UNIVERSITI PUTRA MALAYSIA

# *OPEN-ENDED COAXIAL TECHNIQUE FOR DETECTION OFMASSES AND MICROCALCIFICATIONS IN BREAST PHANTOMS*

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# OPEN-ENDED COAXIAL TECHNIQUE FOR DETECTION OF MASSES AND MICROCALCIFICATIONS IN BREAST PHANTOMS



**By**

**TITY NAZLEEN MOHAMED**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in fulfilment of the Requirements for the Degree of Master of Science**

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**OPEN-ENDED COAXIAL TECHNIQUE FOR DETECTION OF MASSES AND MICROCALCIFICATIONS IN BREAST PHANTOMS**

By

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**May 2017**

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This project examined the viability of detecting masses and microcalcifications in breast phantoms using open ended coaxial technique (OEC) in the frequency range between 1 GHz and 4 GHz. The accuracy and flexibility of the OEC were tested on tomatoes and potatoes samples due to their symmetrical and non-symmetrical shapes, respectively. Both circular OEC and square OEC were used in this work. Calibration equations to predict moisture content from the measured reflection coefficient have been established. The OEC was found to be accurate within 4% in the determination of moisture content in both crops. The calculation of the reflection coefficient of tomatoes were accomplished using finite element method (FEM). Good agreement between FEM and measurement results were found for samples with 91.56% *m.c* at the frequency 2.5 GHz. Four phantoms were used in this work to demonstrate the feasibility of using OEC to detect masses and microcalcifications.

One of the phantom was made by diluting Triton X100 with water. The other two were commercial phantoms CIRS models 052A and Model 010A designed for ultrasound and X-Ray mammography measurements. The OEC was found to have the ability to differentiate between dense and cystic masses in CIRS 052A when compared to ultrasound results. Dense masses have $\varepsilon'$ higher than 9.28 whilst the $|S_{11}|$ greater than 0.54. The OEC was also found to be able to distinguish specifics specks of breast phantom CIRS Model 010A based on the values of permittivity. This can be evinced by the X-ray attenuation data proportionate increased with $\varepsilon'$ , $\varepsilon''$ and $|S_{11}|$ for the three different glandular-adipose compositions. Increasing $CaCo_3$ grain size only for the linearly distributed specks would increase the values of both the $\varepsilon'$ and $\varepsilon''$. The $\varepsilon'$ and $\varepsilon''$ of the epoxy cast matrix were 2.0 and 0.001 whilst the respective values for pure $CaCO_3$ were 2.4 and 0.02

The Triton X-100 phantom allows OEC prediction of $\varepsilon'$ and $\varepsilon''$ based on the amount of *m.c* which in turn can be used to identify the type of tissue which can be categorized either low, medium or high risk tissues. It is possible to detect the cancerous tissue based on the dielectric properties or *m.c* as the dielectric properties of normal and cancerous tissue are not similar.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

**TEKNIK HUJUNG TERBUKA SEPAKSI UNTUK PENGESANAN KETULAN DAN MICROKALSIFIKASI DI DALAM PHANTOM PAYUDARA**

Oleh

**TITY NAZLEEN BT MOHAMED**

**Mei 2017**

**Pengerusi : Professor Madya Zulkifly Abbas, PhD.**
**Fakulti : Sains**


Projek ini mengkaji daya maju mengesan ketulan dan mikrokalsifikasi dalam phantom payudara dengan menggunakan teknik hujung terbuka sepaksi (OEC) pada julat frekuensi antara 1 GHz dan 4 GHz. Ketepatan dan fleksibiliti daripada OEC telah diuji pada sampel tomato dan kentang kerana mereka masing-masing berbentuk simetri dan tidak simetri. Kedua-dua OEC bulat dan OEC segi empat tepat telah digunakan dalam kerja-kerja ini. Persamaan penentukuran untuk meramalkan kandungan kelembapan dari pekali pantulan yang diukur telah dikeluarkan. OEC didapati 4% tepat dalam penentuan kadar air dalam kedua-dua tanaman. Pengiraan pekali pantulan dan visualisasi medan elektromagnet tomato juga telah dilakukan menggunakan kaedah unsur terhingga (FEM). Hubungan yang baik antara FEM dan keputusan pengukuran dijumpai untuk sampel yang kandungan air 91.56%, pada julat frekuensi daripada 2.5 GHz terutamanya.

Tiga phantom digunakan dalam kerja-kerja ini untuk menunjukkan kemungkinan menggunakan OEC untuk mengesan ketulan dan mikrokalsifikasi.

Salah satu phantom itu dihasilkan dengan melarutkan Triton X-100 dengan air. Dua lagi ialah phantom komersial CIRS Model 052A dan Model 010A yang direka untuk ultrasound dan ukuran mamografi X-Ray. OEC didapati mempunyai keupayaan untuk membezakan antara ketulan padat dan sistik dalam CIRS 052A dibandingkan dengan keputusan ultrasound. Ketulan padat mempunyai nilai ε' yang lebih tinggi

daripada 9.28 manakala nilai |S11| lebih besar daripada 0.54. OEC juga didapati dapat membezakan sifat khusus phantom payudara CIRS Model 010A berdasarkan nilai-nilai ketelusan. Ini terbukti dengan data pengecilan X-Ray berkadar sama meningkat dengan ε ', ε'' dan |S11| untuk tiga komposisi kelenjar-adipos berbeza. Peningkatan saiz butiran $CaCO_3$ hanya untuk specks linear akan meningkatkan nilai-nilai kedua-dua ε 'dan ε''. Nilai ε 'dan ε'' masing-masing bagi matriks epoxy cast adalah 2.0 dan 0.001 manakala nilai untuk $CaCO_3$ tulen adalah 2.4 dan 0.02

Phantom Triton X-100 membolehkan ramalan OEC daripada nilai ε' dan ε'' berdasarkan jumlah *m.c* yang seterusnya boleh digunakan untuk mengenal pasti jenis tisu yang boleh dikategorikan sama ada tisu berisiko tinggi, sederhana atau rendah. Ia keberangkalian dapat mengesan tisu kanser berdasarkan sifat-sifat dielektrik atau *m.c*. memandangkan sifat-sifat dielektrik tisu normal dan kanser tidak adalah sama.

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I certify that a Thesis Examination Committee has met on 30 May 2017 to conduct the final examination of Tity Nazleen Mohamed on her thesis entitled "Open-Ended Coaxial Technique for Detection of Masses and Microcalcifications in Breast Phantoms" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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| | |
|---|---|
| *m.c* | Moisture content |
| RF | Radio frequency |
| MW | Microwave |
| OEC | Open Ended Coaxial |
| VNA | Vector Network Analyser |
| RFID | Radio frequency identification |
| NDT | Nondestructive-testing |
| MUT | Material under test |
| EM | Electromagnetic waves |
| SFM | Screen film mammography |
| SMA | SubMiniature version A |
| PEC | Perfect electric conductor |
| TGC | Time gain compression |
| CIRS | Computerized imaging reference system |
| CFOE | Circular flange open ended |
| et al., | And others |
| SFOE | Square flange open ended |
| N/A | Not applicable |
| *v.c* | Volume concentration |
| T1 | Tomato sample 1 |
| T2 | Tomato sample 2 |
| T3 | Tomato sample 3 |
| T4 | Tomato sample 4 |
| P1 | Potato sample 1 |
| P2 | Potato sample 2 |
| P3 | Potato sample 3 |
| P4 | Potato sample 4 |
| mw | Molecular weight |
| FEM | Finite Element Method |
| COMSOL | COMSOL Multiphysics® |
| $m_{wet}$ | Weight of the sample before oven dry |
| $m_{dry}$ | Weight of the sample after oven dry |
| % | Percentage |
| $\|S_{11}\|$ | Reflection coefficient |
| $\varepsilon'$ | Dielectric constant |
| $\varepsilon''$ | Loss factor |
| dc | Direct curent |
| *d* | Thickness |

# CHAPTER 1

# INTRODUCTION

The dielectric properties of moist material depends on its amount of moisture content (*m.c*) (Kandala et al., 2007). The higher the moisture content in a sample the higher will be the water dipole molecule mobility and ionic conductivity. Various techniques have been reported for the past two decades for the determination of the dielectric properties of agricultural products (Nelson et al., 2012). These techniques also include the applications of radio frequency as well as microwave heating (Salema et al.,2013).

Among all the dielectric measurement techniques, the open ended coaxial (OEC) technique is the most commonly used technique for the determination of dielectric properties of agro-based material. Also, OEC technique has been widely used in the determination of the permittivity of human tissues and phantoms. The commercial Agilent (now Keysight) 85070E Dielectric *Probe* Kit is now the de facto industry standard for measurement of permittivity of moist materials. The OEC technique requires the materials in direct contact with the surface of the sensor. The complex permittivity are calculated from the measured reflection coefficient using a Vector Network Analyser (VNA).

In spite of its potential application, the large circular flanged OEC such as the Agilent 85070E Probe has never been reported for determination of moisture content from the measured reflection coefficient and applicability in detection of masses and microcalcifications of breast phantoms.

## 1.1 Microwave Sensors

A microwave sensor operates on the principle wave interactions at the interfaces between the material under test and the sensor. The interactions can be in the form of reflection, refraction, scattering, emission, absorption, or change of speed or phase. Microwave sensors commonly used in the industry are usually categorized either by resonance, transmission or reflection type sensors. Microwave sensors are used for various applications. Microwave sensors are widely used to determine the dielectric properties of materials. In a radio frequency identification (RFID) system, microwave passive reader is used to receive RF signal from a tag or label. Speed of a moving vehicle can be detected using a microwave radar gun based on Doppler Effect.

There are many advantages of microwave sensing techniques (Kraszewski, 1993). Microwave signals do not require mechanical contact between the sensor and the object under test. Microwaves can penetrate any thin, non-conductive materials. The high dielectric contrast between water and most materials allows fast and accurate detection of moisture content in a sample. Microwave signals are not sensitive to environmental conditions such as water vapour, dust and high temperature. The dc conductivity effect is negligible in the microwave frequencies. Microwaves are safe for human if kept at low power.

Microwave sensors are gaining widespread acceptance in the industry due to better components availability and falling costs. Microwave sensors have increasingly found new applications. Development of new specialized sensors with high sensitivity to moisture content are in demand.

## 1.2 Dielectric Properties of Water

The dielectric properties of moist materials are dependable on the amount of *m.c* of the materials. Microscopically, the dielectric constant and loss factor are a measure of the ability of polar molecules to partially polarize when applied with an external electric field. The permittivity of free water is usually described by a Debye type relaxation (Kaatze, 2005) where the permittivity at any frequency can be calculated by knowing the a priori values of the the permittivities The graph shows high dielectric constant values of water at low microwave frequencies. Water has very high static permittivity values due to its high dielectric dipole moment. The high value of the dielectric constant of water allows microwave sensors to detect accurately moisture content in many moist materials. Water molecules in a moist material are tightly bound at the interface. The dielectric properties of bound water are different from free water due to the bonding between water molecules with other molecules. The bound water permittivity values are affected by the distance of water molecules from solid surface and the chemical compositions of moist materials (Or and Wraith, 1999). The effect of bound water is usually noticeable for moisture content less than 30% (Binner, 1992).

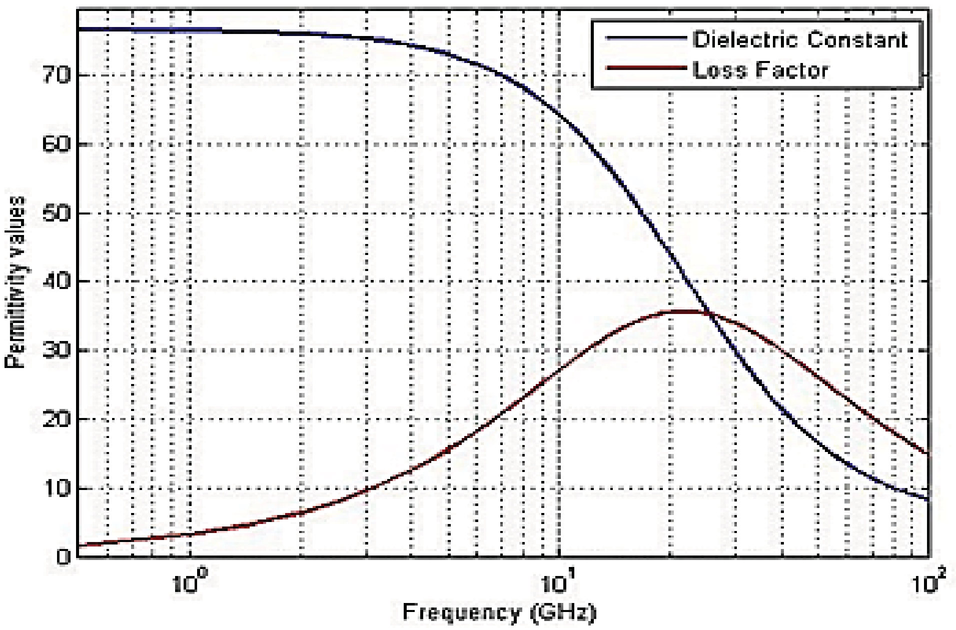


**Figure 1.1: The Permittivity of free water**
(Source: Binner, 1992)

## 1.3 Problem Statement

The circular flanged open ended coaxial (OEC) technique has been widely used to measure the permittivity of materials for more than two decades. The technique is used to calculate the permittivity from the measured reflection coefficient using a vector network analyser. The permittivity model used a mathematical variational technique to calculate the admittance of the sensor loaded with the material under test by matching the measured and calculated reflection coefficients. The calculation is complex and tedious requiring dedicated software to compute the permittivity from the measured reflection coefficient values. However, the full potential and application of the technique have not been explored for detection of masses and microcalcification of breast phantoms.

This project examined the feasibility of using OEC as a fast and accurate method to detect masses and microcalcifications of breast phantoms. First, the accuracy of the OEC was tested using tomatoes and potatoes samples. Both circular OEC and rectangular OEC were used in this work. The crops were selected due to their symmetrical and non symmetrical shapes.

The results of OEC measurement of phantom shall be compared with conventional technique using ultrasounds and X-Ray mammographic technique. Currently, X-ray mammogram is the main technique for detecting abnormalities in the breast tissues. However, it is reported that this technique also gives high false-negative rates and false-positive rates. Although the ultrasound technique has a higher resolution to detect the location and size of the cancerous tissue, unfortunately, is too time consuming method due to its limited scanning area.

## 1.4 Research Objectives

The main research objectives are:

1. To determine the variation of ε' and ε" with *m.c* at different frequencies for both potatoes and tomatoes. Calibration equation to predict *m.c* in potatoes and tomatoes from the measured reflection coefficient values will be established. Finite element method calculates the reflection coefficient and visualize the electric fields due to the samples.

2. To classify the masses and microcalcifications of two different phantoms using OEC.

3. To develop a homemade phantom to simulate tissue based on the dielectric properties of material.

## 1.5 Scope of the Study

The main attention of this study is to examine the application of OEC in the classification of masses and microcalcifications. Chapter 2 presents various conventional methods to determine *m.c* using microwave techniques. This is followed by an overview on the application of OEC for detection of cancerous and noncancerous breast tissues.

Chapter 3 highlights various analytical and numerical methods to calculate the reflection coefficient, $|S_{11}|$ of coaxial sensor with special emphasis on the finite element theory. The FEM implementation in COMSOL Multiphysics® is also covered in this chapter.

Chapter 4 describes detailed experimental procedures to obtain the actual *m.c* and $|S_{11}|$ of potatoes and tomatoes using the standard oven drying method and microwave technique, respectively. Preparation of the diluted Triton-X phantom is also described. The measurement of $|S_{11}|$ of all the phantoms are presented.

Chapter 5 presents the results and discussion. The variation of ε' and ε" with *m.c* at different frequencies for both potatoes and tomatoes are discussed and analysed. The calibration equation to predict *m.c* from the measured reflection coefficient are presented. The measured and calculated the $|S_{11}|$ using finite element method are compared. The permittivity results of OEC of the masses and microcalcifications of three different phantoms are compared with the ultrasound and X-Ray mammograph results.

Lastly, Chapter 6 summarizes all the results and findings obtained in this study. This chapter also presents several recommendations for future works in this study.

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