UNIVERSITI PUTRA MALAYSIA

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By

FARIBA JAFARI

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

July 2007

To
My lovely Mother,
The most wonderful gift from God.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Master of Science

DESIGN AND DEVELOPMENT OF A MICROSTRIP SENSOR FOR MEASUREMENT OF MOISTURE CONTENT IN RICE GRAINS

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FARIBA JAFARI

July 2007

Chairman: Professor Kaida Khalid, PhD

Faculty: Science

A Microstrip moisture sensor is developed based on microwave attenuation and is used for measuring moisture content of rice grains. This sensor is suitable for a broad range of moisture content ranging from 0% to 40 % (wet basis). It was fabricated using RT-Duriod with dielectric properties of 2.2-j0.002 as the substrate, with operating frequency at 9.0 GHz. In this technique only the small part of sample is needed to contact with the microstrip line, therefore the measurement can be done with more accuracy and in a shorter time.

Theoretical analysis based on quasi-transverse electromagnetic mode (TEM mode) in four layered microstrip is carried out to evaluate design parameters such as microstrip characteristic impedance, effective dielectric constant, length and thickness due to the sensitivity of the sensor. The analysis of the complex electromagnetic waves in this system is presented using signal flow graphs and solved by Mason's non-touching loops rules. To this end Visual Fortran programs is written and documented to evaluate all the design parameters needed and to estimate the microstrip patterns.

In the other part of this study, investigation was made to find the relation between the dielectric properties and moisture content of rice grains. The dielectric mixture theory has been derived to solve the problem of non homogenous medium. In the purpose of verifying the mixture theory the theoretical results has been compared with the empirical results. It was found that the dielectric properties of dried rice samples were in the range of 1.20 to 1.88 for ε' and 0.065 to 0.23 for ε'' and even can increased up to 30-j18 in maximum moisture content, respectively. A close and good agreement to theoretical expectation values is found. A computer program EMIX is written to predict the dielectric properties of wet basis rice grain by knowing the values of physical properties for dry basis.

In this study, analyzes of the sensor and various type of the rice grain samples with the effect of density and temperature of rice grains to the total attenuation of the sensor has been studied and the predicted results are compared with experimental results. The effect of air inside the medium and the compactness of the material under the test has been studied and the errors of ± 0.16 dB has been calculated for the measured reflected attenuation of the sensor.

The micrsotrip sensor was tested on five types of rice grains in the range of 1% to

40% moisture content. The sensor has predicted moisture contents with standard error of ±0.22 dB and accuracy of 1.5% MC wet basis compared to standard oven drying method. Moisture contents of rice grain samples were found in the range of 11 to 12.5% at room temperature (25°C).

A new proposed moisture sensor which can measure the moisture content of grains contained in a sack manner has been given. The slim and sharp geometry of the sensor enable it to measure the mean volumetric values of moisture content of rice since it penetrates deep into the sack. Therefore, this method can be so useful in industry for moisture content measurement of rice grains and even some other grains like wheat, corn barley and so on, to determine the proper time of harvest, safe storage and quality control of grains.

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

PEMBANGUNAN DAN REKABENTUK SENSOR/MICROSTRIP KELEMBAPAN BAGI BIJIRIN BERAS

Oleh

FARIBA JAFARI

Julai 2007

Pengerusi: Profesor Kaida Khalid, PhD

Fakulti: Sains

Sensor kelembapan microstrip telah direcabentuk berdasarkan pengecilan gelombang mikro dan digunakan untuk mengukur kandungan kelembapan bijirin beras. Pengesan ini sesuai bagi pelbagai julat kandungan kelembapan bermula dari 0% hingga 40% (asas basah). Pengesan ini direka menggunakan RT-Duriod dengan sifat dielektirk, 2.2-j0.002 sebagai 'substrak' dan frekuensi operasi pada 9.0 GHz. Melalui teknik ini yang hanya memerlukan bahagian kecil sampel untuk menyentuk dengan

garisan microstrip maka pengukuran dapat dilakukan dengan lebih jitu dan dalam jangka masa yang lebih singkat.

Analisis teori berdasarkan mod elektromagnetik mod quasi-TEM melintang (mod TEM) dalam microstrip 4 lapisan dijalankan untuk menilai parameter rekabentuk seperti impedan cirri microstrip, pemalar dielektrik berkesan, panjang, ketebalan dan parameter-parameter lain yang berkaitan dengan sensitiviti pengesan tersebut. Analisis gelombang elektromagnetik kompleks dalam system ini dipersembahkan menggunakan graf-graf aliran isyarat dan diselesaikan oleh hukum gegelung tanpa sentuh Mason. Setakat ini, Program Visual Fortran ditulis dan didokumentasikan untuk dinilai kesemua parameter-parameter rekabentuk yang diperlukan serta untuk menganggarkan bentuk microstrip.

Dalam bahagian lain kajian ini, penyelidikan telah dijalankan untuk mencari hubungan di antara sifat-sifat dielektrik dan kandungan kelembapan bijirin beras. Teori campuran dielektrik telah diterbitkan untuk menyelesaikan masalah meduim tidak homogen. Bagi tujuan mengesahkan teori campuran ini, keputusan teori telah dibandingkan dengan keputusan empirik. Didapati, sifat-sifat dielektrik sampel beras kering adalah di dalam julat 1.20 hingga 1.88 bagi ε' dan 0.065 hingga 0.23 bagi ε''dan akan ditingkatkan dengan kandungan kelembapan ε=30-j18 pada kelembapan maksimum. Suatu persetujuan yang baik dan hampir kepada nilai jangkaan teori telah dikesan. Program komputer ditulis untuk meramal sifat-sifat dielektrik bijirin beras basah dengan mengetahui nilai sifat-sifat fizikal bagi bijirin beras kering.

Dalam kajian ini, analisis sensor pelbagai jenis sampel bijirin beras dengan kesan kepadatan dan suhu bijirin beras kepada jumlah pengecilan pengesan telah dikaji dan keputusan yang dijangka telah dibandingkan dengan keputusan eksperimen. Kesan udara di dalam pengantaraan dan kepadatan sampel di bawah ujikaji telah dikaji dan ralat bagi $\pm$ 0.16 dB telah dihitung bagi pengecilan sensor yang telah diukur.

Sebagai contoh aplikasi, sensor microstripm telah diuji ke atas 5 jenis bijirin beras dalam julat kandungan kelembapan minimum dan maksimum. Sensor telah meramal kandungan kelembapan dengan ralat piawai kepadatan sebanyak ±0.22 dB dan kejituan sebanyak 1.5% kandungan kelembapan berasaskan basah berbanding dengan kaedah pengeringan ketuhar biasa. Kandungan kelembapan sampel bijirin beras dikesan dalam julat 11 hingga 12.5% dalam suhu bilik (25°C).

Dengan persetujuan yang rapat antara nilai yang diramal dan nilai eksperimen, cadangan baru sensor kelembapan yang dapat mengukur kandungan kelembapan bijirin yang terkandung di dalam suatu karung dalam keadaan pantas dan praktikal telah diusulkan. Geometri sensor yang halus dan tajam itu membolehkan ia mengukur nilai min volumetrik bagi kandungan kelembapan beras oleh kerana ia menembusi ke dalam karung. Oleh itu, kaedah ini sangat berguna dalam industri pengukuran kandungan kelembapan bijirin beras dan juga bijirin-bijirin lain seperti gandum, jagung, barli dan lain-lain untuk menentukan masa yang sesuai bagi penanaman, keselamatan simpanan dan kawalan kualiti bijirin.

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I certify that an Examination Committee has met on 25th July 2007 to conduct the final examination of Fariba Jafari on her Master of Science thesis entitled "Design and Development of a Microstrip Sensor for Measurement of Moisture content in Rice Grains" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

W. Mahmood Mat. Yunus, PhD
Professor
Faculty of Graduate Studies
Universiti Putra Malaysia
(Chairman)

Mohd. Maaroof H. A. Moksin, PhD
Professor
Faculty of Graduate Studies
Universiti Putra Malaysia
(Internal Examiner)

Zaidan Abd . Wahab, PhD
Associate Professor
Faculty of Graduate Studies
Universiti Putra Malaysia
(Internal Examiner)

Mazlina Esa, PhD
Associate Professor
Faculty of Electrical Engineering
Universiti Teknologi Malaysia
(External Examiner)

HASANAH MOHD.GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 24 October 2007

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

Kaida Khalid, PhD
Professor
Faculty of Science
Universiti Putra Malaysia
(Chairman)

W.Mohamed Duad W. Yusoff, PhD
Associate Professor
Faculty of Forestry
Universiti Putra Malaysia
(Member)

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

AINI IDERIS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 15 November 2007

DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations, which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.

FARIBA JAFARI

Date: 30 April 2007

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LIST OF ABBREVIATIONS

VNA	Vector Network Analyzer
MUT	Material Under Test
MC	Moisture Content
HPBW	Half-Power Beam Width
BW	Bandwidth
PLF	Polarization Loss Factor
SEC	Standard Error of Calibration
NDT	Non Destructive Testing
VSWR	Voltage Standing Wave Ratio
TEM	Transverse Electric Magnetic Fields
RF	Radio Frequency
HF	High Frequency
VHF	Very High Frequency
UHF	Ultra High Frequency
d.b.	Dry Basis Moisture Content Determination
w.b.	Wet Basis Moisture Content Determination

LIST OF SYMBOLS

Symbol	Quantity	Units
E	Electric Field Intensity	(V/m)
H	Magnetic Field Intensity	(A/m)
ε_0	Permittivity of Vacuum	(F/m)
μ_0	Permeability of Vacuum	(H/m)
ε^*_r	Relative Permittivity (Complex)	(dimensionless)
μ^*_r	Relative Permeability (Complex)	(dimensionless)
η^*	Medium Impedance (Complex)	(Ω)
L	Inductance	(H)
C	Capacitance	(F)
R	Resistance	(Ω)
Z_o	Characteristic Impedance	(Ω)
Y	Admittance	(S)
γ^*	Propagation Constant (complex)	(1/m)
α	Dielectric constant	(1/m)
β	Phase Constant	(rad/m)
σ	Conductivity	(S/m)
ω	Angular Frequency	(rad.Hz)
ε'	Dielectric Constant	(F/m)
ε''	Loss Factor	(F/m)
$\tan\delta$	Loss Tangent	(dimensionless)
Γ^*	Reflection Coefficient (complex)	(dimensionless)

τ^*	Transmission Coefficient (Complex)	(dimensionless)
D	Directivity	(dimensionless)
G	Gain	(dimensionless)
e	Efficiency	(dimensionless)
Q_T	Quality factor	(dimensionless)
RL	Return Loss	(dB)
h	Substrate Thickness	(mm)
s	Thickness of Protective Layer	(mm)
d	Height of Sample or Wet Media	(mm)
W	Width of Line	(mm)
β	Phase Constant	(dimensionless)
ρ	Density	(gr/cm^3)
V	Volume	(cm^3)
v_a	Volume Fraction of air	(dimensionless)
v_g	Volume Fraction of grain	(dimensionless)
v_w	Volume Fraction of water	(dimensionless)
m_a	Mass of air	(gr)
m_g	Mass of Grain	(gr)
m_w	Mass of water content	(gr)
S_{11}	Scattering Parameter (Port 1 to Port 1)	(dB)
S_{12}	Scattering Parameter (Port 2 to Port 1)	(dB)
S_{21}	Scattering Parameter (Port 1 to Port 2)	(dB)
S_{22}	Scattering Parameter (Port 2 to Port 2)	(dB)
C	Capacitance of the structure	(F)

C_a	Line Capacitance	(F)
V_p	Phase Velocity	(m/s)
A	Attenuation	(dB/cm)
ϕ	Electrostatic Potential	
$\rho(x,y)$	surface Charge Density	(C/m^2)
$\rho(\beta)$	Fourier Transform of $\rho(x,y)$	
Q	Total Charge	(C)