Scatering Parameter: Keysight

Figure 3. 14 Keysight measurement device

We can see below the general features of Keysight shown in Figure 3.14 and also specifications of Keysight is given in Table 3 .4 :

- 26.5 GHz max frequency
- Carry the world's most integrated analyzer: standart model includes cable and antena analyzer (as shown in Figure 3.14)
- Expand capabilities with optional VNA, spectrum analyzer, built-in power meter, vector voltmeter, and more
- Save time by determining DTF and TDR in the same sweep
- Simultaneously obtain all four S-parameters
- Make correct spectrum analyzer measurement (± 5 dB) without needing warm-up

- Calibrate simply QuickCal
- Lightest all in analyzer at only 6.6 lb. (3 kg)

Table 3.4 Specifications of Key-sight

CAT/VNA Start Frequency	30 kHz
SA Start Frequency	5 kHz
Dynamic Range	91 dB
Outpu power	-4 dBm
Nurber of Built-in Ports	2 Ports
Cable and Antenna Analyzer	Yes-Standart
Spectrum Analyzer	Yes-Obtional
Vector Network Analyzer	Yes-Obtional

3.3.2 Calibration of Measuring Device Keysight

In order to obtain healthy and efficient results from our measure, we must start with the right calibration. it is useful to determine a calibration according to our measuring device and the method we apply, so we did. First of all, we have selected the previously determined phase values (10.3 and 89.50°) and we use X-band (8.-12.4GHZ) on our measure device. It would be more useful if we describe the short circuit calibration step by step:

- We chose the WR 90 calibration type from TRL for Port 1 and Port 2

Port 1		Port2
N9911 WR90	↔	WR90

- We put front of Port1 one a material which close its opening because of short-circuit calibration and we push mesurement button then recorded.
- Then we did this for Port 2 and mesure it also as shown Figure 3.15

Figure 3. 15 Short-circuit measurement with brass for calibration

- Then we screwed the Port 1 and Port 2 together and made a measurement again and recorded.
- As shown in Figure 3.16 waveguide which have 10.11 dimensions and empty was put between Port1 and Port2 then screwed all together and recorded after was mesured.

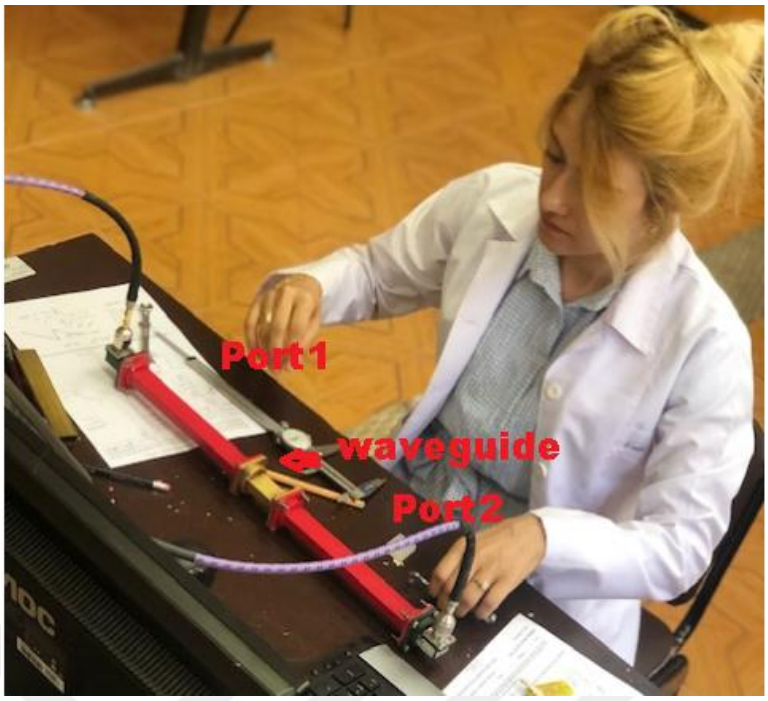

Figure 3. 16 Circuit for calibration of empty rectangular waveguides located between two ports

- After all of this we pushed finish button, so we finished the short-circuit calibration.

3.3.3 Measuring of Samples and Obtainig S-parameters

After calibrating, we could place the 3 samples (M1, M2, M3) that we have obtained as a result of the experiments one by one into the measuring device and obtain the scattering parameters mathematically and graphically. We have placed our samples for our rectangular waveguides, whose features we have previously identified (in Figure 3.17) . Then we put this waveguide between Port1 and Short-circuit (in Figure 3.18) and mesure it for obtaining S-parameters.

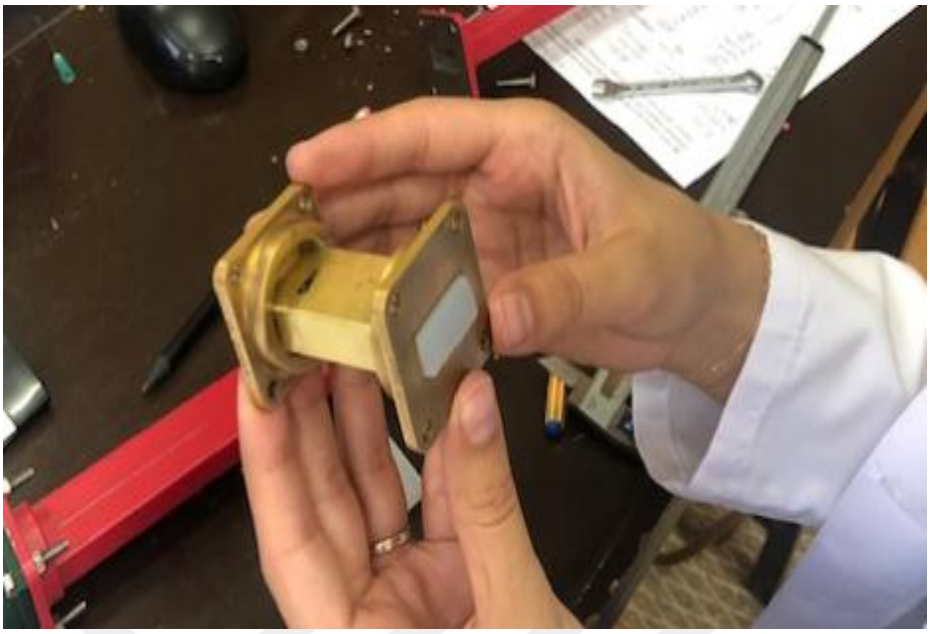

Figure 3. 17 We put the sample we prepared in the rectangular waveguide

Figure 3. 18 Measurement circuit which waveguide filled with sample placed between between Port1 and Short-circuit

We made the necessary adjustments for the measurement and obtained the results for each sample graphically as shown in Figures 3.19, 3.20, 3.21. We measured S-parameters as Real and Imaginary without falling below Log 40. But firt we look into all S-parameters of all samples as Linear which giving smooth graphical results.

Figure 3. 19 Linear grafic of M1

Figure 3. 20 Linear grafic of M2

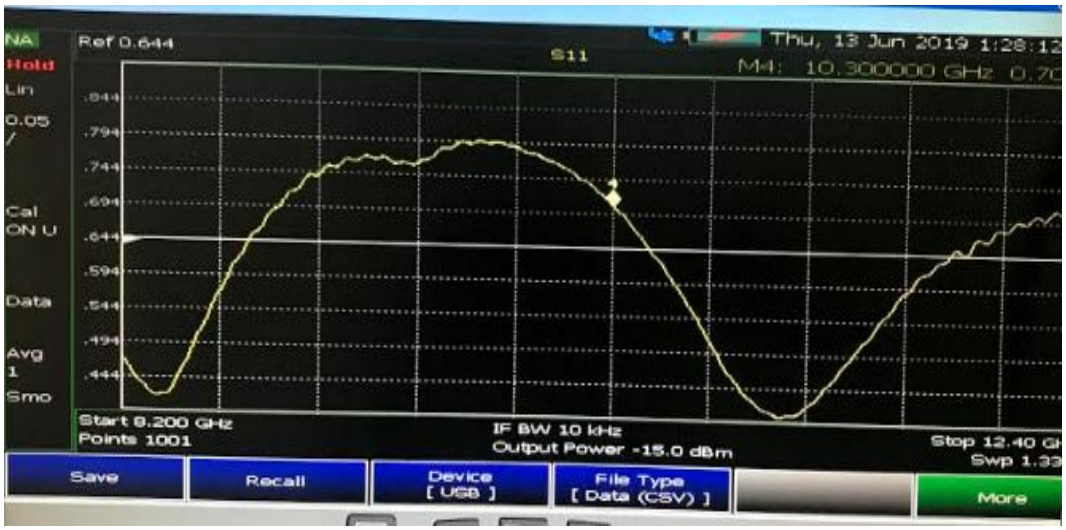

Figure 3. 22 Linear grafic of M3

As can be seen in Figures 3.22 and 3.19, we can eliminate these two samples because the linear graph of M1 and M2 is not smooth. The reason it does not come out properly because may be they do not take the shape we want to give when they curing or may be due to air bubbles. However, the M2 sample was cured to the desired size and because of its structure does not create air bubbles, as shown in Figure 3.20, so; we were able to obtain a smooth linear graph. Because of this we record Real and Imag grafic of only M2. These are shown in Figure 3.23 and Figure 3.24.

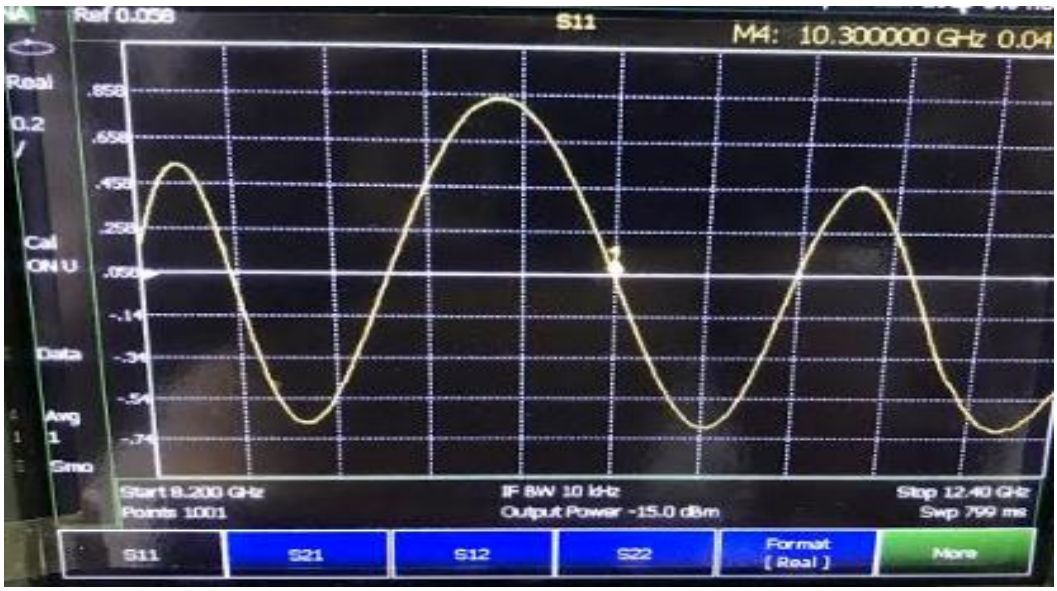

Figure 3. 23 Real grafic of M2

Figure 3. 24 Imaginary grafic of M2

We recorded the S-parameters graphically and then saved the numeric datas in excel for numeric analysis. We made this recording as real and imaginary measured at certain frequencies. Now we have all the datas for numeric analysis, in the next section we will study the necessary studies and results for numeric analysis to obtain the dielectric constant.

CHAPTER 4

NUMERICAL ANALYSIS

4.1 Using Obtained S-parameter Determine The Dielectric Constant with MatLab

We designed matlab code from the equations that we obtained as a result of theoric analysis and used the Real-ferquency and Imag-frequency excel files, which we obtained as a result of pratic analysis, in this code.

Figure 4.1 shows the $|S_{11}{}^{s}|$ and 0.1cos(A)+0.8 value of the material having an electrical permeability value of $\varepsilon_r = 11.1 - i0.099$ and sample's length L=25.5 (as shown in Figure 4.2) depending on the frequency.

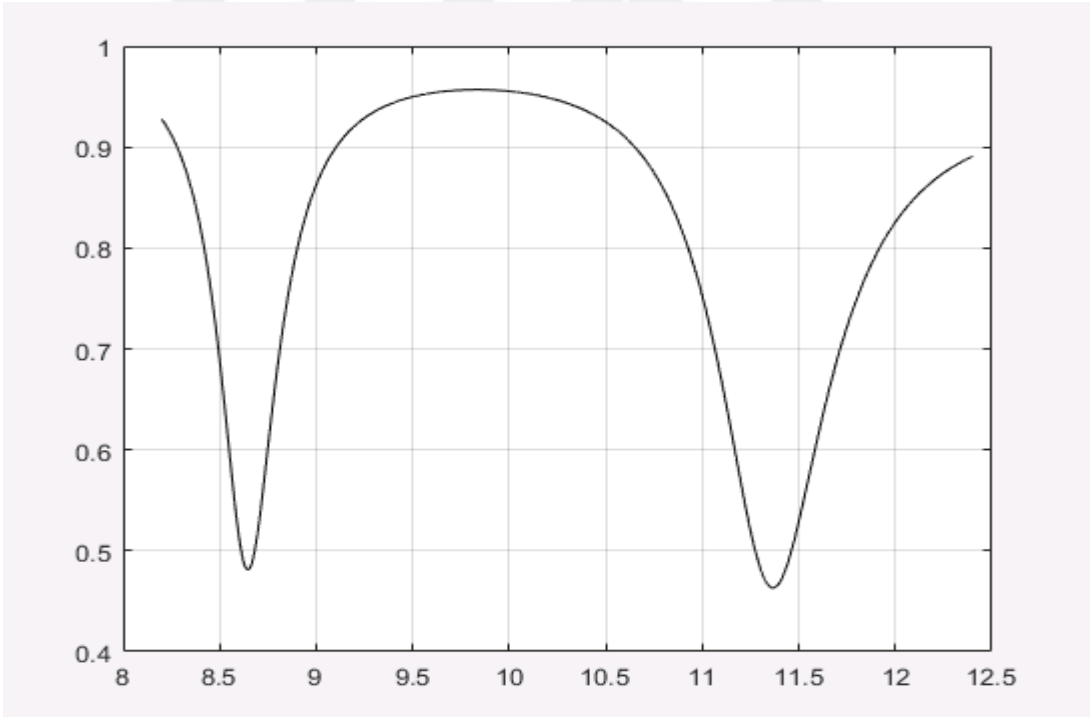

Figure 4. 1 Frequency variation of |S_11^s | and 0.1cos(A)+0.8 of a sample with a thickness of 25.5 mm and ε_r=11.55-i0.55

Figure 4. 2 We measured the size of the sample with a caliper and found 25.5 cm, then we made the necessary calculations by replacing L with this value.

As shown in Figure 4.1 , $|S_{11}{}^{s}|$ value is the minimum value when the cos(A) value is the minimum value ($\cos(A) = -1$). Therefore, as shown in equation (2.39), our analysis is verified. The dielectric constant ($Re\{\varepsilon_r\}$) of the material is directly

$$\cos(A) = -1 = [(2m+1)\pi], \tag{4.1}$$

$$A = 2k_0\chi L = (2m+1)\pi\,, \tag{4.2}$$

$$\chi^2 \cong Re\{\varepsilon_r\} - (f_c/f)^2, \tag{4.3}$$

$$\mathrm{Re}\{\varepsilon_r\} = \left[\frac{(2m+1)\pi}{2k_0 L}\right]^2 + (f_c/f)^2, \tag{4.4}$$

As shown in Figure 4.1 , $|S_{11}{}^{s}|$ value is the minimum value when the cos(A) value is the maximum value ($\cos(A) = 1$). Therefore, as shown in equation (2.39), our analysis is verified. The dielectric constant ($Re\{\varepsilon_r\}$) of the material is directly

$$\cos(A) = 1 = [(2m\pi)], \tag{4.5}$$

$$A = 2k_0\chi L = (2m\pi)\,, \tag{4.6}$$

$$\chi^2 \cong Re\{\varepsilon_r\} - (f_c/f)^2, \tag{4.7}$$

$$\mathrm{Re}\{\varepsilon_r\} = \left[\frac{(2m\pi)}{2k_0 L}\right]^2 + (f_c/f)^2, \tag{4.8}$$

obtainable like this. Here m is the index value.

We also obtained two minimum frequency values and two maximum frequency values shown in Figure 4.1. Maximum frequency value is 9.6 shown in Figure 4.3, minimum frequency values is 8.67 and 11.36 shown in Figure 4.4.

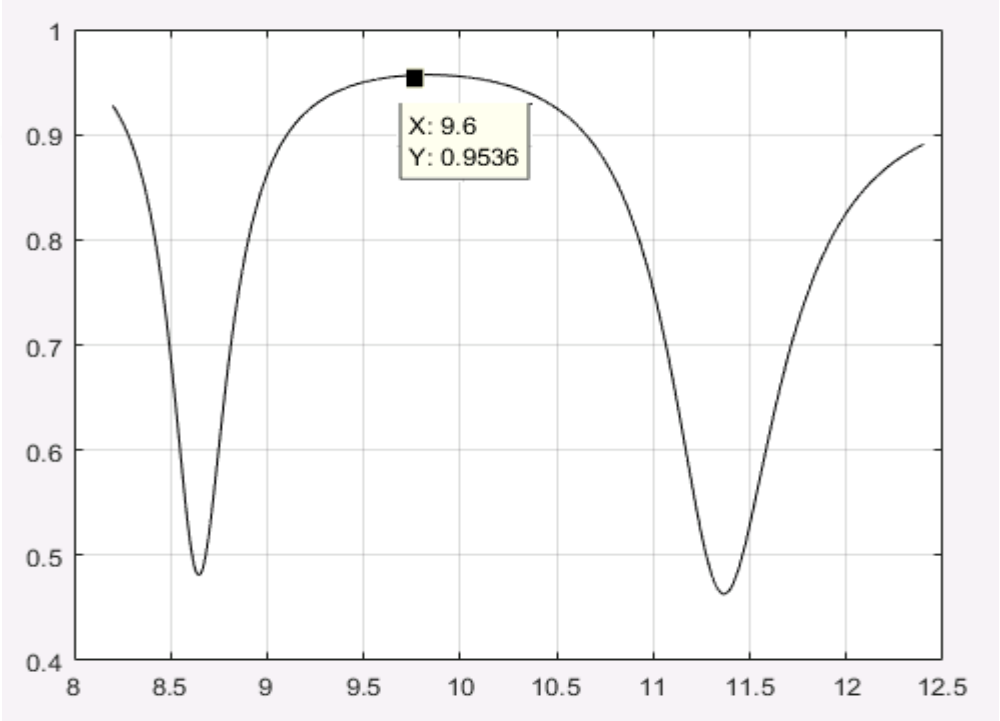

Figure 4. 3 Max frequency value which obtained from Matlab

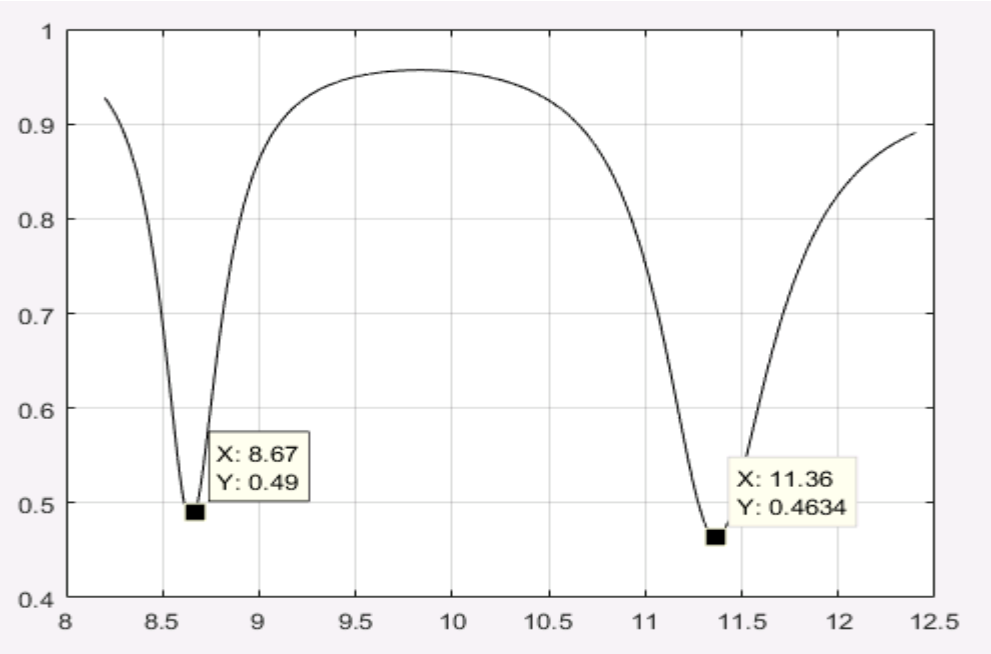

Figure 4. 4 Min frequency values which obtained from Matlab

Using the equations we obtained in theoric section, we calculated the ε value for the max and min frequency values that we found for m values between 0 and 10 in Matlab, but we don't use some values which smaller than 1. We can examine these values from Table 4.1.

Table 4. 1 Values of ε depend on m

	F_max = 9.6	F_min_1= 8.67	F_min_2= 11.36
m =1		1.74539896553866	1.02440574250631
m =2	2.17424795029704	3.8338156364097	2.25013468621859
m =3	4.30878955680231	6.96644064271626	4.088728101787
m =4	7.29714780590968	11.1432739844583	6.54018598921156
m =5	11.1393226976192	16.3643156616359	9.60450834849225
m =6	15.8353142319308	22.6295656742491	13.2816951796291
m =7	21.3851224088444	29.9390240222977	17.571746482622
m =8	27.7887472283603	38.2926907057819	22.4746622574712
m =9	35.04618869047	47.6905657247015	27.9904425041764
m =10	43.15744679519	58.1326490790567	34.1190872227378

So, we see that minimum frequency of value 8.67 and maximum frequency of value 9.6 give us nearly same result which we want. If we crosscheck this two values to match them, we obtain the solution like below table (Table 4.2)

Table 4. 2 Crosscheck of result of max / min frequencies which dependent with m.

m=2	0,42884898475
m=3	0,47497392039
m=4	0,33070716319
m=5	0,00395128683
m=6	0,52900142970
m=7	1,24444326540
m=8	2,15027679393
m=9	3,24650201530
m=10	4,53311892950

As you can see from the table, we can reach the desired result for m = 5 by using max frequency of 9.6 GHz, and min frequency of 8.67 GHz which maximum the $|{S_{11}}^{s}|$ value, the $Re\{\varepsilon_r\}$ value calculated for m = 5 from the equation 4.8 is 11.14, very close to its real value (11.1).

CHAPTER 5
CONCLUSIONS AND FUTURE STUDIES

5.1 Conclusion

To determine the electrical properties of low-loss materials supported by a conductor, we have chosen a method that uses only amplitude, because sometimes only one side of the material can be accessed and the resolution of reflection measurements for low loss samples needs to be increased.

In the method, instead of looking at any frequency, only the maximum minimum frequencies of the amplitude-reflection scattering parameter measurements were examined. We examined the effects of the amplitude of the reflection coefficients, the max and min frequency values, and the uncertainties of sample thickness on the measured relative complex permeability of the sample. To confirm the proposed method, measurements of complex and amplitude-base scatter parameters of a silicon sample of 25.5 mm in length are made. Then, the examination of these datas is done on matlab with the help of codes.

The use of max-min frequencies instead of looking at any frequency, although the analysis slightly prolonged, gives us a lots of convenience and makes it easier to apply to daily life. However, we should not forget that we need to use wideband for max min frequency values. However, it is advantageous because it does not require calculation.

5.2 Future Studies

In the RCM (reflection coefficient method) we proposed in this thesis, we preferred silicon which has a high dielectric constant. Because the use of materials with a high dielectric constant ensures that our method does not yield more efficient results. In our next study, we will discuss how I can improve our method for materials with low dielectric constant.

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