DESIGN AND FABRICATION OF A NOVEL WIDEBAND TEM - CELL FOR DIELECTRIC MEASUREMENTS

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ABSTRACT

Dielectric properties measurement at microwave frequencies is required to illustrate how the electromagnetic waves propagate through the materials. Various methods have been used for the measurement of dielectric properties including both time and frequency domain methods. The existing systems are mainly based on coaxial probes, free space, and reflection/transmission method by using waveguide or coaxial cell and resonance techniques. Waveguide has the advantages of high power handling capability and low loss but it requires the sample to be machined out as fit as the cross section of the waveguide. Practically waveguides are not appropriate for lower frequencies due to the large size. Coaxial line technique has enough bandwidth but not easy to perform dielectric measurement for heavy and porous materials as concrete. It does not provide a uniform electromagnetic (EM) wave and the specimen needs to be in the shape of toroidal which is hard to achieve. In free space method a perfect normal plane wave is hard to achieve and as well as the diffraction effect of the sample edges cannot be avoided. In this project a novel wideband TEM cell in the frequency range from 50 MHz to 800 MHz based on parallel plate waveguide is presented suitable for transmission/reflection method. A specimen of dielectric material is put between the two parallel plates. The scattering parameters (S-parameters) of the two port line are measured using vector network analyzer. The Complex permittivity and permeability can be determined from the measured S-parameters using Nicolson-Ross-Weir (NRW) method. In order to validate the functionality of the parallel plate cell, the dielectric properties of Teflon is determined and shown. A good agreement among the experimental result, simulation result and the published values of the Teflon material is achieved. In addition to that the dielectric properties of concrete, wet and dry wood are investigated as well. Based on this agreement an original result of the dielectric properties of the concrete material is obtained and shown.

Abstrak

Pengukuran sifat dielektrik pada frekuensi gelombang mikro amat diperlukan untuk menggambarkan bagaimana gelombang elektromagnet merambat melalui bahan-bahan.Pelbagai kaedah telah digunakan untuk mengukur sifat-sifat dielektrik iaitu kaedah domain masa dan kaedah domain frekuensi. Sistem yang sedia ada sekarang adalah berdasarkan kabel sepaksi, ruang bebas, dan kaedah pantulan/penghantaran yang menggunakan pembimbing gelombang atau sel sepaksi dan teknik resonan. Pembimbing gelombang mempunyai kelebihan dengan keupayaan mengendalikan kuasa yang tinggi dan kadar kehilangan kuasa yang rendah tetapi ia memerlukan sampel yang memenuhi keratan rentas pembimbing gelombang tersebut. Secara praktikalnya, pembimbing gelombang tidak sesuai untuk pengukuran sampel berfrekuensi rendah disebabkan oleh saiznya yang besar. Teknik kabel sepaksi mempunyai jalur lebar besar tetapi susah dilaksanakan untuk mengukur dielektrik bahan berat dan poros seperti konkrit. Teknik ini juga tidak dapat menghasilkan gelombang elektromagnet yang seragam dan sampel itu perlu berada dalam bentuk toroidal yang sukar untuk dibentuk. Dalam kaedah ruang bebas, gelombang satah normal yang sempurna adalah sukar untuk dicapai dan serta kesan pembelauan dari bucu sampel tidak dapat dielakkan. Dalam projek ini, sel TEM jalur lebar yang asli dihasil berpandukan pembimbing gelombang berplat selari dalam julat frekuensi 50 MHz hingga 800 MHz dibentangkan dan bersesuaian dengan kaedah penghantaran/pantulan. Spesimen bahan dielektrik diletakkan di antara dua plat selari. Parameter berselerak diantara dua kabel penamat diukur menggunakan penganalisis rangkaian vektor. Kebertelusan dan kebolehtelapan kompleks sampel boleh ditentukan daripada parameter berselerak yang diukur dengan mengantikan nilainya ke dalam formula Nicolson-Ross-Weir (NRW). Dalam usaha untuk mengesahkan keberkesanan sel plat selari tersebut, sifat-sifat dielektrik Teflon ditentukan untuk dibandingkan dengan nilai teorinya. Keputusan yang seragam dapat dihasilkan dari uji kaji, simulasi dan nilai-nilai yang berkaitan dengan Teflon yang pernah diterbitkan. Di samping itu, sifat dielektrik konkrit, kayu basah dan kayu kering juga disiasat. Berdasarkan keputusan ini, sifat dielektrik konkrit yang asli telah diperoleh dan disahkan.

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CHAPTER I

INTRODUCTION

1.1. Project Background

DIELECTRIC measurement for the Radio-Frequencies (RF) is related to investigation and reduction of the Electromagnetic-pollution and the radiation of modern communication systems. Shielding materials and its related electrical properties could be the subject of this study. Shielding materials are widely used to build the EMC-Chamber and protected areas against the unknown and unwanted EM-waves. As for the human-body equivalent liquid, it is a very important item for all research on the absorbed EM-waves in human tissue which may be harmful for the mankind.

Classic measurement set-up is usually based on rectangular TE_{10}-mode waveguides which becomes very large, expensive and non-practice for the lower frequencies in the MHz range. A TEM parallel-plate cell can operate from very low-frequencies and for a wideband frequency-range with reduced-size and low-cost fabrication process. Here we use a new technique to provide a wideband coaxial-to-waveguide connector and then to match the parallel-plate cell to the measuring devices for a wide frequency range. The dimensions of the optimal cell should be coherent with the real measurement needs (enough space to handle and set the under-measurement dielectric inside the cell) and in the other hand to keep a matched impedance for the cell and also to reduce the radiation-loss (Kazemipour, 2010).

The existing systems relied on waveguide and coaxial lines. Waveguide has the advantages of high power handling capability and low loss.

Coaxial line is enough wide-band but is not easy to perform dielectric measurement for heavy materials as concrete.

A large parallel plate line can produce uniform and calculable EM-fields between its two conductor plates (Kazemipour, 2010). The closed conductor (rectangular waveguide) can’t support TEM mode but parallel palte waveguide can support TEM mode, since it is formed from two parallel plates and no reflection from the walls (Pozar,1998).

1.2. Problem Statement

Recently the importance of the complex dielectric properties measurement of materials at radio frequency has rapidly increased especially in the research fields, such as material science, microwave circuit design, absorber development, biological research, etc. (Rohde& Schwarz, 2006). The importance of this measurement is attributed to the ability of providing the electrical or magnetic characteristics of the materials, which proved useful in multidisciplinary research.

Accurate measurement and effective shielding is built to protect areas against the unknown and unwanted EM-waves (Schrader et.al, 2010). The permittivity is important factor of the materials that can be used in the shielding effectiveness assessment, antenna substrate and the dielectric (insulator) used in capacitors. Permittivity determination depends on the scattering parameters (S-parameters) measurement of the material under test. The scattering parameters of the material under test require appropriate measurement setup to be measured.

Classic measurement set-up is usually based on rectangular TE-mode waveguides which become very large, expensive and non-practice for the lower frequencies in the MHz range. The identification of electric and magnetic properties of the material can be achieved using various techniques such as: coaxial probe, transmission line, free space and resonant cavity, regarding the targeted frequency range. Free space method suffering from the diffraction effects at the edges of the sample and the measuring antennas. Cavity and waveguide methods involve the sample to be machined as fit as the cross section of the waveguide with negligible air gaps and are not practice for the lower frequencies because of their required large-size. In the coaxial technique, the coaxial line does not provide a uniform electromagnetic (EM) field and the specimen needs to be in the shape of toroidal which is hard to be prepared especially for porous material like concrete and cement and a well-machined cell is generally very expensive.

Wideband parallel-plate TEM waveguide can overcome most of these problems. It is a wideband open Tr-line with its well-matched coaxial-to-waveguide connector. This structure can produce uniform TEM field between its two conductor plates and enough far from the open-sides. This TEM parallel-plate cell can operate from very low-frequencies and for a wideband frequency-range with reduced-size and low-cost fabrication process.

Here we use a new technique to provide a wideband coaxial-to-waveguide connector and then to match the parallel-plate cell to the measuring devices for a wide frequency range. The dimensions of the optimal cell should be coherent with the real measurement needs (enough space to handle and set the under-measurement dielectric inside the cell) and in the other hand to keep a matched impedance for the cell and also to reduce the radiation-loss (Kazemipour, 2010).

1.3. Project Objectives

The major objective of this project is to measure the dielectric constant of the material under test. This measurement is directly related to the human safety of electromagnetic pollution. To assess the shielding effectiveness of the buildings, the electrical properties of the shielding material as concrete have to be known.

Permittivity is very important value that can describe the transmitted and reflected waves from concrete. This measurement set-up can be used to find S-parameters of the material under test then convert these S-parameters to permittivity value. The measurable objectives are as follow:

- To design and fabricate novel wideband TEM-cell operating from 50 MHz up to 800MHz and must ensure field uniformity with 50 ohm impedance
- To investigate the ability of parallel plate to provide a uniform TEM mode and its feasibility to be used as standard dielectric measurement set-up.
- To determine the dielectric properties of the solid material as concrete from 50 MHz up to 800MHz based on the measured S-parameters of the material.

1.4. Project Scopes

The scope of this project can be clarified as follow:

- **TEM-Cell instead of a classic TE-waveguide**

  Classic waveguide facilities are limited in frequency range because of the nature of dominant TM and TE propagation modes. A TEM transmission line is, in theory, frequency independent and can be used as a wideband cell.
- **Wide frequency range from 50 MHz to 800MHz**

  Measurements of the dielectric constant in Microwave frequencies for some material in TEM mode are carried out on specific design. This project is primarily concerned with the design of TEM cell based parallel plate waveguide. In this research CST MICROWAVE STUDIO® is used to simulate the designed TEM cell.
- **Low-cost fabrication and compact size**

  Simple design with large size is easier to fabricate than low cost.
- **Project limitation**

  This project is limited in frequency range between 50MHz to 800 MHz for TEM mode. The practical cell is fabricated from aluminium material. In this project the measurement is based on S-parameters. S-parameters are then converted to the dielectric constant using one of the conversion techniques.

CHAPTER II

THEORY AND LITERATURE REVIEW

2.1. Technology Developments

Electromagnetic pollution tend to increase in recent years especially in cities and work places where the level of RF power in the ambient is high due to the massive use of electronic devices, broadcasting devices that used for mobile applications and other electrical equipment. Most of these electronic devices operate in concrete based constructed buildings. The materials which are used in the construction have different electrical properties.

2.1.1. Introduction

Concrete is one of the construction materials that are used in the building as walls. These walls can be considered as shield from the Radio Frequency (RF). The effectiveness of the concrete walls to prevent the RF waves from penetration into the walls is called shielding effectiveness.

Shielding effectiveness of the concrete depends on the concrete permittivity measurement. Permittivity measurements and their relation with some materials parameters are becoming more and more important for many applications during the recent years such as agriculture, food engineering, medical treatments, bioengineering, and the concrete industry (Hasar, 2010).

Dielectric measurements have been performed at National Physical laboratory (NPL) over much of the twentieth century but work in the microwave region of the spectrum only commenced in earliest in the late 1960s. Instruments developed under that programme are varied as TE_{10}-mode cavities and open resonators (Clarke, 2002).

In radio frequency (RF) and microwave (MW) design it is important to understand how the electric and magnetic fields propagate into, through materials (Collier & Skinner, 2007). To accomplish this understanding, it requires the identification of dielectric and magnetic properties of the material by using various techniques as: coaxial probe, transmission line, free space and resonant cavity, regarding the targeted frequency range (Clarke et. al, 2003).

Various methods have been used for the measurement of dielectric properties including both time and frequency domain methods. Economically a frequency domain method is selected due to automatic measurement systems (Weng et.al, 1991).

These techniques can roughly be divided into two groups; resonant methods and non-resonant methods. Resonant methods have much better accuracy and sensitivity than non-resonant methods at discrete frequencies. They are applied for characterization of low-loss materials, as well as high-loss materials. On the other hand, non-resonant methods have relatively higher accuracy over a broad frequency band and necessitate less sample preparation compared to resonant methods. They allow the frequency- or time-domain analysis, or both. Owing to their relative simplicity, broad frequency coverage, and higher accuracy, transmission–reflection method (a kind of non-resonant method) are widely utilized for characterization of materials (Hasar, 2010).

The existing systems are mainly based on waveguides coaxial probes, free space, reflection –transmission method and resonance techniques (Schrader et.al, 2010). Waveguide has the advantages of high power handling capability and low loss but it require the sample to be machined out as fit as the cross section of the waveguide. Practically waveguides are not appropriate for lower frequencies due to the large size.

Open-ended coaxial sensors are very widely used because of their relative convenience and their ability to measure complex permittivity non-invasively. The dielectric under Test (DUT) is placed up against an open-ended coaxial line and its permittivity is computed from the reflection coefficient measured at the end of the line. Unfortunately, measurements by these means on thin, low loss or rigid specimens can suffer from large uncertainties, particularly if inadequate models are used to describe the electromagnetic fields which fringe into the material.

Coaxial line technique is enough wideband but is not easy to perform dielectric measurement for heavy and porous materials as concrete. It does not provide a uniform electromagnetic (EM) as well as the specimen needs to be in the shape of toroidal which is hard to achieve for rigid material as concrete and cement. In the resonant techniques the amount of frequency shift in the resonant mode of the cavity determines the dielectric properties of the specimen. The disadvantage of this method is that the measurements cannot be carried out over a range of frequencies without changing of the cavity dimensions. In free space method a perfect normal plane wave is hard to achieve and as well as the diffraction effect of the sample edges cannot be avoided.

2.1.2. Resonance methods

Resonators and cavities are one of the measurement cells that can be used effectively for very low loss materials measurement. The accuracy of measurement for real part of the permittivity is high. Resonant methods can be divided into two categories. The first category includes different kinds of resonant cavities (including re-entrant cavities, cylindrical and rectangular cavities), open resonators and resonators loaded with a dielectric (e.g., split post dielectric resonators) as shown in figure 2.1(a). For the second category the sample under test, itself, can create a dielectric resonator. Cavities and open resonators operate at a single, dominant or higher order well-established modes have been used for measurement of dielectric materials for more than 60 years.

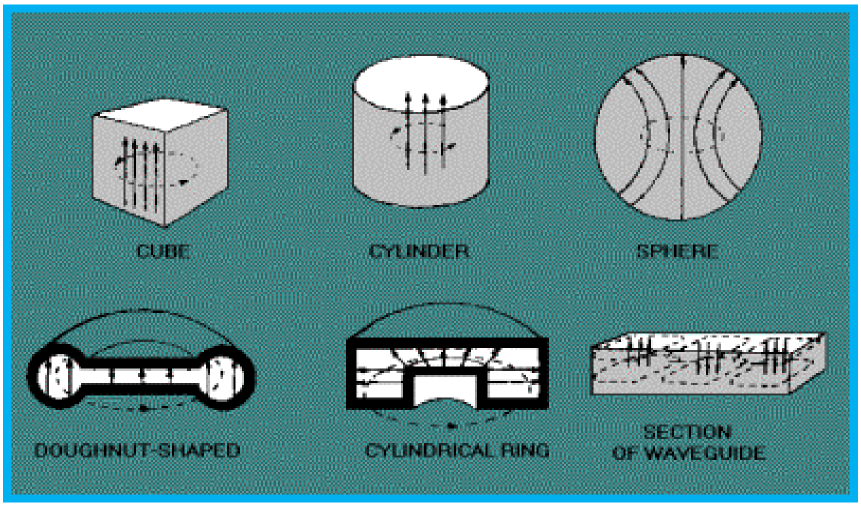

Figure 2.1(a): Several types of cavities.

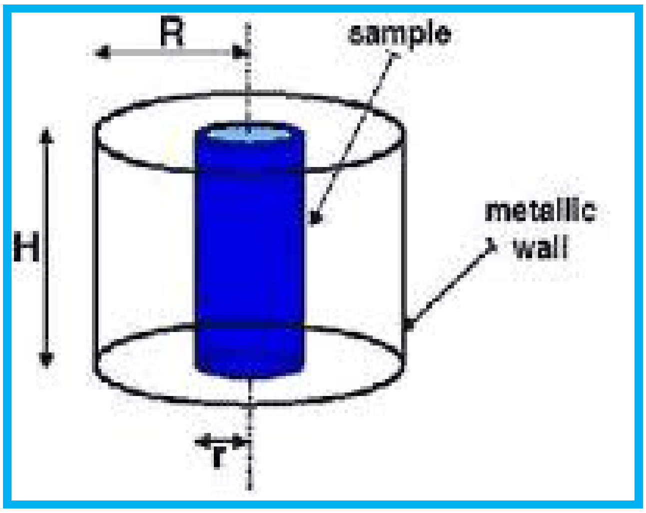

Figure 2.1(b): Cylindrical cavity resonator.

In the second category, figure 2.1(b) shows a cylindrical dielectric sample under test, enclosed in a metal shield or situated in an open space, constitutes a dielectric resonator, where the resonance frequencies predominantly depend on permittivity and dimensions of the sample. Progress in measurements of dielectrics employing resonant techniques during the last decades has been associated with two factors: the development of new low-loss dielectric materials and the advances in rigorous techniques of electromagnetic field computations (Ghodgaonkar et.al, 1989).

2.1.3. TE_{01} mode dielectric resonators

Initially, the dielectric resonator technique for measurements of permittivity and losses of low-loss dielectrics was introduced by Hakki – Coleman in 1960 employing the TE_{011} mode of operation in a rod resonator terminated from both sides by conducting planes. Since its discovery, it has become one of the most accurate and the most frequently used techniques for measurements of permittivity and dielectric losses of solid materials. It is also known under different names as the Courtney or parallel plate holder and it is also proposed as one of International Standards IEC techniques for measurements of the complex permittivity of low-loss solids. A very simple measurement configuration and easy access for putting and removing specimens are advantages of this cell.

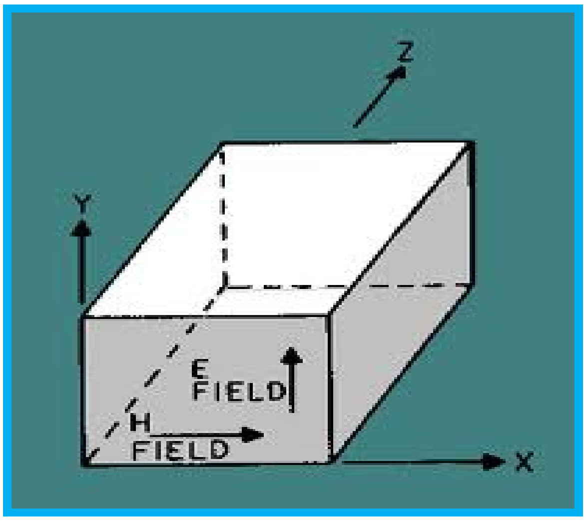

Figure 2.2: Rectangular cavity resonator.

Figure 2.2 show that classic measurement set-up is usually based on rectangular TE_{10}-mode waveguides which becomes very large, expensive and non-practice for the lower frequencies in the MHz range. A TEM parallel-plate cell can operate from very low-frequencies and for a wideband frequency-range with reduced-size and low-cost fabrication process.

In this research a new novel design of Parallel Plate Waveguide (PPW) is provided. This design can be used from 10 MHz frequency up to 1GHz.

2.2. Parallel Plate Waveguide (PPW) Design

2.2.1. Introduction

It's difficult to get uniform TEM field due to different propagation modes. Classical waveguides cannot support TEM fields. A parallel-plate waveguide can be used as TEM cell wideband frequency range. To increase the efficiency of the PPW to operate up to 1GHz, the radiation losses and higher propagation modes should be controlled. The feeding section should be matched to get minimum return loss. A novel design is pioneered to obtain good matching. A parallel plate waveguide based on conical feeding section is designed as new wideband cell that can provide uniform e-field (Kazemipour, 2010). In this project a simple propsed prototype can be used up to 1GHz without tapering the ends of the two plates. This cell has good ability to measure the electrical properties of the material from 10 MHz range up to 1GHz.

2.2.2. Analysis of parallel plate waveguide

The parallel plate waveguide can provide uniform TEM fields but the other classical waveguides cannot be used as TEM cell due to other propagation modes TM and TE. In the geometry of the parallel plate waveguide that figure 3 shows it, the strip width (***W***) is assumed to be much greater than separation (***d***), so that fringing fields and any x-axis variation can be ignored. A material with permittivity (ε) and permeability (μ) is assumed to fill the region between the two plates (Pozar, 1998).

- **TEM modes analysis**

The TEM mode solution can be obtained by solving Laplace's equation for the electrostatic potential 1between the two plates

Thus

$$\nabla_t^2 \varphi(x, y) = 0 \tag{2.1}$$

For $0 \leq x \leq w,\ 0 \leq y \leq d$

If we assume that the bottom plate is at ground (Zero) potential and the top plate at a potential of V_0 (Fig. 2.3) then the boundary conditions for $\varphi(x, y)$ are

$$\varphi(x, 0) = 0 \tag{2.2}$$

$$\varphi(x, d) = V_o \tag{2.3}$$

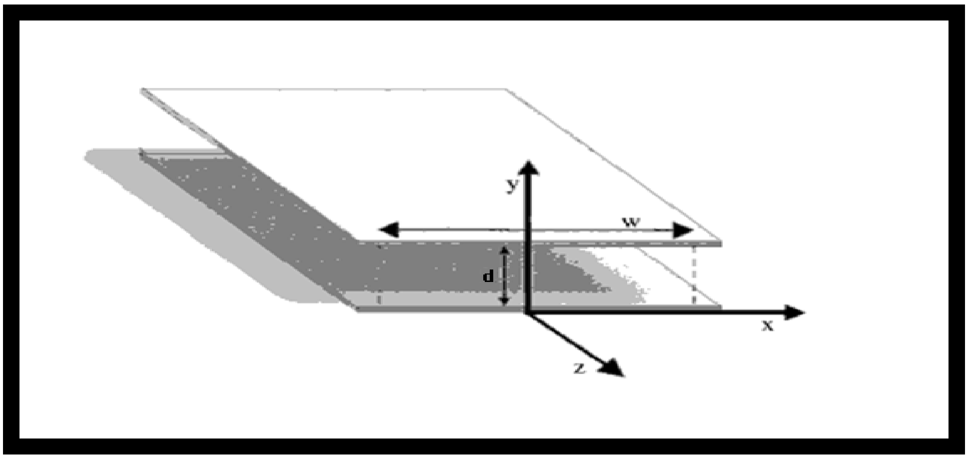

Figure 2.3: Parallel plate waveguide

Since there is no variation in x, the general solution for $\varphi(x, y)$ is

$$\varphi(x, y) = A + By \tag{2.4}$$

And the constants ***A, B*** can be evaluated from the boundary conditions to give final solution as

$$\varphi(x,y)=\frac{V_0 y}{d} \tag{2.5}$$

The transverse electric field is

$$\bar{e}(x,y)=-\nabla_t \Phi(x,y)=-\hat{y}\frac{V_0}{d} \tag{2.6}$$

So

$$\bar{E}(x,y,z)=\bar{e}(x,y)e^{-jkz}=-\hat{y}\frac{V_0}{d}e^{-jkz} \tag{2.7}$$

Where $k=\omega\sqrt{\mu\varepsilon}$ is the propagation constants of the TEM wave.

The magnetic field is

$$\bar{H}(x,y,z)=\frac{1}{\eta}\hat{z}\times\bar{E}(x,y,z)=\hat{x}\frac{V_0}{\eta d}e^{-jkz} \tag{2.8}$$

Where $\eta=\sqrt{\mu/\varepsilon}$ is the intrinsic impedance of the medium between the parallel plates. The voltage of the top plate with respect to bottom plate can be calculated as follow

$$V=-\int_{y=0}^{d} E_y dy=V_0 e^{-jkz} \tag{2.9}$$

As expected the total current on the top plate can be found from amper's law or the surface current density

$$I=\int_{x=0}^{w} J_s \cdot \hat{z}dx=\int_{x=0}^{w}(-\hat{y}\times\bar{H})\cdot\bar{z}dx=\int_{x=0}^{w} H_x dx=\frac{\omega V_0}{\eta d}e^{-jkz}$$

(2.10)

Thus the characteristic impedance can be found as

$$Z_0=\frac{V}{I}=\frac{\eta d}{\omega} \tag{2.11}$$

Where η_{Air} is 120π ohm (Pozar, 1998).

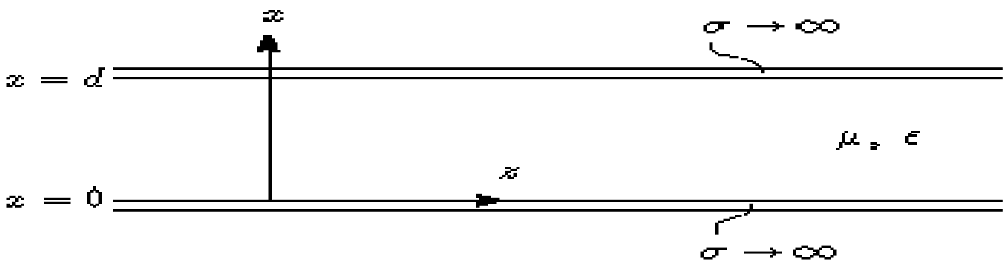

Figure 2.4: Side view of parallel plate waveguide

Figure 2.4 shows that to obtain an optimum design PPW a structural analysis of the simulator characteristics must include investigation of field distribution inside the simulator, effect of plate width, effect of plate separation, and the effect of the feed taper.

2.2.3. The Proposed model

Permittivity measurement based on free space method suffering from the diffraction effects at the edges of the sample and the measuring antennas. Cavity and waveguide methods require the sample to be machined as fit as the cross section of the waveguide with negligible air gaps and are not practice for the lower frequencies because of their required large-size (Rohde & Schwarz, 2006). In the coaxial technique, the coaxial line does not provide a uniform electromagnetic (EM) field (Kazemipour, 2010) and the specimen needs to be in the shape of toroidal which is hard to be prepared especially for porous material like concrete and cement and a well-machined cell is generally very expensive.

In this project PPW is designed to be large enough for immersing a MUT between the two plates. This model is operating from 50 MHz up to 800 MHz. The main challenge is to perform good matching and low loss for the above frequency rang. To solve this issue the feeding section should be designed adequately. This model is simulated by using CST MICROWAVE STUDIO® software. The feeding section position is evaluated in the bottom plate.

As mentioned previously, we need to measure the S-parameters of porous materials such as concrete. As a result, the two plates should be enough spacey to immerse the material under test between the two plates while the width of the cell is adjusted for characteristics impedance of 50 ohm in the sample region.

The restriction is that the higher propagation modes limit the highest operating frequency. RF Coaxial connectors are used to connect the TEM cell to vector network analyzer. The inner conductor of the RF connector is connected to the lower plate while the outer conductor is connected to the lower plate.

A conical shape is inserted between the upper plate and the inner conductor of the RF connector. The conical shape is tapered at 60^0 to improve the matching and to reduce the non- uniformity of the system.

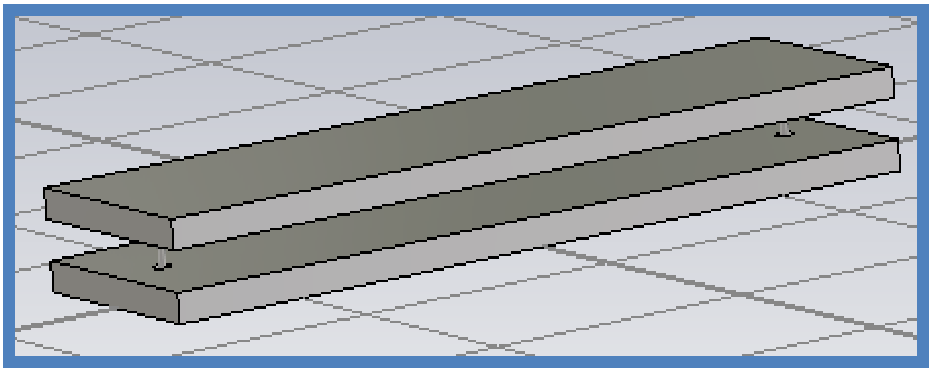

Figure 2.5: Non-tapered coaxial line type feeding section

Figure 2.5 below shows that the design of the feeding section is in the bottom plate in form of coaxial-line type. The coaxial-line type design also is not matched adequately.

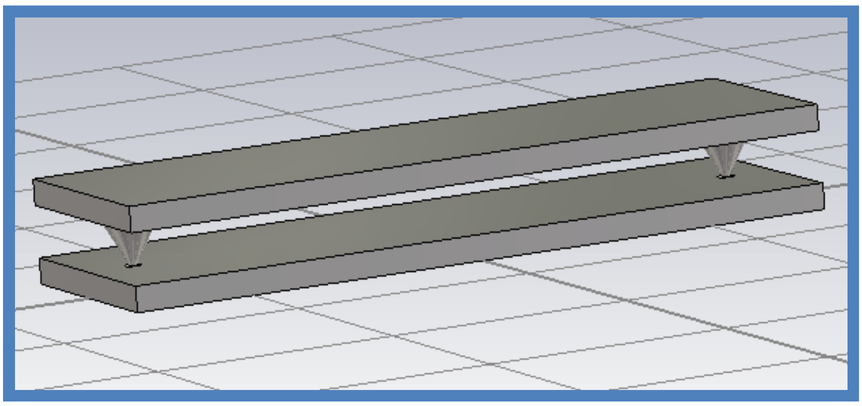

Figure 2.6(a): 3-D view of PPW with conical shape feeding section

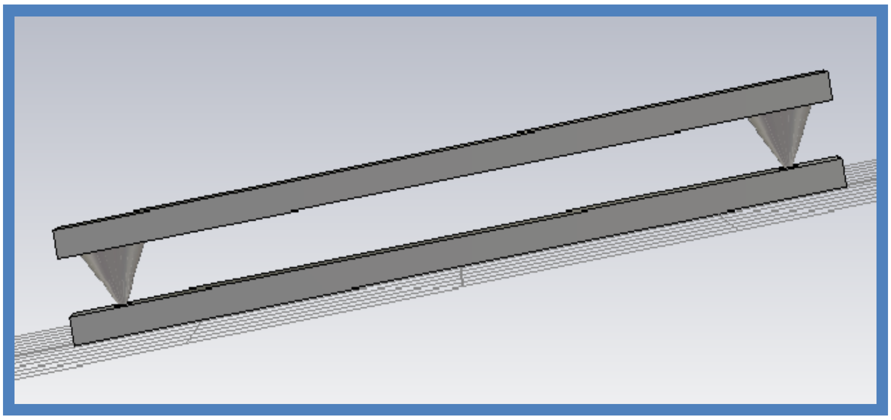

Figure 2.6(b): Side view of PPW with conical shape tapered feeding section

Figure 2.6 shows that the matching of this model is improved due to the tapering of the inner conductor of the coaxial line in form of conical shape. This novel design shows good matching behaviour from a few 50 MHz up to 800 MHz.

CHAPTER III

METHODOLOGY

3.1. Overview

Every material has a unique set of electrical characteristics that are dependent on its dielectric properties (Jerzy, 2006). Scientists and engineers can be provided by precise measurements of these properties with valuable information to appropriately integrate the material into its planned application.

Recently, the dielectric properties of materials have received increasingly attention such as complex permittivity. The dielectric properties of a material relate with other material characteristics. It can be used to find out properties such as moisture content, bulk density and chemical concentration.

Commonly, the incorporation of material in an application system requires the strict knowledge of its dielectric parameters (permittivity and permeability). In the literature, several techniques have been introduced on permittivity and permeability mining of materials.

TEM coaxial- lines type do not provide a uniform EM –field and therefore they can not be used as measurement cell.

A new dielectric measurement device has been designed and constructed for permittivity measurement of MUT. The permittivity is measured in the frequency range 50 MHz–800MHz. The cell has to be used as TEM cell and it should be in large size. In the other hand, the cell should be enough spacey to allow the immersing of material under test). A large parallel palte line can produce uniform and calculable EM-fields between its two conductor plates .

3.2. Research design

The electrical properties of the dielectric materials is such important to show the behavior of the incident electromagnetic waves on these materials. Dielectric constant is one of the facrors that indicate the refection and absorption of these materials. To maesure the dielectric constant of porous materials as concrete , a new measurement set-up has to be introduced.

Wideband parallel-plate TEM waveguide can overcome most of the problems that are faced in previuos designs . It is a wideband open Tr-line with its well-matched coaxial-to-waveguide connector (Kazemipour, 2010). This structure can produce uniform TEM field between its two conductor plates and enough far from the open-sides (Figure. 3.1).

Figure 3.1: The cross section of the TEM parallel plate cell without dielectric.

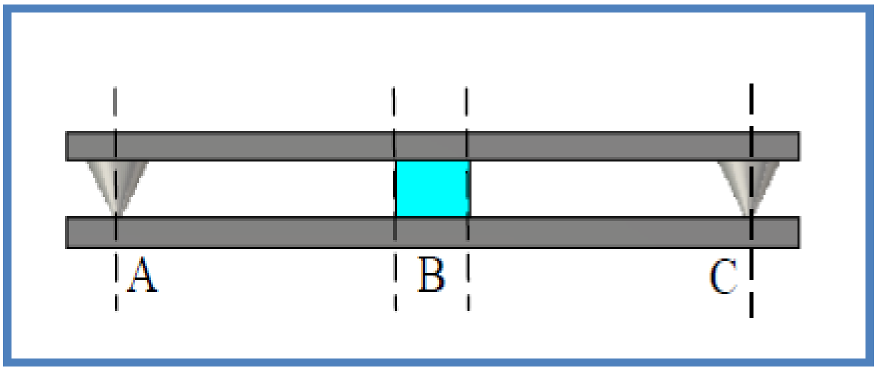

Figure 3.2: Cross section of the TEM parallel plate cell when the dielectric is inserted.

The dielectric material will be placed at the middle section of the cell during the measurement, as shown in Figure 3.2.

3.3. Research activities

This project has been conducted into four phases:

The first phase is to design the cell. The design depends on the geometry of the parallel plates. The width (***W***) and the separation (***d***) of the two parallel plates would be used to get the PPW's characteristic impedance which should be matched to the characteristic impedance of the coaxial –type connector input ports as shown on figure 3.3.

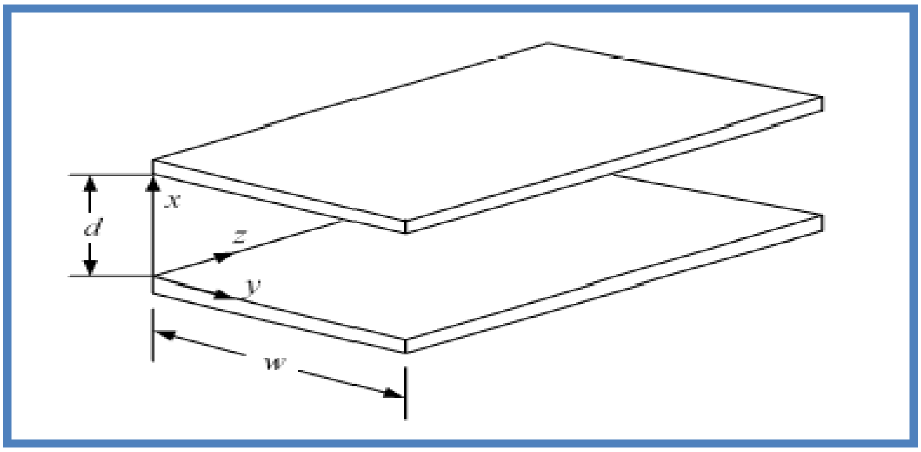

Figure 3.3: Parallel plate waveguide model

The design matching can be enhanced using wideband feeding section. The inner conductor of the feeding section should be tapered to obtain a conical shape. As shown below in figure 3.4. This conical shape should be fully connected to the top plate to obtain TEM mode.

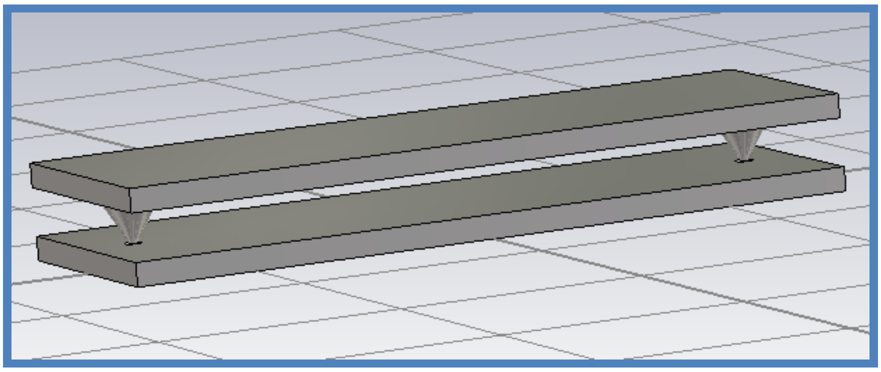

Figure 3.4: The proposed cell with conical shape feeding section

The second phase of this project is to simulate this novel design using CST MICROWAVE STUDIO®. The simulation has shown good results for the range from 50 MHz up to 800MHz.

The third phase is to fabricate the model which is simulated in the second phase. The material of fabrication is aluminum material which has high conductivity as shown in figure 3.5. This fabricated cell is calibrated using material with known permittivity (as Teflon) to show that the cell is good for measurement.

Figure 3.5: A picture of the fabricated TEM cell

The last phase of this project is to measure the S-parameters of the material under test then to calculate the complex permittivity of that material based on the measured S-parameters.

Figure 3.6: Proposed TEM cell measurement set-up

Figure 3.6 shows the designed TEM cell measurement set-up. As shown this cell is connected through coaxial cables to the vector network analyzer. The S-parameters are displayed on the screen of vector network analyzer in the picture above. The measured S-parameters are then post processed to determine the complex dielectric properties using a matlab program. There are various conversion techniques to calculate the dielectric parameters from the measured S-parameters.

The conversion technique that can be used in the conversion process is Nicholson-Ross-Weir (NRW). This technique provides direct calculation of the permittivity from the S-parameters. It's the most commonly used for performing such conversion. As a summary the research activity can be described with the following flow chart.

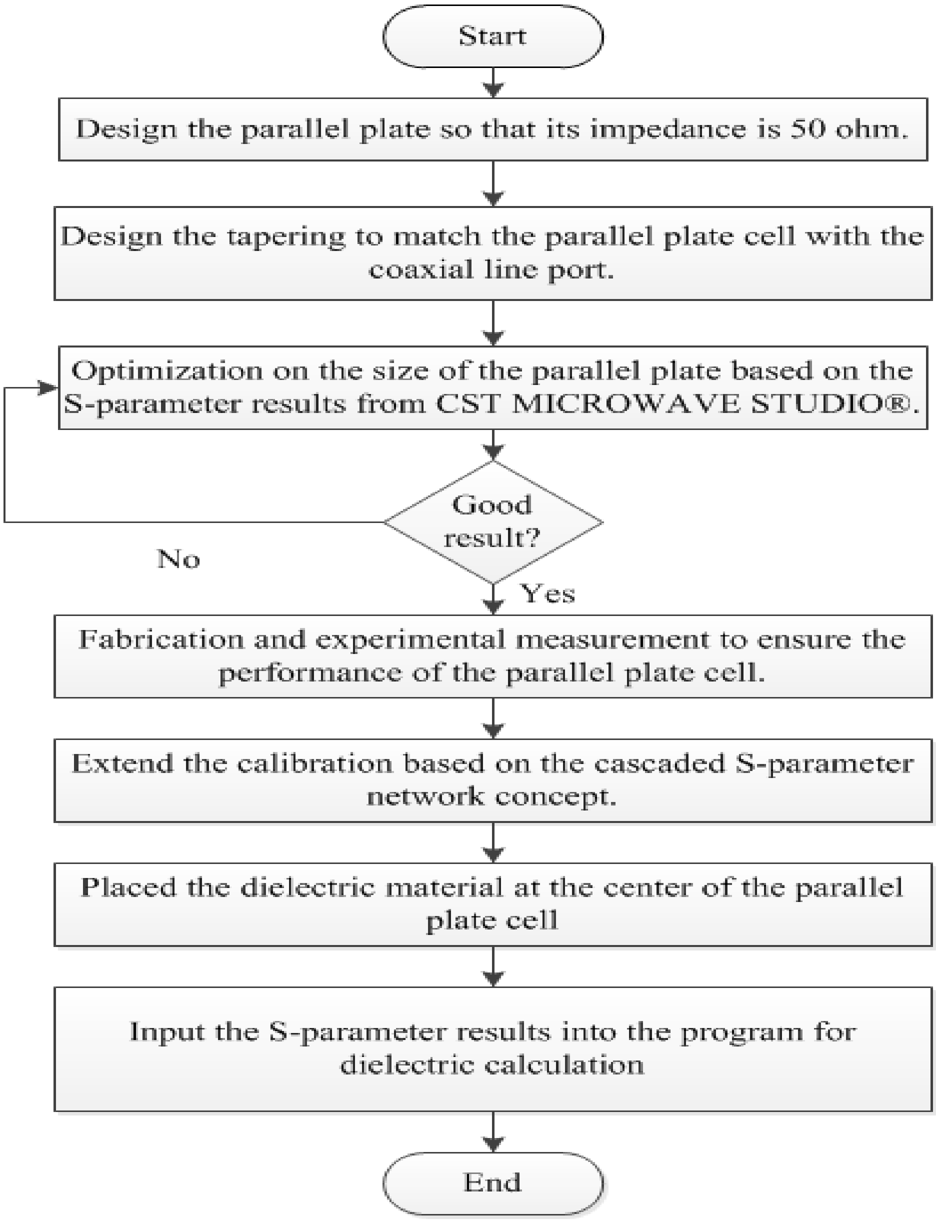

Figure 3.7: Flowchart for research activity

3.4. Analysis and Design

The electrical properties of the construction material as concrete are important as they affect many of the applications. The real part of the complex permittivity of the concrete has a basic function in assessing the capability of concrete to do as shield. The propagation of electromagnetic waves through the concrete can be used to assess the capability of concrete to hinder the incident EM waves. This has direct relevance to such applications as the protection of sensitive circuits that are housed in concrete or reinforced concrete structures. The real part of the complex permittivity and the effective conductivity of concrete are key design parameters that influence the object shielding effectiveness significantly.

- **Plane wave attenuation due to concrete wall**

The shielding effectiveness of a concrete material can be estimated analytically using the familiar transmission line approach provided that many simplifications are introduced. An actually simplified structure such as concrete walls has to be analysed due to the complexity and dimensions of real buildings.

Aperture effects due to openings such as doors, windows and ventilation holes are not considered. Furthermore, the impinging electromagnetic wave is a uniform plane wave normal to an infinite plane and the concrete wall is assumed isotropic and homogeneous. The shielding effectiveness can then be obtained as the sum of three contributions, i.e. absorption loss, reflection loss and an additional corrective term to take account of the multiple reflections inside the concrete wall (Paul, 2006) as follow

$$SE_{dB} = A_{dB} + R_{dB} + B_{dB} \tag{3.1}$$

Where A_{dB} is the absorption loss. R_{dB} & B_{dB} are the reflection loss and multiple reflection correction term, respectively

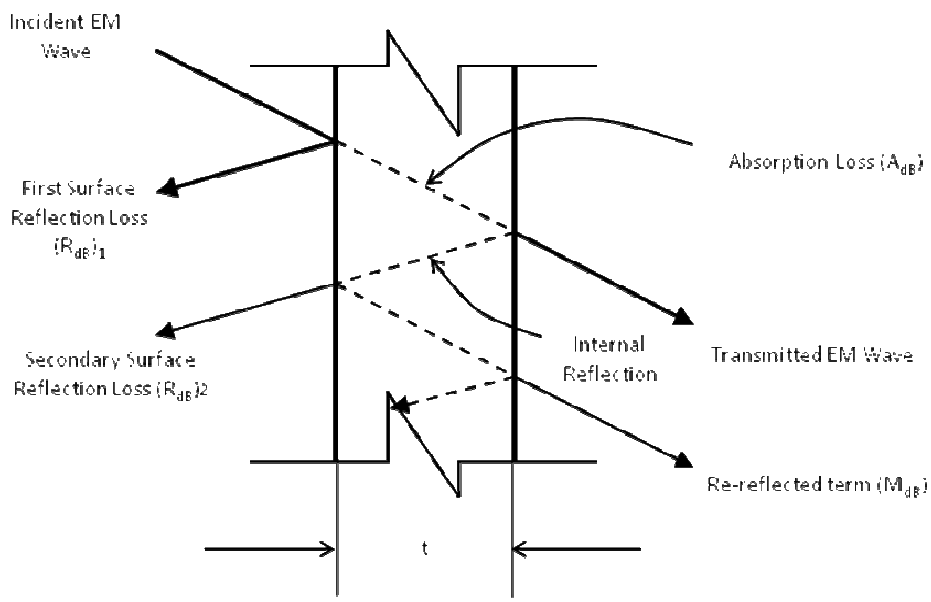

Figure 3.8: Illustration of multiple reflections within a shield.

Figure 3.8 show that ***(t)*** is the thickness of the concrete wall. The concrete considered to be anon-magnetic material, as no filler. As such, the magnetic permeability of concrete is deemed equal to that of free space.

- **Reflection loss**

Assuming that the barrier thickness is much greater than a skin depth at the frequency of the incident wave, the portion of the incident wave that is transmitted across the left interface in Fig. 3.8 is greatly attenuated by the time it reaches the right interface. Thus the reflected wave, when it arrives at the left interface, is not of much consequence and so contributes little to the total reflected wave.
The reflection loss term can be calculated based on the following equation

$$E_{t2} = \frac{4Z_w Z_s}{(Z_w + Z_s)^2} E_i \tag{3.2}$$

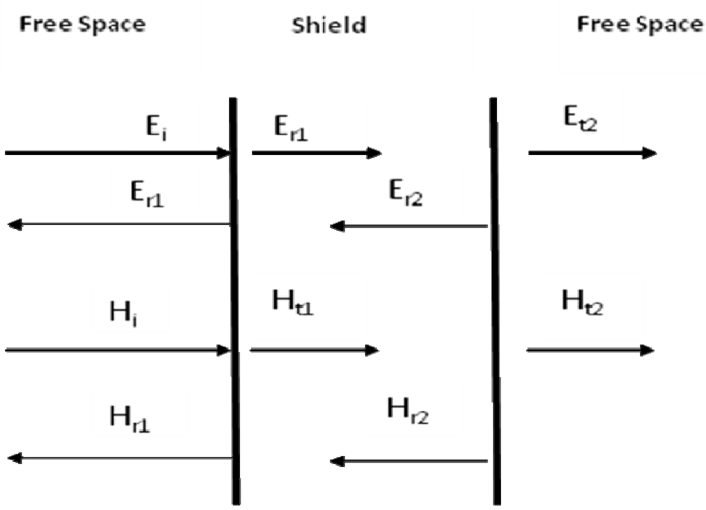

Figure 3.9: Illustration of incident and reflected waves from the shield.

Where

E_i : Incident electric field

E_{t2} : The transmitted electric field behind the shield

The reflection loss for either E or H field is

$$R = 20\log\frac{|E_i|}{|E_{t2}|} = 20\log\frac{|H_i|}{|H_{t2}|} = 20\log\frac{|(Z_w + Z_s)^2|}{|4Z_w Z_s|} \tag{3.3}$$

Where:

H_i : Incident magnetic field

H_{t2} : The transmitted magnetic field behind the shield

R : The reflection loss

Z_w : Intrinsic impedance of the incident wave

Z_s : The characteristic impedance of the shielding Material

Practically far-field source $|Z_w|$=**377 ohm** is considered

But the property of any materials to which EM wave travels is best described by its characteristic impedance

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