UNIVERSITI PUTRA MALAYSIA

MOISTURE CONTENT DETECTION IN ANCHOVY SAUCE USING MICROSTRIP SENSOR

OMAR AYAD FADHIL

FS 2014 24

MOISTURE CONTENT DETECTION IN ANCHOVY SAUCE USING MICROSTRIP SENSOR

By

OMAR AYAD FADHIL

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

June 2014

DEDICATION

"„, and of knowledge ye have been vouchsafed but little"

Holy Qur'an

"Do not worry about your difficulties in mathematics I can assure mine are still greater."

Albert Einstein

To my beloved parents and siblings for their lasting encouragement, help & support

Thank you for being there

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

MOISTURE CONTENT DETECTION IN ANCHOVY SAUCE USING MICROSTRIP SENSOR

By

OMAR AYAD FADHIL

June 2014

Chairman: Associate Professor Zulkifly Abbas, PhD
Faculty: Science

Water is the most important parameter to determine the quality of Anchovy Sauce. The changes of *m.c* in Anchovy Sauce also linked to physicochemical and microbiological changes. Unfortunately to-date, a quick, reliable and accurate method to determine moisture content *m.c* in Anchovy Sauce has not been reported in the literature.

This thesis presents an extensive investigation on the design of a microstrip sensor as a new technique for determination of *m.c* in Anchovy Sauce in the microwave frequencies from 2 GHz to 3 GHz. The relationships between the dielectric constant as well as loss factor with frequency in Anchovy Sauce has been established. The dielectric constant of the Anchovy Sauce increased almost linearly with increasing *m.c.* In contrast, the loss factor decreased exponentially with increasing the frequency. The visualization of the electric field distribution of a microstrip loaded with Anchovy Sauce of different percentages of *m.c* was realized using COMSOL 3.5. It was found that the higher the *m.c*, the higher will be the detachments of the electric field distribution.
The variation of transmission coefficients for different percentages of *m.c* were measured in the microwave frequencies from 2 to 3 GHz. The results were analyzed and compared to the calculated values using the Finite Element Method (FEM). This is the first work using FEM to evaluate the transmission coefficients of a microstrip sensor loaded with Anchovy Sauce. It was found that the comparison between the calculated and measured magnitude of transmission coefficient of the lowest percentages of *m.*c exhibit the lowest error and vice versa for the phase of transmission coefficient. The sample with 17.3% of *m.c* recorded the lowest error of the magnitude of transmission coefficient, while the mean erros of phase of transmission coefficient suggest that the water has the lowest mean error followed by samples with highest percentage of *m.c* (80.2%). This could be attributed to the inaccurate permittivity model employed by the Agilent Probe.

The transmission coefficient of the sensor was found to be highly correlated to the amount of *m.c* in the Anchovy Sauce for all frequencies except below 2.1 GHz due to the bound water relaxation frequency. Calibration equations to predict the amount of *m.c* from measured magnitude and phase of transmission coefficient have been established. The calibration equation based on the magnitude of transmission coefficient at 2.55 GHz was found to give the highest accuracy within 1.6% when compared to the actual *m.c* obtained from the oven drying method.

Abstrak tesis dikemukan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains

PENGESANAN KANDUNGAN KELENGASAN BUDU MENGGUNAKAN DERIA MICROSTRIP

Oleh

OMAR AYAD FADHIL

Jun 2014

Pengerusi: Profesor Madya Zulkifly Abbas, PhD
Fakulti: Sains

Air merupakan parameter terpenting untuk menentukan kualiti sos ikan bilis. Perubahan kadungan lembapan dalam sos ikan bilis juga dikaitkan dengan perubahan fisiokimia dan mikrobiologi. Malangnya sehingga kini, cara yang cepat, boleh dipercayai dan tepat dalam menentukan kandungan lembapan sos ikan bilis masih belum dilaporkan.

Tesis ini mengandungi hasil penyelidikan yang ekstensif dalam pembentukan pengesan mikrostrip sebagai salah satu teknik untuk menentukan kandungan lembapan sos ikan bilis dalam frekuensi gelombang mikro dari 2 GHz hingga 3 GHz. Hubungan antara pemalar dielektrik dengan faktor kehilangan frekuensi dalam sos ikan bilis juga turut ditentukan. Pemalar dielektrik bagi sos ikan bilis bertambah secara linear apabila kandungan lembapan bertambah. Sebaliknya, faktor kehilangan berkurang secara eksponen apabila frekuensi bertambah. Taburan medan elektrik bagi mikrostrip dengan sos ikan bilis yang berbeza kandungan lembapan dikaji dengan menggunakan COMSOL 3.5. Hasil kajian mendapati semakin tinggi kandungan lembapan, semakin tinggi pemisahan taburan medan elektrik.

Variasi bagi pekali penghantaran untuk peratusan kandungan lembapan yang berbeza diukur dalam gelombang mikro berfrekuensi dari 2 GHz hingga 3 GHz. Keputusan dianalisa dan dibandingkan dengan pengiraan menggunakan Kaedah Unsur Terhingga (FEM). Ini adalah kajian yang pertama menggunakan FEM untuk menilai pekali penghantaran bagi mikrostrip bersama sos ikan bilis. Hasil perbandingan ini mendapati kandungan lembapan dengan peratusan terendah mempamerkan ralat yang terendah dan sebaliknya untuk fasa pekali penghantaran. Sampel dengan 17.3% kandungan lembapan merekodkan ralat yang terendah bagi magnitud pekali penghantaran manakala purata ralat bagi fasa pekali penghantaran menunjukkan air mempunyai purata ralat yang terendah diikuti oleh sampel dengan peratusan kandungan lembapan yang tertinggi (80.2%). Ini mungkin disebabkan oleh model ketulusan yang tidak tepat dalam Agilent Probe.

Pekali penghantaran bagi pengesan didapati saling berhubung kait dengan jumlah kandungan lembapan dalam sos ikan bilis untuk semua frekuensi kecuali frekuensi kurang dari 2.1 GHz kerana kurangnya keterikatan air pada frekuensi tersebut. Persamaan kalibrasi untuk meramalkan kandungan lembapan daripada pengukuran magnitud dan fasa pekali penghantaran telah berjaya ditubuhkan. Persamaan kalibrasi adalah berdasarkan pada magnitud pekali penghantaran pada 2.55 GHz memberi ketepatan yang paling tinggi dlam 1.6% apabila dibandingkan dengan bacaan sebenar kandungan lembapan yang didapati daripada kaedah pengeringan ketuhar.

ACKNOWLEDGEMENTS

"In the name of Allah, the most beneficent and the most merciful"

First and foremost, all praise is due to Allah Almighty *subhanahu wa-ta'ala,* on whom we ultimately depend, for His endless blessing and allowing me to achieve what I have achieved today.

The student would like to take this opportunity to express the deepest thanks and appreciation to the chairperson of supervisory committee, Associate Professor Dr. Zulkifly Abbas for being a great advisor, motivator as well as teacher throughout the period it took to complete this thesis.

Furthermore, the student would like to extend his gratitude to the member of supervisory committee, Dr. Nurul Huda Binti Osman for her encouragement and advice during the period of study.

Above all, the student would love to deeply express his special gratitude to his family who have given him their unequivocal support, especially beloved parents, Ayad Fadhil and Iman Sofi for their unconditional love, encouragements, guidance and support. The author would love to also offer his regards and blessings to all siblings for their unconditional support in all aspects during his life. Last but not least, special love and thanks to his sweetest nephews ever.

Special thanks to his friends Parnia Tohidi, Faiz, Ahmad Fahad, Amizadillah, Sakinah, Mardiah, , Dr Ashry, Rahimah, Abo Baker and all the members in the RF & Microwave Instrumentation Lab, past and present, for their guidance, help and support.

The student would like to express his lovely, deep and sincere love and appreciations to Ethar Yahya Salih, Mohammed Abdulkareem Jawad & Aysar S. Keiteb for their everlasting love, help as well as encouragement. Thanks you so much

The student would like to express his hearty gratitude and appreciations to Ali Khairullah Zahi, & Nawal Hadi for their love, encouragement as well as being always there with me. Thanks for being always there.

Finally, the student would love to sincerely appreciate his dearest friend Fahmiruddin Esa for his endless encouragements, support and help during the period of study.

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:

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

Nurul Huda Osman, PhD
Senior Lecturer
Faculty of Science
Universiti Putra Malaysia
(Member)

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

Date:

DECLARATION

Declaration by the Student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ___________________

Name and Matric No. : Omar Ayad Fadhil (GS32321)

Declaration by the Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature:
Name of Chairman of Supervisory Committee: **Zulkifly Abbas, PhD**

Signature:
Name of Member of Supervisory Committee: **Nurul Huda Osman, PhD**

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

FEM	-	Finite Element Method
$m.c$	-	Moisture content
$\|S_{21}\|$	-	Transmission coefficient magnitude
ϕ_{21}	-	Transmission coefficient phase
ε'	-	Dielectric constant
ε''	-	Loss factor
RF	-	Radiofrequency
T	-	Thickness of conducting line
W	-	Width
H	-	Thickness of substrate
ε_r	-	Relative dielectric constant
ε		Permittivity
μ	-	Permeability
DC	-	Direct current
Z_c	-	Characteristics Impedance
$\mathcal{E}_{\mathrm{eff}}$	-	Effective dielectric constant
V_ρ	-	Propagation velocity
λ_e	-	Dipole Rotation
δ	-	Conductivity of strip conductor
m_{wet}	-	Wet mass
m_{dry}	-	Dry mass
MMM	-	Microwave moisture measurement

EMP	-	Evanesced microwave probe
NDT	-	Non-destructive technique
MSA	-	Integrated microstrips antenna
MoM	-	Method of Moment
FDTD	-	Finite Difference Time Domain
ABC	-	Absorbing boundary condition
RBC	-	Reflectionless boundary condition
LLNL	-	Lawrence Livermore National Laboratories
NEC	-	Numerical electromagnetic cod
EM	-	Electromagnetic
ε^{jwt}	-	Implicit dependency
$\vec{E}$	-	Electric field
$\vec{D}$	-	Electric displacement
$\vec{H}$	-	Magnetic field
$\vec{B}$	-	Magnetic flux density
ρ_q	-	Charge density
w	-	The angular frequency
$\vec{J}$	-	Current density
K_0	-	The wave number of the free space
f_r	-	Resonant frequency
ε_d	-	Dry content permittivity
ε_w	-	Water content permittivity
Z_s	-	characteristic impedances of the unloaded microstrip

Z_m	-	characteristic impedances of the loaded microstrip
β	-	phase constant
α_d	-	Attenuation constant
γ	-	Propagation constant
FDM	-	Finite Difference Method
BEM	-	Boundary Element Method
CSM	-	Charge Simulation Method
FEA	-	Finite element analysis
3D	-	Three-dimensional
DXF	-	Drawing exchange format
$FeCl_3$	-	Ferric Chloride
SOLT	-	short-open-load-thru
SOL	-	short-open-load
PML	-	Perfect match layer
Z_s	-	The characteristic impedances of the unloaded
Z_m	-	The characteristic impedances of loaded microstrip
DXF	-	Drawing Exchange Format
CAD	-	Computer-aided design
PnP	-	Press-n-Peel
$FeCl_3$	-	Ferric chloride
$\tan \delta$	-	Loss tangent
GHz	-	Giga hertz

CHAPTER 1

INTRODUCTION

1.1 An Overview of Anchovy Sauce

In Malaysia, the Anchovy Sauce called Budu is locally made from Anchovy fish. The process of making the Anchovy sauce was by conflating salt as well as fish in the range of 1:2 and keeping for fermentation for approximately 140 to 200 days. It can be considered that, the main key that plays an important role in the process of making the Anchovy sauce is the ratio of salt. The various flavors of the Anchovy Sauce are attributed to the effects of the different concentration of salt on the enzymatic and activity microbial. It was found that the microorganisms during the process are basically categorized as halophile (Abdullah et al., 1978). The halophilic is the microorganisms that discovered while the Anchovy Sauce production under process. The feature of this sauce is an obviously brown liquid which is the sequence of fish fermentation at high salt content (Saisithi, 1994).

Furthermore, the microorganisms play significant function in degradation of protein and flavor-aroma development. The Anchovy Sauce considered a matured measure ready to be harvested as an oil film produced on its surface. In order to separate the liquid as well as the dregs of the bone, the anchovy sauce is filtered by using the standard filtration method. Afterwards, the Anchovy sauce will be under the process of caning as well as packaging, and then will be distributed to the markets. Anchovy Sauce considered very popular production in several countries but with different names such as: ‘colombo-cure’ in India and Pakistan, ‘ishiru’ or ‘shottsuru’ in Japan, ‘aejeot’ in Korea, ‘yeesu’ in China, ‘patis’ in Philippines, ‘ketjap-ikan’ in Indonesia ‘ngapi’ in Burma and ‘nuoc mam’ in Vietnam.

The content of the Anchovy Sauce has many nutrients, which benefits the consumer. Anchovy sauce considered a source of vitamin B such as: vitamin B1 (thiamin), B2 (riboflavin), niacin, pantothenic acid, vitamin B6 and vitamin B12 (cyanocobalamin). The deficiency of vitamin B12 will lead to lack in the production of red blood cells. Hence, vitamin B12 considered very important since the lack of this vitamin will cause loss of weight, anemia perisiosa and stomach ache.

Another advantage that can be found in Anchovy Sauce is a magnificent ability to hunt free radicals. Therefore, it prevents degenerative illness such as: diabetes, cardiovascular coroner, atherosclerosis and cancer in an earlier stage since the Anchovy Sauce has Genistein and phytoestrogen, which prevent breast cancer. Also, it helps to slow down the aging process as the components it has. Furthermore, it has been found by some researcher that the anchovy sauce not only can decrease blood cholesterol, but prevent cardiovascular diseases as well as hypertension also.

Moreover, as the Anchovy sauce has a dietary fibre sauce, it facilitates the process of the digestion. Thus, the benefits, which caused by the nutritious component of Anchovy sauce satisfies all body needs. Figure 1.1 shows the Anchovy sauce that utilized as a sample for the measurement

Figure 1.1: Anchovy sauce

The process of fish protein hydrolysis leads to Anchovy Sauce (fish sauce), with a product of fermented fish at high salt concentration (Chaveesuk et al., 1994). For many years, the fish fermentation has been considered a product in Southeast Asian. For the purpose of achieving the simpler components of fish, high percentages as well as fermentation are needed. The usual action of fermentation, especially in sub-region of Southeast Asian, continues around three to nine months; therefore, the flesh of fish might be dissolved or become a paste (Vilhelmasson, 1997). Fermented products, which is considered aquatic (taking a place in water), prepared in a different ranges such as: whole fish, fish sauces as well as pastes (Wheaton and Lawson, 1985).

To avoid rottenness of the fish, the processing and canning technology of fish considered crucial demand; hence, the quality of fish obtained. There are several differences of using the conventional and modern way to prepare Anchovy. In the traditional way, the equipment, which is utilized, is simple. While in modern way, the equipment is developed and the additions are more. Due to several factors such as the habits of local people and availability of salt, techniques of different processing are utilized in fish fermentation from a place to another.

1.2 Microwave Sensor

The developments of many types of microwave sensors for determining the moisture content *m.c* in materials have been achieved. Microwave sensors utilize electromagnetic fields and devices internally operating at frequencies starting from ~300 MHz up to the terahertz range. Microwave sensors considered very applicable in several fields such as environment, medicine, industry and in a large degree in agricultural industry to assess the quality. In essence, the principles, functions and limitation play a significant role in the selection and deployment of microwave sensor. Coaxial type, waveguide, horn antenna and microstrip are the most popular microwave sensors as illustrated in Figure 1.2. Furthermore, bandwidth, ease and size of the fabrication, the capability of power handling as well as the range of the frequency considered important factors in terms of comparing between the transmission lines

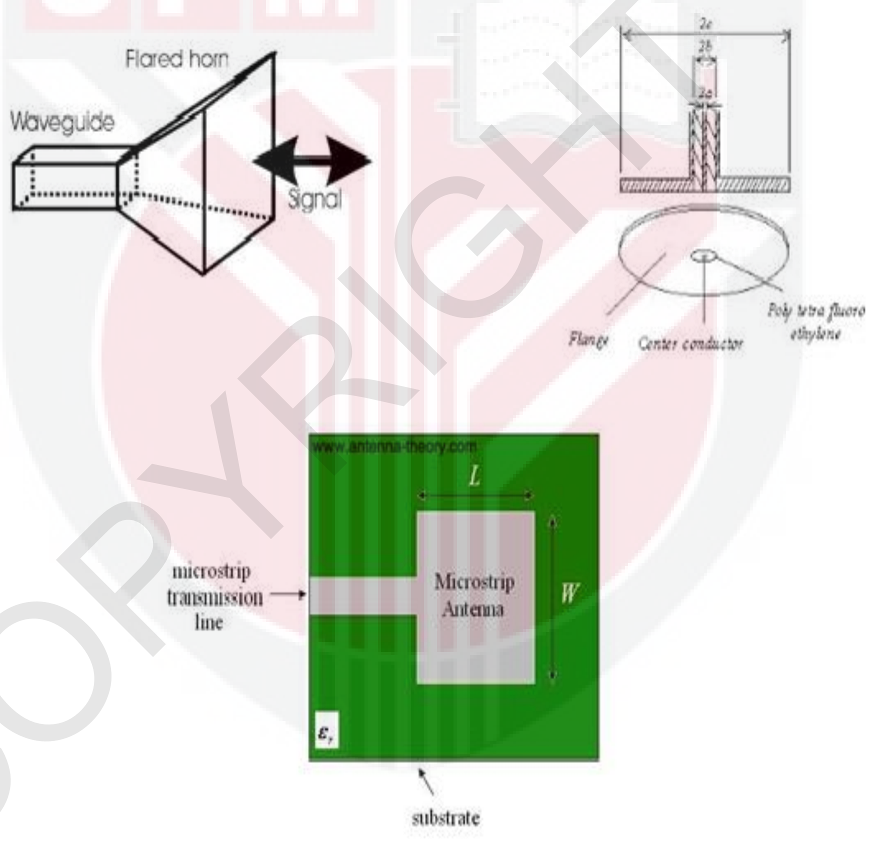

Figure 1.2: Examples of microwave sensors (Saunders and Aragón, 2007)

Microwave technique is one of many methods to determine moisture content of the moist materials. The benefits of different sensors are tremendously dependent on the particular applications as listed below (Nyfors and Vainikainen, 1989):

i. Due to the penetration of the microwaves to all materials except metals, the surface and the volume of the material can be represented;

ii. Contact to the object (material) is not necessary for microwaves; hence, the possibility of implementing the on-line measurements from a distance is usually achieve, where there is no interference to the industrial process;

iii. In contrast to infrared method, microwave sensors are not sensitive to the environmental conditions, for instance, dust and water vapour. Also, in contrast to semiconductor sensors, it is insensitive to high temperatures;

iv. At low frequencies such as capacitive and resistive sensors, the electrical properties of materials are often controlled by the DC conductivity. In addition, the DC conductivity is dependent heavily on the ion content as well as temperature. However, the effect of DC conductivity vanishes at microwave frequencies;

v. In contrast to radioactive ionizing radiation, the non-ionizing radiation (microwaves) are considered safer at the power level that used in the measurements;

vi. In contrast to radioactive sensors, microwave sensors are fast;

vii. The microwave techniques have been proven to be important in agricultural especially for moisture content measurements of agricultural products. The applications of microwave in agriculture have been reported in (Krazewski et al., 1997; 1998; Khalid et al., 2006; Guo et al., 2007).

1.3 Problem Statement

Fresh Anchovy sauce consists of 60% to 75% moisture, 4% to 11 % lipid, 19% to 23% protein, 1% to 2 % ash, and 1% to 3% carbohydrate (Kocatepe, 2011; Lopetcharat and Park, 2002). Critical analyses suggested a reduction of 3% moisture in Anchovy sauce within 5 days after fermentation and continued to decrease up to 60 days after fermentation (Lopetcharat and Park, 2002). Changes in *m.c* were also linked to physicochemical and microbiological changes especially on the salt and nitrogen content as well as the acidity of the fish sauce. Unfortunately to date, the only method to determine *m.c* in Anchovy sauce is based on the standard oven drying method.

In spite of its rich source of iron and salt content, the dielectric properties of Anchovy Sauce have not been reported in the literature. The relationship between the dielectric constant ε', loss factor ε'' and *m.c* is especially important. The ε' is the ability to store energy under applied external electric field whilst the ε'' is the tendency to loose energy. Most materials have ε'' lower than the ε'. Thus it would be interesting to examine the dielectric properties of a lossy material such as Anchovy Sauce having a high percentage of *m.c*, salt and iron content. This project will use a microstrip sensor where the transmission coefficient is very much affected when the sensor is loaded with a lossy material. In addition to aforementioned, a pioneering work on the application of microstrip sensor will be used to evaluate the amount of moisture content using regression equation based on transmission coefficient. The measured results shall be compared with the calculated values using FEM.

1.4 Research Objectives

The objectives of this study are:

1. To establish equations relating the dielectric constant and loss factor to the amount of moisture content in Anchovy Sauce

2. To design, fabricate and test microstrip sensor for determination of moisture content in Anchovy Sauce and to determine the most accurate calibration equation to predict the amount of moisture content using the microstrip sensor

3. To compare the measured transmission coefficient with the theoretical values and to visualize the electric field distribution of a microstrip sensor loaded with Anchovy sauce using Finite Element Method (FEM)

1.5 Scope of Thesis

Chapter 2 begins with basic concepts of a microstrip, followed by literature review on the various methods to calculate the impedance of the microstrip line. This is followed with a brief critical description on microwave moisture measurement techniques. Numerical techniques to calculate impedance of microstrip are also described. The basic theory of the microstrip and finite element method are described in detail in Chapter 3. . The fabrication and measurement procedure for the microstrip sensor and moisture determination using oven drying method are described in Chapter 4. Also, the implementation of finite element method using COMSOL software is also detailed in Chapter 4. All the results related to the research objectives are presented and analyzed in Chapter 5. Finally, Chapter6 summarized the main contributions and suggestions for future work.

REFERENCES

Abbas, Z., Mokhtar, R., Khalid, K., Hashim, M., & Aziz, S. A. (2007). RDWG technique of determination of moisture content in Oil Palm Fruits. The European Physical Journal Applied Physics, 40(02), 207-210.

Abbas, Z., Yeow, Y. K., Shaari, A. H., Khalid, K., Hassan, J., & Saion, E. (2005). Complex permittivity and moisture measurements of oil palm fruits using an open-ended coaxial sensor. Sensors Journal, IEEE, 5(6), 1281-1287.

Abdullah, M. I., Idrus, A. Z., & MARDI, S. (1978). The fish processing industry in Peninsular Malaysia. In Indo-Pacific Fishery Commission Symposium on Fish Utilization Technology and Marketing in the IPFC Region, Rep (No. 147, pp. 8-11).

Ahmad, A. F., Abbas, Z., Obaiys, S. J., Jusoh, M. A., & Talib, Z. A. (2012). Analysis and Optimal Design of a Microstrip Sensor for Moisture Content in Rubber Latex Measurement. Adv. Studies Theor. Phys, 6(2).

Ashcraft, C., & Grimes, R. G. (1999, March). SPOOLES: An Object-Oriented Sparse Matrix Library. In PPSC.

Austin, J., Rodriguez, S., Sung, P. F., & Harris, M. (2013). Utilizing microwaves for the determination of moisture content independent of density. *Powder Technology*, *236*, 17-23.

Austin, J., Rodriguez, S., Sung, P. F., & Harris, M. (2013). Utilizing microwaves for the determination of moisture content independent of density. *Powder Technology*, *236*, 17-23.

Awang, Z., Zaki, F. A. M., Baba, N. H., Zoolfakar, A. S., & Bakar, R. A. (2013). A Free-Space Method for Complex Permittivity Measurement of Bulk and Thin Film Dielectrics at Microwave Frequencies. *Progress In Electromagnetics Research B*, *51*, 307-328.

Bahl, I. J., & Garg, R. (1977). Simple and accurate formulas for a microstrip with finite strip thickness. Proceedings of the IEEE, 65(11), 1611-1612.

Bahl, I. J., & Stuchly, S. S. (1980). Analysis of a microstrip covered with a lossy dielectric. Microwave Theory and Techniques, IEEE Transactions on,28(2), 104-109.

Balanis, C. A. (1989). Advanced engineering electromagnetics.

Balanis, C. A. (2012a). Advanced engineering electromagnetics (Vol. 111). John Wiley & Sons.

Balanis, C. A. (2012b). Antenna theory: analysis and design. John Wiley & Sons.

Barton, M. L., & Cendes, Z. J. (1987). New vector finite elements for three-dimensional magnetic field computation. Journal of Applied Physics, 61(8), 3919-3921.

Bin Khalid, K., Hassan, J., Abbas, Z., & Hamami, M. (2005). Microwave Dielectric Properties of Hevea Rubber Latex, Oil Palm Fruit and Timber and Their Application for Quality Assessment. In Electromagnetic Aquametry (pp. 467-490). Springer Berlin Heidelberg.

Blackham, D. V., & Pollard, R. D. (1997). An improved technique for permittivity measurements using a coaxial probe. IEEE Transactions on Instrumentation and Measurement, 46(5), 1093-1099.

Booton, R. C. (1992). Computational methods for electromagnetics and microwaves. Wiley.

Brenner, S. C., & Scott, R. (2008). The mathematical theory of finite element methods (Vol. 15). Springer.

Chaveesuk, R., Smith, J. P., & Simpson, B. K. (1994). Production of fish sauce and acceleration of sauce fermentation using proteolytic enzymes. Journal of Aquatic Food Product Technology, 2(3), 59-77.

Ciarlet, P. G. (1978). The finite element method for elliptic problems. Elsevier.

Courant, R. (1943). Variational methods for the solution of problems of equilibrium and vibrations. Bull. Amer. Math. Soc, 49(1), 1-23.

Davidson, D. B. (2005). Computational electromagnetics for RF and microwave engineering. Cambridge University Press.

Davis, T. A. (2004). A column pre-ordering strategy for the unsymmetric-pattern multifrontal method. ACM Transactions on Mathematical Software (TOMS),30(2), 165-195.

Davis, T. A., & Duff, I. S. (1997). An unsymmetric-pattern multifrontal method for sparse LU factorization. SIAM Journal on Matrix Analysis and Applications,18(1), 140-158.

Davis, T. A., & Duff, I. S. (1999). A combined unifrontal/multifrontal method for unsymmetric sparse matrices. ACM Transactions on Mathematical Software (TOMS), 25(1), 1-20.

Denlinger, E. J. (1980). Losses of Microstrip Llines. IEEE Transactions on Microwave Theory Techniques, 28, 513-522.

Edwards, T. C., & Edwards, T. C. (1981). Foundations for microstrip circuit design (p. 265). Chichester etc.: Wiley.

Franks, F. (1972). Water: a comprehensive treatise.

Garg, R., & Bahl, I. J. (1978). Microstrip discontinuities. International Journal of Electronics Theoretical and Experimental, 45(1), 81-87.

Guo, W. C., Nelson, S. O., Trabelsi, S., & Kays, S. J. (2007). 10–1800-MHz dielectric properties of fresh apples during storage. Journal of food engineering,83(4), 562-569.

Hammerstad, E., & Jensen, O. (1980, May). Accurate models for microstrip computer-aided design. In Microwave Symposium Digest, 1980 IEEE MTT-S International (pp. 407-409). IEEE.

Hassan, J., Khalid, K., Yusof, W., & Daud, W. M. (1997). Microwave dielectric properties of hevea rubber latex in the temperature range of-30 C to 50 C.Pertanika Journal of Science & Technology, 5(2), 179-190.

Hestenes, M. R., & Stiefel, E. (1952). Methods of conjugate gradients for solving linear systems (Vol. 49, pp. 409-436). NBS.

Hong, J. S. G., & Lancaster, M. J. (2004). Microstrip filters for RF/microwave applications (Vol. 167). John Wiley & Sons.

Jayanthy, T., & Sankaranarayanan, P. E. (2005). Measurement of dry rubber content in latex using microwave technique. Measurement Science Review,5(3), 50-54.

Jin, J. M., & Riley, D. J. (2009). Finite element analysis of antennas and arrays. John Wiley & Sons.

Jin, J. M., Jin, J., & Jin, J. M. (2002). The finite element method in electromagnetics (pp. 553-554). New York: Wiley.

K.C. Gupta, R. grag, I. Bahl, and P. Bhartis (1996), Microstrip Lines and Slotlines, Second Edition, Artech House, Boston

Khalid, K. (1988). application of microstrip sensors for determination of moisture content in Hevea rubber latex. Journal of microwave power and electromagnetic energy: a publication of the International Microwave Power Institute.

Khalid, K., Ghretli, M. M., Abbas, Z., & Grozescu, I. V. (2006, September). Development of planar microwave moisture sensors for hevea rubber latex and oil palm fruits. In RF and Microwave Conference, 2006. RFM 2006. International(pp. 10-15). IEEE

Khamis, N. H. H., Ramli, S., Ean, T. C., & Bakar, W. Z. A. W. (2005, December). Application of microwave technology for home industry. In Applied Electromagnetics, 2005. APACE 2005. Asia-Pacific Conference on (pp. 4-pp). IEEE.

Kinayman, N., & Aksun, M. I. (2005). Modern microwave circuits. Artech House.

Kirschning, M., & Jansen, R. H. (1984). Accurate wide-range design equations for the frequency-dependent characteristic of parallel coupled microstrip lines.Microwave Theory and Techniques, IEEE Transactions on, 32(1), 83-90.

Klaus, K. (2005). Electromagnetic Algometry: Electromagnetic Wave Interaction with Water and Moist Substances, Springer-Verlag Berlin Heidelberg, Germany.

Kobayashi, M. (1988). A dispersion formula satisfying recent requirements in microstrip CAD. Microwave Theory and Techniques, IEEE Transactions on,36(8), 1246-1250.

Kocatepe, D., Turan, H., Taskaya, G., Kaya, Y., Erden, R., & Erdoğdu, F. (2011). Effects of cooking methods on the proximate composition of Black Sea anchovy (Engraulis encrasicolus, Linnaeus 1758). GIDA/The Journal of FOOD,36(2).

Kompa, G. (2005). Practical microstrip design and applications. Artech House.

Kraszewski, A. (1978). MODEL OF THE DIELECTRIC PROPERTIES OF WHEAT AT 9.4-GHZ. JOURNAL OF MICROWAVE POWER AND ELECTROMAGNETIC ENERGY, 13(4), 293-296.

Kraszewski, A. (1996). Microwave aquametry: electromagnetic wave interaction with water-containing materials. IEEE.

Kraszewski, A. W. (1991). Microwave aquametry-needs and perspectives.Microwave Theory and Techniques, IEEE Transactions on, 39(5), 828-835.

Kraszewski, A. W. (2005). Recent developments in electromagnetic aquametry(pp. 1-12). Springer Berlin Heidelberg.

Kraszewski, A. W., & Nelson, S. O. (1995, July). Application of microwave techniques in agricultural research. In Microwave and Optoelectronics Conference, 1995. Proceedings., 1995 SBMO/IEEE MTT-S International (Vol. 1, pp. 117-126). IEEE.

Kraszewski, A. W., & Nelson, S. O. (2004). Microwave permittivity determination in agricultural products. Journal of Microwave Power and Electromagnetic Energy, 39(1), 41-52.

Kraszewski, A. W., Trabelsi, S., & Nelson, S. O. (1997). Moisture content determination in grain by measuring microwave parameters. Measurement Science and Technology, 8(8), 857.

Kraszewski, A. W., Trabelsi, S., & Nelson, S. O. (1999). Temperature-compensated and density-independent moisture content determination in shelled maize by microwave measurements. Journal of agricultural engineering research, 72(1), 27-35.

Kraszewski, A., Kulinski, S., & Matuszewski, M. (1976). Dielectric properties and a model of biphase water suspension at 9.4 GHz. Journal of Applied physics, 47(4), 1275-1277.

Laverghetta, T. S. (2000). Microwave materials and fabrication techniques.

Logan, D. L. (2012). A first course in the finite element method. Cengage Learning.

Lopetcharat, K., & Park, J. W. (2002). Characteristics of Fish Sauce Made from Pacific Whiting and Surimi By-products During Fermentation Stage. Journal of food science, 67(2), 511-516.

Lucas, E. W., & Fontana, T. P. (1995). A 3-D hybrid finite element/boundary element method for the unified radiation and scattering analysis of general infinite periodic arrays. Antennas and Propagation, IEEE Transactions on,43(2), 145-153.

Marin, S. P. (1982). Computing scattering amplitudes for arbitrary cylinders under incident plane waves. Antennas and Propagation, IEEE Transactions on,30(6), 1045-1049.

Matthew M. Radman, (2007). RF &Microwave Design Essentials: Engineering Design and Analysis from DC to Microwave. pp. 312-313.

Mei, K. K. (1974). Unimoment method of solving antenna and scattering problems. Antennas and Propagation, IEEE Transactions on, 22(6), 760-766.

Musil, J., & Zacek, F. (1986). Microwave measurements of complex permittivity by free space methods and their applications. NASA STI/Recon Technical Report A, 87, 20354.

Nelson Jr, R. M. (2000). Prediction of diurnal change in 10-h fuel stick moisture content. Canadian Journal of Forest Research, 30(7), 1071-1087.

Ney, M. M. (1985). Method of moments as applied to electromagnetic problems. Microwave Theory and Techniques, IEEE Transactions on, 33(10), 972-980.

Noyan, K. M. and Aksum, I. (2005). Modern Microwave Circuits, Artech House, INC. Norwood.

Nyfors, E., & Vainikainen, P. (1989). Industrial microwave sensors (pp. 207-212). Norwood (MA, USA): Artech House.

Nyfors, E., & Vainikainen, P. (1994). Industrial microwave sensors. Artech House.

Okamura, S. (2000). Microwave technology for moisture measurement.Subsurface sensing technologies and applications, 1(2), 205-227.

Pandey, G., Kumar, R., & Weber, R. J. (2013, November). Design and implementation of a self-calibrating, compact micro strip sensor for in-situ dielectric spectroscopy and data transmission. In *Sensors, 2013 IEEE* (pp. 1-4). IEEE.

Pozar, D. M. (2009). Microwave engineering. John Wiley & Sons.

Pucel, R. A., Masse, D. J., & Hartwig, C. P. (1968). Losses in microstrip.Microwave Theory and Techniques, IEEE Transactions on, 16(6), 342-350.

Roslina, M. (2004). RDWG Technique for Determination of Complex Permittivity and Moisture Content of Oil Palm Fruits. Master's dissertation, Universiti Putra Malaysia.

Saad, Y., & Schultz, M. H. (1986). GMRES: A generalized minimal residual algorithm for solving nonsymmetric linear systems. SIAM Journal on scientific and statistical computing, 7(3), 856-869.

Sadiku, M. N. (2000). Numerical techniques in electromagnetics. CRC press.

Saisithi, P. (1994). Traditional fermented fish: fish sauce production. InFisheries processing (pp. 111-131). Springer US.

Saunders, S., & Aragón-Zavala, A. (2007). Antennas and propagation for wireless communication systems. John Wiley & Sons.

Schenk, O., Gärtner, K., & Fichtner, W. (2000). Efficient sparse LU factorization with left-right looking strategy on shared memory multiprocessors.BIT Numerical Mathematics, 40(1), 158-176.

Schmugge, T. J. (1983). Remote sensing of soil moisture: Recent advances.Geoscience and Remote Sensing, IEEE Transactions on, (3), 336-344.

Sharpe, L. M. (1988). Dielectric Covered Microstrip Patch Antennas (No. RADC-TR-88-307). ROME AIR DEVELOPMENT CENTER GRIFFISS AFB NY.

Siew, W. L. Tang, T. S. and Tan, T. A. (1995). PORIM Test Methods P4.2, Palm Oil Research Institute of Malaysia: Bangi, 112-113.

Silvester, P. P., & Ferrari, R. L. (1996). Finite elements for electrical engineers. Cambridge university press.

Snyder, A. W., & Love, J. (1983). Optical waveguide theory (Vol. 190). Springer.

Sokolnikoff, I. S., & Specht, R. D. (1956). Mathematical theory of elasticity(Vol. 83). New York: McGraw-Hill.

Trabelsi, S., Kraszewski, A. W., & Nelson, S. O. (1998). Nondestructive microwave characterization for determining the bulk density and moisture content of shelled corn. Measurement Science and Technology, 9(9), 1548.

Trabelsi, S., Paz, A. M., & Nelson, S. O. (2013). Microwave dielectric method for the rapid, non-destructive determination of bulk density and moisture content of peanut hull pellets. *Biosystems Engineering*, *115*(3), 332-338.

Tsipogiannis, C. Microwave materials characterization using waveguides and coaxial probe.

Ulaby, F. T., Michielssen, E., & Ravaioli, U. (2010). Fundamentals of applied electromagnetics. Prentice Hall.

Vilhelmsson, O. (1997). The state of enzyme biotechnology in the fish processing industry. Trends in Food Science & Technology, 8(8), 266-270.

Von Hippel, A. R. (1954). Dielectric Materials and Applications. Papers by 22 Contributors. New York.

Wheaton, F. W., & Lawson, T. B. (1985). Processing aquatic food products.

Yee, K. S. (1966). Numerical solution of initial boundary value problems involving Maxwell's equations. IEEE Trans. Antennas Propag, 14(3), 302-307.