UNIVERSITI PUTRA MALAYSIA

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

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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 Fullfilment of Requirements for the Degree of Doctor of Philosophy

September 2013

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

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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 pengesahan 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 pengesan mikrostrip. Teknik perubahan, Kaedah Momen dan Kaedah Unsur Terhingga telah digunakan untuk menentukan frekuensi resonans dan parameter lain bagi pengesan mikrostrip bersama udara dan sampel getah.

Persediaan pengukuran untuk penentuan pemantulan terdiri daripada pengesan 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 pengesan 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.

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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.

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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:

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DECLARATION

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

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NOR ZAKIAH BINTI YAHAYA

Date: 4 September 2013

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