UNIVERSITI PUTRA MALAYSIA

CRITICAL ANALYSIS OF RECTANGULAR WAVEGUIDE FOR DETERMINATION OF MOISTURE CONTENT IN HEVEA RUBBER LATEX

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By

RAHIMAH MUSTAPA ZAHARI

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

December 2013

Dedicated to:

My Family

Thank you for your support.

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

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December 2013

Chairman: Associate Professor Zulkifly Abbas, PhD
Faculty: Science

The thesis describes a detailed investigation on the application of rectangular waveguide technique for determination of moisture content in hevea rubber latex samples in the frequency range between 8.2 GHz and 12.4 GHz. The actual moisture content in natural rubber obtained using oven drying method is too time consuming and laborious. Several microwave techniques have been proposed but the simultaneous effects of moisture content on the transmission and reflection properties of latex of various sample thicknesses have not been described. In this work, theoretical and experimental results for both the transmission and reflection coefficients were carried out for a range of samples of different percentages of moisture content. The microwave measurement system consists of a rectangular waveguide joined to a pair of input and output waveguide to coaxial adapters connected to a Professional Network Analyzer by coaxial cables. Each set of transmission and reflection data consisted of 201 numbers of points. Effects of multiple reflections in the samples were found to be negligible for sample thickness greater than 25 mm. The industry standard Agilent *85070E* Dielectric Probe Kit was used to calculate complex permittivity of hevea latex samples from the measured data. The mean relative error between waveguide and open ended coaxial technique in determination of dielectric constant and loss factor of hevea latex of various percentages of moisture content were 0.3011 and 0.2861, respectively. It was found that two sets of linearity range could be observed for the relationship between real and imaginary parts of permittivity with moisture content beyond 64% moisture content when using the Agilent Probe Kit. This could be probably due to the inaccuracy of the dielectric model adopted by the probe. The permittivity values were used as inputs to calculate the transmission and reflection coefficients using the Nicholson Ross Weir method and transmission line equation with an optimization method. Calibration equations relating complex permittivity, reflection and transmission coefficients to moisture content in hevea latex samples were established for several selected frequencies. The waveguide technique in conjunction with Nicholson Ross Weir method was found to be sufficiently accurate to calculate the permittivity of samples in the *X*-band frequency. The higher the amount of moisture content in the sample, the lower was the magnitude of transmission coefficient. The measured and calculated reflection and transmission coefficient using Nicholson Ross Weir method was found to be in very good agreement at the upper end of the frequency. The optimum thickness for magnitude of reflection coefficient measurement of all latex samples was 25 mm where magnitude of transmission coefficient reduced exponentially to almost zero suggesting almost complete absorption of the probing wave. Accurate prediction of magnitude of transmission coefficient can be obtained using an optimization method with a mean error as small as 0.0132. The calibration equation based on the magnitude of the reflection coefficient at 8.4 GHz was found to be most accurate within ±5% in the determination of moisture content in hevea latex.

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

ANALISIS KRITIKAL PANDUGELOMBANG UNTUK PENENTUAN KANDUNGAN KELENGASAN DALAM GETAH HEVEA LATEKS

Oleh

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Tesis ini menghuraikan perincian penyelidikan terhadap aplikasi teknik pandu-gelombang bersegi empat tepat bagi penentuan kandungan kelengasan di dalam getah lateks hevea dalam had frekuensi di antara 8.2 GHz dan 12.4 GHz. Kandungan kelengasan sebenar di dalam getah asli diperolehi menggunakan kaedah pengeringan ketuhar adalah sangat menggunakan masa dan sukar. Beberapa teknik gelombang-mikro telah pun dicadangkan tetapi kesan-kesan serentak kandungan kelengasan terhadap sifat-sifat penghantar dan pantulan terhadap lateks terhadap berbagai-bagai ketebalan sampel masih tidak dihuraikan. Dalam kerja ini, keputusan-keputusan berdasarkan teori dan ujikaji untuk kedua-dua pekali penghantar dan pantulan telah dilakukan untuk had sampel-sampel yang berbeza peratusan kandungan kelengasan. Sistem pengukuran gelombang-mikro terdiri daripada pandu-gelombang bersegi empat tepat dihubungkan kepada sepasang masukan dan hasilan pendu-gelombang kepada penghubung sepaksi disambung kepada Penganalisis Rangkaian Profesional dengan kabel sepaksi. Setiap satu set data penghantar dan pantulan terdiri daripada 201 bilangan nombor. Kesan-kesan pantulan berganda di dalam sampel-sampel telah didapati akan menjadi tidak penting bagi ketebalan sampel lebih besar daripada 25 mm. Piawai industri Peralatan Pengesan Dielektrik Agilent *85070E* telah digunakan bagi mengira ketelusan permitiviti kompleks sampel lateks hevea daripada data yang diukur. Purata kesalahan relatif di antara pandu-gelombang dan teknik sepaksi hujung terbuka dalam penentuan pemalar dielektrik dan faktor kehilangan terhadap lateks hevea terhadap pelbagai peratusan kandungan kelengasan ialah 0.3011 dan 0.2861, berturut. Dua set had lineariti telah didapati boleh diperhatikan untuk hubungan di antara bahagian nyata dan khayalan melewati 64% kandungan kelengasan apabila menggunakan Peralatan Pengesan Agilent. Ini mungkin barangkali dianggap berpunca daripada ketidaktepatan model dieletrik yang diguna pakai oleh perisian pengesan tersebut. Nilai-nilai permitiviti telah digunakan sebagai masukan bagi mengira pekali-pekali penghantar dan pantulan menggunakan kaedah Nicholson Ross Weir dan persamaan talian penghantar dengan kaedah penyelarasan. Persamaan penentukuran berhubung ketelusan permitiviti kompleks, pekali-pekali pantulan dan penghantar dengan kandungan kelengasan di dalam sampel lateks hevea telah ditubuhkan untuk beberapa frekuensi terpilih. Teknik pandu-gelombang dihubungkan dengan Nicholson Ross Weir didapati menjadi tepat memadai untuk mengira permitiviti sampel-sampel dalam frekuensi *X*-band. Semakin tinggi jumlah kandungan kelengasan dalam sampel, semakin rendah magnitud pekali penghantar. Pekali pantulan dan penghantar yang diukur dan dikira menggunakan kaedah Nicholson Ross Weir didapati menjadi persetujuan sangat baik pada frekuensi tinggi hujung. Ketebalan optima untuk pengukuran magnitud pekali pantulan terhadap semua sampel lateks ialah 25 mm dimana magnitud pekali penghantar berkurangan secara eksponen kepada hampir kosong mencadangkan penyerapan hampir lengkap terhadap perisian pengesan tersebut. Jangkaan tepat terhadap magnitud pekali penghantar boleh didapati menggunakan kaedah penyelarasan dengan purata kesalahan serendah 0.0132. Persamaan penentukuran berdasarkan magnitud pekali pantulan pada 8.4 GHz telah dijumpai lebih tepat dalam lingkungan ±5% bagi penentuan kandungan kelengasan dalam lateks hevea.

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I certify that a Thesis Examination Committee has met on 6 December 2013 to conduct the final examination of Rahimah Mustapa Zahari on her thesis entitled "Critical Analysis of Rectangular Waveguide for Determination of Moisture Content in 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 Master of Science.

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LIST OF SYMBOLS

ε’	dielectric constant
ε”	dielectric loss factor
σ	conductivity
μ	permeability
tanδ	loss tangent
$\lvert S_{11} \rvert$	magnitude of reflection coefficient
$\lvert S_{21} \rvert$	magnitude of transmission coefficient
m_w	mass of wet matter
m_d	mass of dry matter
ε*	complex permittivity
E	electric field intensity
H	magnetic field intensity
D	electric flux density
B	magnetic flux density
M	magnetic current density
J	electric current density
ρ	electric charge density
$\varepsilon = \varepsilon_0$	permittivity of free space
$\mu = \mu_0$	permeability of free space
σ	conductivity of the medium
ω	angular frequency of the wave

$e^{j\omega t}$	time dependence
k	wavenumber
γ	propagation constant for a medium
α	attenuation constant
β	phase constant
$\omega\varepsilon'' + \sigma$	an effective conductivity of the lossy dielectric
a	width of waveguide
b	height of waveguide
c	offset (*y*-intercept)
m	residual mass after drying
m_0	initial mass
ε, ε_r^*, ε_R	complex permittivity
μ_r^*, μ_R	complex permeability
Y	admittance
G	conductance
B	susceptance
R	reflection coefficient (theory)
T	transmission coefficient (theory)
Z_0	free space impedance
P_{theory}	propagation factor due to the dielectric slab
$\|T\|$	magnitude of transmission coefficient
d	length/sample thickness

β_S	phase constant
funZ	objective function
ϕ_{S11}	phase S_{11}
ϕ_{S21}	phase S_{21}
$\Delta\phi_{S11}$	phase shift S_{11}
$\Delta\phi_{S21}$	phase shift S_{21}
$\boldsymbol{h_z}$	longitudinal magnetic field
$\boldsymbol{e_z}$	longitudinal electric field
∇	laplacian operator
∇_t	vector Laplacian operator
γ_I, γ_{III}, γ_S	complex propagation constant in media I, II and III
I, *II*, *III*	media I, II and III
l	distance corresponding to an integer number of half-wavelengths in the sample
S_{11}, S_{21}	scattering parameters, reflection coefficient and transmission coefficient (measurement)
Z_0	free space impedance
R, *T*	reflection and transmission coefficients calculated from the boundary conditions of a sample placed between two homogeneous media (theory)
$z = 0$, $z = d$	boundaries
Γ_A, Γ_B	reflection coefficients at interfaces $z = 0$ and $z = d$
R^2	regression coefficient

LIST OF ABBREVIATIONS

m.c.	moisture content
SMR 20	Standard Malaysian Rubber 20
R&D	Research and Development
FDTD	Finite Difference Time Domain
NRW	Nicholson Ross Weir
DRC	Dry Rubber Content or Rubber Hydrocarbon
NRS	Non-Rubber Solid
PNA	Professional Network Analyser
S-parameters	Scattering parameter
SOLT	Short-Open-Load-Thru
TRL	Thru-Reflect-Line
TEM	Transverse electromagnetic
TE	Transverse electric
TM	Transverse magnetic
MATLAB	Matrix laboratory
NRC	Non-Rubber Constituents
TSC	Total Solid Content
SIRIM	Standards and Industrial Research Institute of Malaysia
LED	Light Emitting Diode
TROTEC T600	Material Moisture Meter
EM	Electromagnetic
PVC	Polyvinylchloride

MNDT	Microwave Non-Destructing Testing
WR90	X-band Rectangular Waveguide
UPM	Universiti Putra Malaysia
VNA	Vector Network Analyzer

CHAPTER ONE

INTRODUCTION

1.1 Rubber Industry in Malaysia

The rubber industry is considered as the most important agricultural crop in Malaysia. Since World War One, rubber had been one of the main contributors to the Malaysian economy and is still among the world's most important rubber growing nation. The high demand for rubber market in the world, as illustrated in Figure 1, caused the rubber price increased, thus the government take the initiative to carry out the project of planting rubber which significantly contributes to the country income.

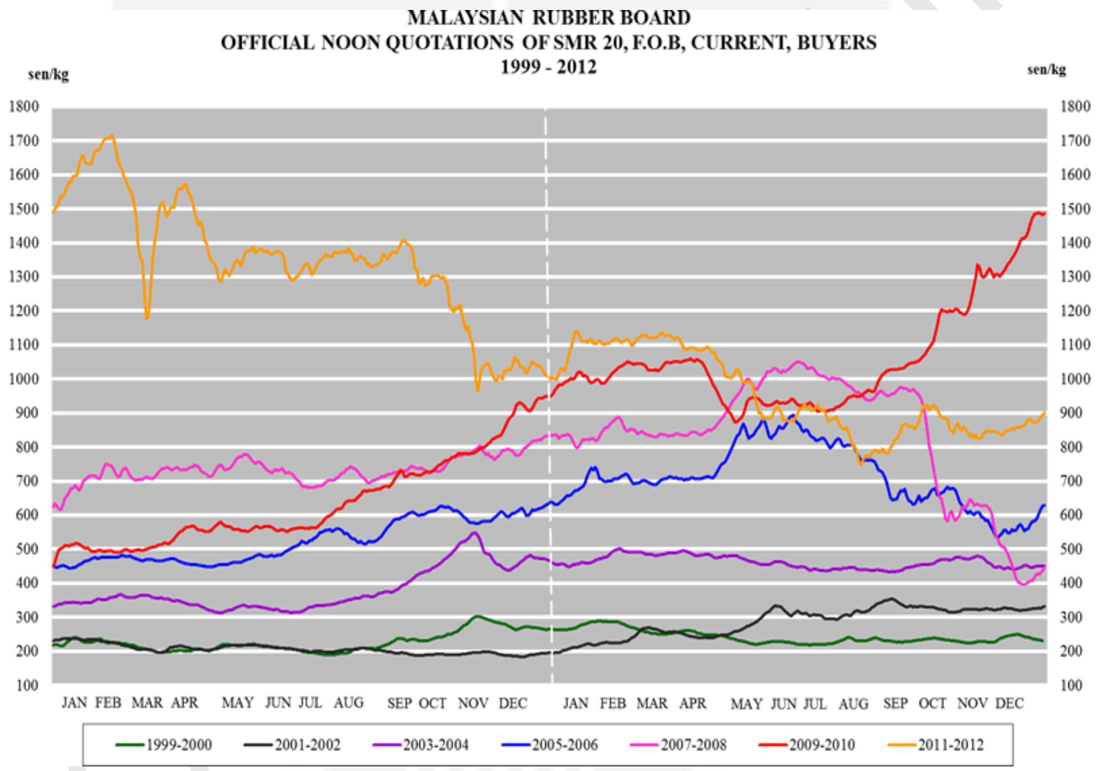


Figure 1. Statistic of *SMR* 20 prices, 1999 – 2012
(Source: Malaysia Rubber Board)

It is clearly seen that the rubber price drastically increased at the end of 2010. In Malaysia, the introduction of rubber industry began with the failure of coffee (Grist, 1936). A total of 22 plants of rubber tree were brought here. The first rubber planting was done at Kuala Kangsar, in 1877. Malaysia has an appropriate annual temperature throughout the year which allows for rubber cultivation widespread. Moreover, the soil, climate, cost and life expectancy for a rubber tree also affect the rubber planting in Malaysia.

1.2 Natural Rubber

Rubber seed's originated from Brazil. Mr. Henry William introduced the rubber seed to the East in 1876-1877 through the Royal Botanic Gardens, Kew. The history of rubber industry began with the consequent demand for rubber tyres and tubes due to the rapid improvement in the internal combustion engine effects of phenomenal development motor-vehicle industry. The world's destroyed various wild plants in order to obtain the rubber. It has been found that present day rubber source, the indigenous Para rubber tree (Hevea Brasiliensis species) of the Amazon districts of South America, gives the most satisfactory returns where the extraction of rubber does not necessitate the destruction of the tree.

In 1905, the rubber plantations in Malaysia yielded less than 200 tons compared to the jungle product of South America (35,000 tons) and the rest of the world (27,000 tons). In 1910, the real shortage of raw rubber made the price of rubber soared to over 12 shillings per pound. As mentioned above, this is due to the phenomenal development motor-vehicle industry. Some ten or twelve years later, production had increased so greatly as to exceed the demand. These phenomena resulted in the manufacture of tyres which attained twice to three times the previous mileage per tyre.

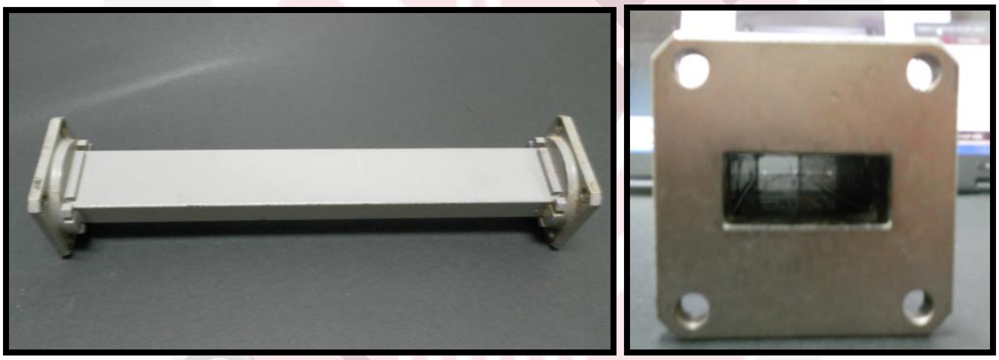
From 1905-1913, the plantations of rubber industry of the East made great strides, principally Malaysia, Ceylon and the Netherlands Indies – produced more rubber than was obtained from South America and in the next year exceeded the production of wild rubber from all parts of the world (Grist, 1936).

1.3 Problem Statement

The quality of fresh latex depends on the amount of moisture content (*m.c.*). Climatic conditions and tapping techniques affect the concentration of hevea latex. The higher the amount of *m.c.* the less will be the amount of dry rubber content (*DRC*). The industrial acceptable amount of *m.c.* for a freshly tapped natural rubber latex sample is usually between 40% and 65%. Bad practices such as addition of too much water could affect the actual price of latex. Unfortunately conventional oven drying method for determination of latex concentration is too laborious and time consuming. Alternative methods have been proposed where the microwave techniques are probably the most popular (Kupfer, 2005). However all the microwave techniques (Ansarudin *et al.*, 2012; Ali *et al.*, 2011) were mostly based on one-port measurement. Thus the effect of the *m.c.* in latex on the wave absorption was not fully emphasized. Only microstrip techniques have been reported using a full two-port measurement for latex. However the effect of *m.c.* on wave absorption could not be distinguished from other factors due to the open nature of the microstrip transmission line. The effect of sample thickness in the direction of wave propagation was not investigated as the length of the microstrip was fixed. The above problems could be resolved by replacing the microstrip with a waveguide. Unlike the microstrip, the attenuation of the propagating wave in a waveguide loaded with latex can be considered totally due to latex. The effect of conducting loss of a waveguide is negligible whilst the radiation loss is completely eliminated due to the skin depth effect. Additionally the two-port waveguide technique allows measurement of sample of different thicknesses. Attenuation measurement of thin sample can be done easily with the waveguide. Also the two-port waveguide measurement can also be used to test the accuracy of the Nicholson-Ross-Weir (*NRW*) algorithm in predicting the values of the transmission and reflection coefficient of a semisolid material such as latex.

1.4 Rectangular Waveguide

Rectangular waveguide is a type of antenna and a sensor. It is used for guided waves or transmits signal or power in certain frequencies. The waveguide wall is made up from the conducting plate, as illustrated in Figure 2. The propagations of electromagnetic (*EM*) waves inside the waveguide depends on the structure of the waveguide, material within it and the frequency of the wave. The measurement of reflection and transmission coefficients can be done using microwave techniques. In this project, the closed waveguide techniques were used to determine *m.c.* in latex samples



(a) (b)

Figure 2. Rectangular Waveguide TE_{10} mode, WR90 (a) Waveguide holder (b) Front View

1.5 Research Objectives

This thesis presents a detailed investigation on the theoretical and experimental analyses of the effect of *m.c.* of latex on the transmission and reflection properties of a waveguide. The main research objectives include:

1. To determine the relationship between complex permittivity ε^* and *m.c.* of latex at various frequencies.
2. To compare the ε^* values between the Agilent *85070E* Open-Ended Coaxial Probe technique and waveguide technique using *NRW* method, respectively. To apply optimization technique to improve the accuracy of *NRW* calculation of permittivity.
3. To establish calibration equations between magnitude of both the reflection and transmission coefficient with *m.c.* Also to determine the effect of samples

with different *m.c.* on the phase shift. To compare results between the measured and calculated transmission and reflection coefficients of latex samples in waveguide.

1.6 Thesis Outline

This work studying on the effect of *m.c.* of hevea latex using waveguide sensor. Chapter 2 reviews about rubber latex and describes the techniques that are used to calculate the Dry Rubber Content (*DRC*) and *m.c.* in latex samples. This chapter also describes the microwaves moisture measurement, microwave techniques for latex and review the microwaves waveguide technique for determination of *m.c.* in materials. Chapter 3 discuss about *EM* theory and calculation for wave equation, the reflection and transmission coefficients, the *NRW* method, the half-wavelength effect due to sample thickness and an optimization method. Chapter 4 describes the research methodology. This chapter explains about the preparation of samples, the measurement set-up, calibration process of cable and waveguide sensor and the determination of *m.c.* in samples by microwave oven drying method. Chapter 5 consists of the experimental results. This chapter compares the measured and calculated reflection and transmission coefficients of hevea latex samples. This chapter also discussed the dielectric properties (ε^*) of hevea latex using Agilent Technologies *85070E* Dielectric Probe Kit and waveguide sensor. The effect of sample thickness, the relationship between dielectric constant (ε'), dielectric loss factor (ε''), *m.c.* and frequency using waveguide technique are also presented. This chapter also presents the optimization technique and the comparison between predicted and measured *m.c.* for all samples. Finally, Chapter 6 discuss the main contribution, conclusions and suggestions for future work.

REFERENCES

Abbas, Z., Pollard, R.D. and Kelsall, R.W. (1998). A Rectangular Dielectric Waveguide Technique for Determination of Permittivity of Materials at vl-4-band. *IEEE Transactions on Microwave Theory and Techniques*, 46(12), 2011-201.

Afsar, M.N., Birch, J.R. and Clarke, R.N. (1986). The Measurement of the Properties of Materials. *Proc. IEEE*, 74, 183-199.

Alex, R., Premalatha, C.K., Nair, R.B., and Kuriakose, B. (2003). Measurement of dry rubber content of fresh natural rubber latex by a titration method. *Journal of Rubber Research*, 6(4), 221-230.

Ali, A.H., Abbas, Z., Hassan, J., Jusoh, A. and Zahari, R.M. (2011). Microwave Antenna Sensing Technique for Determination of Moisture Content in Hevea Latex from Hevea Brasilliensis Tree. *Australian Journal of Crop Science*, 5(11), 1326-1333.

Ansarudin, F., Abbas, Z., Hassan, J., Yahaya, N.Z. and Ismail, M.A. (2012). A Simple Insulated Monopole Sensor Technique for Determination of Moisture Content in Hevea Rubber Latex. *Measurement Science Review*, 12(6), 249-254.

Baghurst, D.R. and Mingos, D.M.P. (1988). Application of Microwave Heating Techniques for the Synthesis of Solid State Inorganic Compounds. Journal of Chemical Society, *Chemical Communications*, 2(12), 829-830.

Banwell, C.N. and McCash, E.M. (2000). *Fundamentals of Molecular Spectroscopy*. New Delhi: Tata McGraw-Hill Publishing Company Limited.

Birch, J.R. and Clarke, R.N. (1982). Dielectric and Optical Measurements from 30 to 1000 GHz. *The Radio and Electronic Engineer*, 52, 565-584.

Blackham, D.V. (1992). Calibration Method for Open-Ended Coaxial Probe/Vector Network Analyzer System. *In Microwave Processing of Materials Ill*, 269, 595 -599.

Blackham, D.V. and Pollard, R.D. (1997). An Improved Technique for Permittivity Measurements Using Coaxial Probe. *IEEE Trans. on Inst. and Measurement*, 46, 1093-1099.

Chen, S. (1979). Composition of Hevea Latex. In Training Manual on Analytical Chemistry. Rubber Research Institute of Malaysia Press. *Latex and Rubber Analysis*, 44.

Chen, B.S. (1982). Buoyancy method for the determination of dry rubber content in field latex. *Chinese Journal of Trop Crops*, 3(2), 97-104.

Chin (1979). RRIM Training Manual on Analytical Chemistry, Research Institute Malaysia, Kuala Lumpur, 67.

Collin, R. (1960). *Field Theory of Guided Waves*. New York. McGraw-Hill.

Grist (1936). *An Outline to Agriculture*. Department of agriculture, Straits Settlements and Federated Malay states.

Guo, L.F., Zhao, Z.M. and Gao, M.J. (2005). Study of the compatibility between light-cured repair materials and composite materials by holographic interferometry. *Optical Eng*., 44(10), 1056021-1056023.

Gutierrez, E., Loupy, A., Bram, G. and Ruiz-Hitzky, E. (1989). Inorganic solids in dry media – an efficient way for developing microwave irradiation activated organic reactions. *Tetrahedron Letters*, 30, 945.

Hamza, Z.P., Dilfi, K.F.A. and Muralidharan, M.N. (2008). Microwave oven for the rapid determination of total solids content of natural rubber latex. *Int. J. Polym. Mater*., 57(9), 918-923.

Hassan, J., Khalid, K. and Yusoff, W.M.W. (2010). Microwave Dielectric Characterization of Hevea Rubber Latex at 2.6, 10 and 18 GHz. *Pertanika J. Sci. & Technol*, *18*(1), 121-138.

Hippel, V. (1954). *Dielectric Material and Application*. New York. Wiley.

Ida, N. (1992). *Microwave NDT*. Netherlands: Kluwer Academic Publishers.

Ishimaru, A. (1991). *Electromagnetic Wave Propagation, Radiation and Scattering*. New Jersey. Prentice Hall.

Jayanthy, T. and Sankaranarayanan, P.E. (2005). Measurement of Dry Rubber Content in Latex using Microwave Technique. *Measurement Science Review*, 5(3), 50 -54.

Jusoh, A., Abbas, Z., Azmi, B.Z., Hassan, J., Meng, C.E., and Ahmad, A.F. (2011). A simple procedure to determine complex permittivity of moist materials using standard commercial sensor. *Measurement Science Review*, 11 (1), 19-22.

Khalid, K. (1982). Determination of Dry Rubber Content of Hevea Latex by Microwave Technique. *Pertanika*, 5(2), 192-195,

Khalid, K. (1988). The Application of Microstrip Sensors for Determination of Moisture Content in Hevea Rubber Latex. *J. Microwave Power and EM Energy*, 23(1), 45-52.

Khalid, K., Wahab, Z.A. and Kasmani, A.R. (1988). Microwave Drying of Hevea Rubber Latex and Total Solid Content (TSC) Determination. *Pertanika*, 11(2), 289-297.

Khalid, K., Hassan, J. and Yusof, W.D.W. (1997). Dielectric Phenomena in Hevea Rubber Latex and Its Applications. *Proceedings of the 5th International Conference on Properties and Applications of Dielectric Materials*, 78-81.

Khalid, K., Ghretli, M.M., Abbas, Z. and Grozescu, I.V. (2006). Development of Planar Microwave Moisture Sensors for Hevea Rubber Latex and Oil Palm Fruits. *International RF and Microwave Conference*, 10-15.

Kim, L.K. (2004). Development of a 500 MHz Reflectometer Using Stripline Coupler for Moisture Measurement of Oil Palm Fruits. Masters thesis, Universiti Putra Malaysia, 61-87.

Kraszewski, A.W., Trabelsi, S. and Nelson, S.O. (1998). Temperature compensated and density-independent Moisture Content Determination in Shelled Maize by Microwave Measurements. *Journal of Agricultural Engineering Research*, 72: 27-35.

Kraszewski, A.W., Kulinski, S. and Stosio, Z. (1977). A Preliminary Study on Microwave Monitoring of Moisture Content in Wheat. *J. Microwave Power & Electromagnetic Energy*, 12(3), 241-252.

Kraszewski, A.W. and Member, IEEE. (1991). Microwave Aquametry – Needs and Perspectives. *IEEE Transactions on Microwave Theory and Techniques*, 39(5), 828-835.

Kumar, W. and Nelson, S.O. (2007). Dielectric Relaxation Characteristics of Fresh Fruits and Vegetables from 3 to 20GHz. *Journal of Microwave Power and Electromagnetic Energy*, 32(2), 114-122.

Kupfer, K. (2005). *Electromagnetic Aquametry*. Electromagnetic Wave Interaction with Water and Moist Substances. Springer. Germany.

Li, J. (2006). Analysis of Systematic Errors in ISO 126-1995 for the determination of dry rubber content. *Modern Science Instrumentation*, 6, 84-85.

Malaysia Rubber Board (MRB) (2012). Natural Rubber Market Review. MRB Digest, Department of Statistic.

Malaysian Standard (1987). MS466: Methods of Sampling and Testing Field Latex (First Revision), SIRIM: Standard & Research Institute of Malaysia.

Mathwork, 2010. MATLAB The Language of Technical Computing. Computation. Visualization. Programming. Graphics Reference Manual.

Meredith, R. (1998). *Engineers' Handbook of Industrial Microwave Heating*. England: The Institution of Electrical Engineers.

Mohammadi, A., Khalid, K., Bafti, P.S., and Homaiee, M. (2012). Development of Microcontroller-based Microwave System to Measure Solid Content of Hevea Rubber Latex. *Measurement*, 45 (3), 571-579.

Nicolson, A.M., Member, IEEE, Ross, G.F. and Senior, Member, IEEE, (1970). Measurement of the Intrinsic Properties of Materials by Time-Domain Techniques. *IEEE Transactions on Instrumentation and Measurement*, 19(4), 377-382.

Nyfors, E. and Vainikainen, P. (1989). Industrial Microwave Sensor. Norwood. MA: Artech House, Inc.

Pozar (2005). Microwave Engineering. New Jersey: John Wiley & Sons, Inc., USA.

Robert, S. and Hippel, A.R.V. (1946). A New Method of Measuring Dielectric Constant and Loss in the Range of Centimetre Waves. *J. Appl. Phys*., 17, 610-616.

Rohdes and Schwarz Application Note: Measurement of dielectric material properties, 2006, Rohde & Schwarz ApplicationCenter Asia/Pacific.

Rouane, A. and Koutiche, D. (2012). Characterization of microwave antennas for intracardiac ablation frequencies 915 and 2450 MHz. *Measurement Science Review*, 12 (1), 34-39.

Schulz, J., Frank, C. and Hill, C. (1984). US Patent NO. 4446725. Washington, US. Patent and Trademark Office.

Serdyuk, V.M. (2008). Dielectric Study of Bound Water in Grain at Radio and Microwave Frequencies. *Progress in Electromagnetics Research*, 84, 379-406.

Stuchly, S.S. and M.A. Stuchly (1983). Industrial Scientific, Medical and Domestic Application of Microwaves IEEE Proceeding.

Sucher, M. and Fox, J. (1963). *Handbook of Microwave Measurements*. Vol. II, New York: Wiley.

Tillekerathe, L.M., Karunanayake, K.L., Sarath Kurnara, P.H. and Weeraman S. (1989). A Rapid and Accurate Method for Determining the Dry Rubber Content and the Solid Content of NR Latex. *Polymer Testing*, 8(5), 353-358.

Toll, J.S. (1956). Causality and the Dispersion Relation: Logical Foundations. *Physical Review*, 104, 1760-1770.

Tøgersen, G., Arnesen; J.F., Nilsen, B.N. and Hildrum, K.I. (2003). On-line Prediction of Chemical Composition of Semi-Frozen Ground Beef by Non-Invasive NIR Spectroscopy. *Meat Science*, 63(4), 515-523.

Wang, Y. and Afsar, M.N. (2003). Measurement of Complex Permittivity of Liquids Using Waveguide Techniques. *Progress in Electromagnetics Research*, 42, 131-142.

Weir, W.B. and Member, IEEE. (1974). Automatic Measurement of Complex Dielectric Constant and Permeability at Microwave Frequencies. *Proceedings of the IEEE*, 62(1), 33-36.

Yeow, Y.K., Abbas, Z. and Khalid, K. (2010). Application of Microwave Moisture Sensor for Determination of Oil Palm Fruit Ripeness. *Measurement Science R.*, *10*(1), 7-14.

Zhao, Z.M., Xin, Y.J., Wang, L.X., Zhu, W.H., Zheng, M., Guo, X., (2008). Measurement and Analysis of Absorption Spectrum of Human Blood. *Spectroscopy Spectral Analysis*, 281(1), 138-140.

Zhao, Z.M., Jin, X.-d. Zhang, Lin Yu, Xiao-lei. (2010). Novel Measurement System for Dry Rubber Content in Concentrated Natural Latex based on annular photoelectric sensor. *International Journal of Physical Sciences*, 5(3), 251-260.

Zhu, W.H., Zhao, Z.M., Guo, X., Chen, H. (2009). Study of Cholesterol Concentration based on Serum UV2Visible Absorption Spectrum. *Spectroscopy Spectral Analysis*, 9(4), 1004-1007.