



UNIVERSITI PUTRA MALAYSIA

**DEVELOPMENT OF SIMPLE RECTANGULAR MICROSTRIP SENSOR FOR
DETERMINING MOISTURE CONTENT OF HEVEA RUBBER LATEX**

NOR ZAKIAH BINTI YAHAYA

FS 2013 19



**DEVELOPMENT OF SIMPLE RECTANGULAR MICROSTRIP SENSOR
FOR DETERMINING MOISTURE CONTENT OF HEVEA RUBBER LATEX**

By

NOR ZAKIAH BINTI YAHAYA

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in
Fulfillment of Requirements for the Degree of Doctor of Philosophy**

September 2013

COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



DEDICATION

To my beloved husband Muhamad Zamri Yahaya,

parents, parents-in-law and Brothers

Thanks for everything



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

DEVELOPMENT OF SIMPLE RECTANGULAR MICROSTRIP SENSOR FOR DETERMINING MOISTURE CONTENT OF HEVEA RUBBER LATEX

By

NOR ZAKIAH BINTI YAHAYA

September 2013

Chairman: Associate Professor Zulkifly Abbas, PhD

Faculty: Science

Various techniques have been proposed to determine the dry rubber content or moisture content in Hevea Rubber Latex (*Hevea Brasiliensis*). Unfortunately the techniques are either laborious, inaccurate, expensive or bulky. This thesis describes the design, fabrication, testing, analysis and validation of a microstrip patch sensor frequency range between 1 GHz and 4 GHz for determination of moisture content of Hevea Rubber Latex. Three different computational methods were used in the theoretical design and analysis of the microstrip sensor. The variational technique, Method of Moment and Finite Element Method were used to determine the resonance frequency and other parameters of the unloaded and latex loaded microstrip sensor.

The measurement setup for determination of reflectivity consists of the microstrip patch sensor and an N5230A Agilent Professional Network Analyzer in the frequency range

between 1 GHz and 4 GHz. All calibrations were performed using Agilent N4691-60004 (300 kHz - 26.5 GHz) Electronic calibration Module. Permittivity values for the Hevea Rubber Latex samples of different percentages of moisture content were obtained using both dielectric mixture model and a 4 mm open-ended coaxial line probe (Agilent 85070E). These permittivities were used as inputs to both variational and numerical methods to calculate the reflection coefficient of the unloaded and loaded sensor. The latter employed both Finite Element Method (FEM) and Method of Moment (MoM) implemented in 3D and 2-5D using COMSOL Multiphysics version 3.5 and Microwave Office version 7.03 software, respectively. FEM was utilized to investigate electric fields distribution in the samples. Comparison of results between the measured and calculated resonance frequency, magnitude and phase of the reflection coefficient, phase shift, frequency shift, conductance and susceptance for a range of latex samples of different percentages of *m.c* from 36 % to 86 % have been discussed in this work. It was found that the FEM provided the most accurate results.

Calibration equations have been established to predict the amount of moisture content from the measured microwave parameters. The equations were validated by comparing the results with the actual moisture content obtained using the standard oven drying method. The calibration equations based on the magnitude and conductance measurements were found to be most accurate at 3 GHz and 3.2 GHz, respectively whilst both the phase shift and susceptance were at 4 GHz. However, the calibration equation with lowest mean percentage error 2.0 % was found when using the frequency shift of the peak of the magnitude of the reflection coefficient.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

**PEMBENTUKAN PENGESAN MIKROSTRIP RINGKAS BERBENTUK
SEGI EMPAT TEPAT BAGI MENENTUKAN KANDUNGAN LEMBAPAN
GETAH HEVEA LATEX**

Oleh

NOR ZAKIAH BINTI YAHAYA

September 2013

Pengerusi: Profesor Madya Zulkifly Abbas, PhD

Fakulti: Sains

Pelbagai teknik telah dicadangkan untuk menentukan kandungan getah kering atau kandungan kelembapan dalam Getah Hevea Lateks (*Hevea Brasiliensis*). Malangnya teknik-teknik ini rumit, tidak tepat, mahal dan besar. Tesis ini menerangkan reka bentuk, fabrikasi, pengujian, analisis dan pengesanan mikrostrip pada frekuensi di antara 1 GHz dan 4 GHz untuk penentuan kandungan lembapan Getah Hevea Latex.

Tiga kaedah pengiraan yang berbeza telah digunakan dalam teori rekabentuk dan analisis pengesanan mikrostrip. Teknik perubahan, Kaedah Momen dan Kaedah Unsur Terhingga telah digunakan untuk menentukan frekuensi resonans dan parameter lain bagi pengesanan mikrostrip bersama udara dan sampel getah.

Persediaan pengukuran untuk penentuan pemantulan terdiri daripada pengesanan mikrostrip tampalan dan alat Agilent Profesional Network N5230A dalam julat

frekuensi antara 1 GHz dan 4 GHz. Semua penentukuran telah dilakukan dengan menggunakan Modul penentukuran Elektronik Agilent N4691-60004 (300 kHz – 26.5 GHz). Nilai ketulusan untuk sampel Getah Hevea Lateks bagi peratusan kandungan lembapan yang berbeza telah diperolehi dengan menggunakan kedua-dua model campuran dielektrik dan garisan sepaksi hujung terbuka 4 mm terbuka (Agilent 85070E). Ketulusan ini telah digunakan sebagai input kepada kedua-dua kaedah ubahan dan numerik untuk mengira pekali pantulan pegas bersama udara dan sampel. Kedua-dua Kaedah Unsur Terhingga (FEM) dan Kaedah Moment (MoM) yang digunakan akan dilaksanakan dalam 3D dan 2-5D masing-masing dengan menggunakan perisian COMSOL Multiphysics versi 3.5 dan Microwave Office versi 7.03. FEM telah digunakan untuk menyelidiki taburan medan elektrik dalam sampel. Perbandingan frekuensi resonan, magnitud pekali pantulan, fasa pekali pantulan, anjakan fasa, anjakan frekuensi, kekonduksian dan rentanan bagi sampel lateks yang pelbagai peratusan kelembapan dari 36 % kepada 86 % telah diukur dan dikira. Didapati bahawa FEM memberikan hasil yang paling tepat.

Persamaan penentukuran dari parameter gelombang mikro yang diukur telah dibangunkan untuk meramalkan jumlah kandungan lembapan. Persamaan telah disahkan dengan membandingkan keputusan dengan kandungan kelembapan sebenar yang diperolehi menggunakan kaedah pengeringan ketuhar standard. Persamaan penentukuran yang berdasarkan ukuran magnitud dan kealiran dapati yang paling tepat masing-masing pada 3 GHz dan 3.2 GHz, manakala kedua-dua anjakan fasa dan rentanan pada 4 GHz. Walau bagaimanapun, persamaan penentukuran dengan peratusan ralat terendah 2.0 % ralat ditemui apabila menggunakan anjakan kekerapan puncak magnitud pekali pantulan.

ACKNOWLEDGEMENTS

“In the name of Allah, the most beneficent and the most merciful”

I would like to express my highest gratitude to my supervisor, Prof. Madya Dr. Zulkifly Abbas, whose expertise, understanding, and patience, added considerably to my graduate experience. I appreciate his vast knowledge and skill in many areas, and his assistance in writing thesis, which have on occasion made me "GREEN" with envy.

My special thanks to my colleagues Alif, Farizah, Amizadillah, Sakinah, Mardiah, Ali Hamad, Ethar, Parnia, Omar, Muhamad, Dr Ashry, Ahmad Fahad, Rahimah, Fahmi, Faiz, and all members in the RF & Microwave Lab, past and present, for their guidance, help and support. I would like to thank Prof. Madya Dr. Jumiah Hassan and Prof. Dr. Borhanuddin Ali from the Faculty of Sciences and Faculty of Engineering, respectively for taking time out from their busy schedule to serve as my supervisor's committee. I wish both of you the best than life can offer. But most of all, I appreciate your encouragement and kindness.

Finally, I would also like to thank my family for the support they provided me through my entire life and in particular, I must acknowledge my husband, Zamri, without whose love, encouragement and editing assistance, I would not have finished this thesis. I would be horribly remiss if I did not take the opportunity to thank my friends, for their love and support.

I certify that a Thesis Examination Committee has met on 4th September 2013 to conduct the final examination of Nor Zakiah Binti Yahaya on her thesis entitled "Development Of Simple Rectangular Microstrip Sensor For Determination Of Moisture Content Of Hevea Rubber Latex " 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 Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

Abd Halim Shaari, PhD

Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Zaidan Abdul Wahab, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Hishamuddin Zainuddin, PhD

Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Internal Examiner)

Josaphat Tetuko Sri Sumantyo, PhD

Professor
Center for Environmental Remote Sensing (CEReS), Chiba University
Japan
(External Examiner)

NORITAH OMAR, PhD

Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 September 2013

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Zulkifly Abbas, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

Jumiah Hassan, PhD
Associate Professor
Faculty of Science
Universiti Putra Malaysia
(Member)

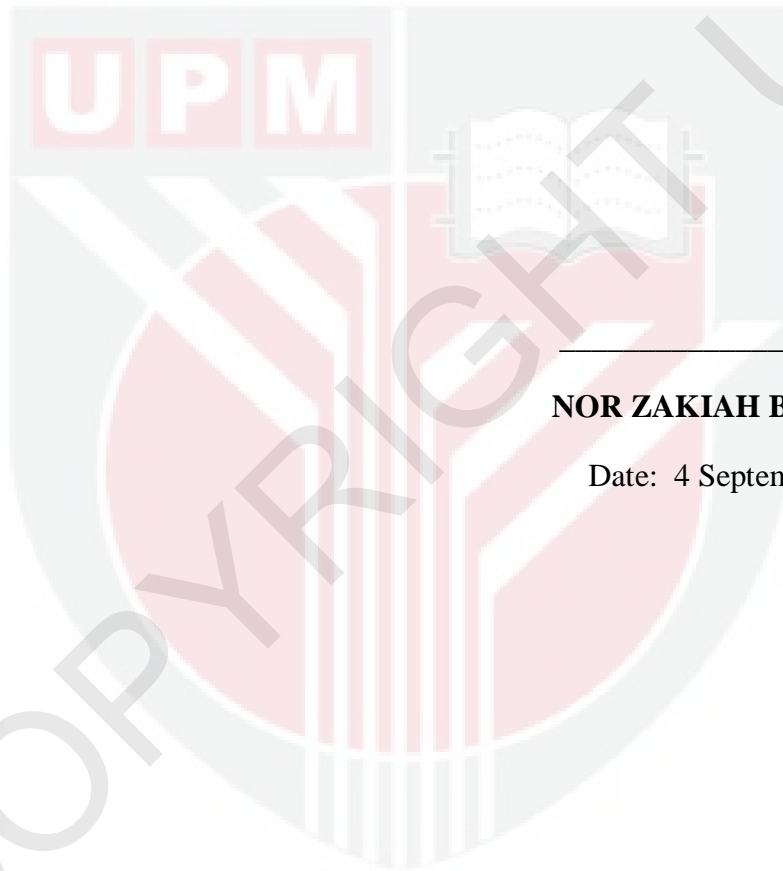
Borhanuddin Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except quotation and citations which have been duly acknowledged. I also declare that it has not previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.



NOR ZAKIAH BINTI YAHAYA

Date: 4 September 2013

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	vii
APPROVAL	viii
DECLARATION	x
LIST OF TABLES	xiv
LIST OF FIGURES	xvi
LIST OF ABBREVIATIONS	xxi
CHAPTER	
1 INTRODUCTION	
1.1 An Overview of Hevea Rubber Latex	3
1.2 Interactions of microwaves with materials	4
1.3 Microwave sensors	7
1.3.1 Microwave Moisture Measurement	8
1.4 Dielectric Properties of Materials	11
1.5 Problem Statements	16
1.6 Objectives	17
1.7 Scope of the Study	18
2 LITERATURE REVIEW	
2.1 Standard Methods to determine Moisture Content in Moist Materials	20
2.2 Techniques for Determination of Latex concentration	21
2.2.1 Oven Drying Method	21
2.2.2 Hydrometer Method	22
2.2.3 Titration Method	23
2.2.4 Buoyancy Method	24
2.2.5 Optical Technique	24
2.2.6 Microwave Techniques	24
2.3 An Overview of Microstrip	27
2.3.1 Microstrip sensor	29
2.3.2 Microstrip Models	30
2.3.2.1 Transmission Line Model	31
2.3.2.2 Cavity Models using Model Expansion Technique	32
2.3.2.3 Capacitance Model	35
2.4 Numerical techniques	36
2.4.1 Finite Difference Time Domain (FDTD)	37
2.4.2 Method of Moments (MoM)	39
2.4.3 Finite Element Method (FEM)	40
2.4.4 Comparison between Numerical Techniques	43
3 THEORY OF PATCH ANTENNA	
3.1 Permittivity Models for Hevea Latex	47
3.1.1 Dielectric Mixture Model of Rubber Latex	48
3.1.2 Permittivity Model of Agilent Dielectric Probe	49

3.2	Microstrip Patch Sensor	50
3.2.1	Variational Method	53
3.2.1.1	Four-layer Microstrip	54
3.2.1.2	Three Layer Microstrip	58
3.2.1.3	Two Layer Microstrip (covered Microstrip)	59
3.2.2	Finite Element Method	61
3.2.2.1	Discretization of the Domain	61
3.2.2.2	Formulation of the System of Equations	65
3.2.2.3	Solution of the System of Equations	65
3.2.2.4	Characteristic Impedance	66
3.2.2.5	Power and Current Computation from the Fields	67
3.2.3	Method of Moment	70
3.2.3.1	Air-Dielectric Microstrip	70
3.3	Results	77
4	METHODOLOGY	
4.1	Sample preparation and Moisture Content Measurement	82
4.2	Circuit layout, fabrication and testing of the patch antenna	85
4.3	Fabrication and testing of the patch antenna	87
4.4	Experimental set-up	88
4.4.1	Complex Permittivity Measurement of the Samples	88
4.4.2	Reflection measurement of the Microstrip Patch Sensor	89
4.5	FEM Procedure to Calculate Reflection Coefficient Using COMSOL	92
4.5.1	FEM Results and Analysis	103
4.6	MoM Simulation of patch sensor using Microwave Office	111
5	RESULTS AND DISCUSSIONS	
5.1	Dielectric properties of Hevea Latex	119
5.1.1	Variation in Complex Permittivity and loss tangent of Latex with frequency for different percentage <i>m.c</i>	120
5.1.1.1	Dielectric Constant, ϵ'	120
5.1.1.2	Loss Factor, ϵ''	122
5.1.1.3	Loss Tangent, $\tan \delta$	122
5.1.2	Relationship between Dielectric constant, Loss factor and loss tangent with different percentage moisture content	126
5.1.2.1	Variation in Dielectric constant and Loss factor with <i>m.c</i>	126
5.1.2.2	Variation in Loss tangent with <i>m.c</i>	132
5.1.3	Development of Calibration equation for determination of moisture content at 1 GHz to 5 GHz	133
5.2	Magnitude, $ \Gamma $ of reflection coefficient	137
5.2.1	Magnitude, $ \Gamma $ of reflection coefficient of unloaded sensor With frequency	137
5.2.2	Effect of moisture content on the resonant frequency of the loaded sensor	139
5.2.3	Calibration Equation based on frequency shift, f_{shift}	142
5.2.4	Comparison between measured and calculated $ \Gamma $ with percentage moisture content, <i>m.c</i>	143
5.3	Relationship between phase, phase shift, frequency and moisture content	148

5.3.1	Phase, ϕ of the reflection coefficient	148
5.3.2	Phase shift, Θ of reflection coefficient of loaded sensor with <i>m.c</i>	154
5.4	Relationship between conductance and susceptance, frequency and moisture content	158
5.4.1	Unloaded Sensor	158
5.4.2	Variation in Conductance and Susceptance with Moisture Content	160
5.4.3	Variation in Resonant Frequency and Frequency Shift with Moisture Content	165
5.5	Performance analysis	169
6	CONCLUSION AND SUGGESTION	
6.1	Main Contributions	173
6.2	Recommendations for Further Work	176
	REFERENCES	177
	APPENDICES	187
	BIODATA OF STUDENT	206
	LIST OF PUBLICATIONS	207