APPLICATION OF MICROWAVE IN WOOD TOMOGRAPHY

MOHD HAFIZ BIN A. JALIL @ ZAINUDDIN

A project report submitted in partial fulfillments of the
requirements for the award of the degree of
Master of Engineering (Electrical – Mechatronic and Automatic Control)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2005

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

To my beloved parents, A. Jalil Ali Amran and Rogayah Kormin and my brothers, sister, and relatives, thanks for endless support and give me inpsiration for me to move forward.

And also my beloved fiance Rohaiza bte Hamdan for your devotion, concern, caring and thanks for everything.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ACKNOWLEDGMENT

I wish to express my highest gratitude to my supervisor Assoc Prof Dr Ruzairi Bin Abdul Rahim and my co-supervisor Dr Mohamad Kamal Bin A. Rahim for their priceless, ideas, assistance, guidance and support throughout the completion of this project. . Thus, my thank are dedicated especially to all Faculty of Electrical Engineering University Technology Malaysia staff who helping me seeing clearly what should be done. I would also like to thank my panels that have given their time and effort to assess my presentation.

I would also like to express my utmost gratitude to all who have been involved directly or indirectly. I'm also indebted to Kolej Universiti Teknologi Tun Hussein Onn (Kuittho) for providing the opportunity and funding me to further my study

I would like to give my sincere thanks to my family for the support they gave me to achieve my dream and for their unending prayers. My thanks also to my entire course mate, my housemates and friends for their moral support and guidance they have given me. May Almighty Allah bless and reward them for their generosity.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Wood degradation and defects, such as voids and knots, affect the quality of lumber. The ability to detect the internal defects in the log can save mills time and processing costs. In this case, the microwave propagation is used to investigate the internal defect of wood. The principle of this case study is to measure the attenuation of microwave signal when propagates through the wood. The microwave trainer Type (e) 4510 that transmit 14.5 GHz with 20mW microwave signal is used and the measurements are made in voltage using multi-meter that connected with detector. The development of amplification circuit has been developed to amplify the received signal from detector. Rubber wood is used as material under test, (MUT) with thickness used between 20mm to 60mm. The wood defection is created with known size and the wood is immersed in water in order to study the effect of moisture content on microwave signal. Several experiments must be performed with several samples of woods and results of measurement must be studied in order to determine the different measurement between the defect wood and good wood. Artificial Neural Network (ANN) is applied in Visual Basic to recognize the pattern voltage based on experiment data to develop 2D image and determine the internal characteristic of wood. All data presented are based on experiment results. The results from this work will determine the suitability to use microwave signal in wood scanning.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRAK

Penurunan kualiti dan kecacatan kayu, seperti rongga kosong dan mata kayu, dapat memberi kesan kepada kualiti papan. Kebolehan untuk mengesan kecacatan dalaman pada kayu dapat menjimatkan masa pengilangan dan kos pemprosessan. Bagi kes ini, penyebaran isyarat mikrowave telah diaplikasikan untuk menyiasat kecacatan dalaman suatu kayu. Prinsip utama bagi kajian kes ini adalah untuk mengukur kadar pengurangan isyarat mikrowave apabila ianya disebarkan melalui kayu. Alat latihan microwave jenis (e) 4510 yang memancarkan 14.5 GHZ berserta 20 mW isyarat microwave telah digunakan dan pengukuran adalah dibuat di dalam unit voltan menggunakan meter pelbagai yang disambungkan kepada alat pengesan. Litar pembesaran telah dibentuk untuk membesarkan isyarat yang diterima daripada alat pengesan. Kayu getah telah digunakan sebagai bahan ujikaji, (MUT) dengan ketebalan di antara 20 mm hingga 60 mm. Kecacatan pada kayu telah dicipta dengan saiz yang diketahui telah direndam di dalam air bagi mengkaji kesan kandungan kelembapan kepada isyarat microwave. Beberapa eksperiment telah dilaksanakan ke atas beberapa sampel kayu dan keputusan eksperimen dikaji bagi menentukan perbezaan pengukuran diantara kayu cacat dan kayu elok. ANN telah dilaksanakan melalui Visual Basic untuk mengesan corak voltan berdasarkan data eksperimen bagi membentuk image dua dimensi serta menentukan ciri-ciri dalaman sesebuah kayu. Kesemua data yang dilaporkan adalah berdasarkan kepada keputusan-keputusan eksperimen. Hasil daripada kajian ini akan menentukan kesesuaian menngunakan isyarat microwave dalam penelitian kayu dan juga sebagai keputusan awal untuk tomografi kayu.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

TABLE OF CONTENT

CHAPTER	TITLE	PAGE
	DECLARATION	ii
	DEDICATION	iii
	ACKNOWLEDGEMENT	iv
	ABSTRACT	v
	ABSTRAK	vi
	TABLE OF CONTENTS	vii
	LIST OF TABLES	x
	LIST OF FIGURES	xi
	LIST OF SYMBOLS / ABBREVIATIONS	xvii
	LIST OF APPENDICES	xx
I	INTRODUCTION	
	1.0 Introducing wood scanning	1
	1.1 Project Background	3
	1.2 Objective Of Project	4
	1.3 Scope of Work	5
	1.4 Thesis Outline	6

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

II LITERATURE REVIEW OF TOMOGRAPHY

2.0	Introduction of Tomography Technology	7
2.1	Definition of Tomography	8
2.2	Tomography History	9
2.3	Basic Technique of Tomography	10
	2.3.1 Data Acquisition	12
	2.3.1.1 Transducers and Sensors	12
	2.3.1.2 Signals	13
	2.3.1.3 Signal Conditioning	14
	2.3.1.4 DAQ hardware	15
	2.3.1.5 Driver and application software	15
	2.3.2 Computer/ PC	16
	2.3.3 Image Reconstruction	16
2.4	Introduction of Wood Scanning	18
	2.4.1 Optical	18
	2.4.2 Ultrasound	19
	2.4.3 Nuclear Magnetic Resonance (NMR)	21
	2.4.4 X-ray	22
2.5	Introduction of Microwave Inspection	24
	2.5.1 Technology Overview	25

III MICROWAVE FUNDAMENTALS AND BASIC WOOD PROPERTIES

3.1	Introduction	27
3.2	Microwave Background	27
3.3	What Are Microwave?	30
3.4	Microwave Generating Oscillator	33

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

3.5	Detection Device	40
3.6	Transmission Line	43
	3.6.1 Coaxial Lines	43
3.7	Antenna	45
	3.7.1 Arrangement of Antenna	49
3.8	Wood Properties	51
	3.8.1 Wood Anatomy and Physiology	51

IV **RESEARCH METHODOLOGY**

4.0	Introduction	54
4.1	Introduction of Wood Scanning Using Microwave	55
4.2	Process Overview	56
4.3	Frequency Selection	56
4.4	Instrument Selection	57
4.5	Basic Principle of Measurement	58
4.6	Sample	60
	4.6.1 Sample 1	60
	4.6.2 Sample 2	61
	4.6.3 Sample 3	62
	4.6.4 Sample 4	63
4.7	Experiment Method	64
4.8	Antenna Arrangement	65
4.9	Selection Distance Between Transmitter and Receiver	66
4.10	Basic Structure of The System	67
4.11	ANN Model Algorithm	69

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

V RESULTS AND ANALYSIS

5.0	Introduction		75
5.1	Experiment Results		75
	5.1.1	Effect of Microwave Signal on Woods Thickness	76
	5.1.2	Effect of Wood Defection Size Upon Microwave Signal Attenuation	77
		5.1.2.1 Results Experiment for 30mm wood With Internal Defection	78
		5.1.2.2 Results Experiment for 40mm Wood With Internal Defection	79
		5.1.2.3 Results Experiment for 50mm Wood with Internal Defection	80
		5.1.2.4 Results Analysis for Experiment 2	81
	5.1.2	Effect of Microwave Attenuation on Water Contains in Wood	82
5.2	Offline Application Using Visual Basic		85
	5.2.1	Offline Application using Visual Basic for 30mm Wood	85
	5.2.2	Offline Application using Visual Basic for 40mm Wood	87
	5.2.3	Offline Application using Visual Basic for 50mm Wood	89
5.3	Example Application		91

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

VI CONCLUSION AND RECOMMENDATIONS FUTURE WORK

6.0	Conclusion	96
6.1	Recommendations for Future Work	97

REFERENCES 99

APPENDICES

APPENDIX A	Microwave Trainer Type(e) 4510)
APPENDIX B	Single Operational Amplifier
APPENDIX C	Source Code Program
APPENDIX D	Experiment Data

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

FIGURE	TITLE	PAGE
2.1	Basic block diagram for tomography system	12
2.2	Positioning of log for sound wave transmission test	20
2.3	Photographs of sliced log corresponding to CT scans	20
2.4:	Block diagram of NMR scanner	21
2.5	A conceptual view of the tangential scanner shows a log that rotates and translates, a detector array parallel to the axis of rotation, and an X-ray source	22
3.1	Available Frequency Spectrum	30
3.2	Principle structure of a tunnel diode	35
3.3	Current voltage characteristic of a tunnel diode (top) resistance curve over the voltage (bottom)	36

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

3.4	Structure (schematical) of an impatt diode	37
3.5	Gunn element, schematic arrangement of zones (top) and electron velocity v over the field strength E (bottom)	39
3.6	Simplified Crystal Detector Circuit	41
3.7	Simplified Crystal Detector Circuit	43
3.8	Diagram to Determine the Wave Impedance of Coaxial Cables	45
3.9	Coaxial Line with Dipole	46
3.10	Antenna Arrangement with Horn (H) and Reflector (R)	47
3.11	Reflector Antenna with Eccentric Parabolic Section	48
3.12	Diagram of an Isotropic Radiator (I) and a Horn (H)	49
3.13	Alternatives to antenna arrangements; (a) Reflection only (b) Reflection and transmission (c) Arrangement to receive the scattered field in multiple directions	50
3.14	Description of wood properties	52
3.15	Propagation of wave through wood	53
4.1	Overview of optimization process in wood industry	56
4.2	Effect of electromagnetic wave when interface on wood	59

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

4.3	Propagation of wave through wood	60
4.4	Size of wood for experiment	61
4.5	Size of defection for 30mm wood	62
4.6	Size of defection for 40mm wood	63
4.7	Size of defection for 50mm wood	63
4.8	Bi-static antenna arrangement	66
4.9	Microwave attenuation over distance between transmitter and receiver	67
4.10	Overall block diagram for the system	68
4.11	Schematic diagram for amplification device	68
4.12	Experiment set-up in laboratory	69
4.13	Artificial Neural Network model	71
4.14	Neural Network Implementation using Visual Basic	73
4.15	Flowchart for the GUI application	74
5.1	Attenuation of microwave signal in voltage over the thickness of wood	76
5.2	Correlation between microwave attenuation with size of	78

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

	defection for 30mm wood	
5.3	Correlation between microwave attenuation with size of defection for 40mm wood	79
5.4	Correlation between microwave attenuation with size of defection for 50mm wood	80
5.5	Average reading voltage relation between microwave attenuation with size of defection for 30mm, 40mm, and 50mm wood	82
5.6	Measurement of microwave attenuation versus moisture contains in wood in time (minute)	83
5.7	Comparison between experiment value with predicted value for 30mm wood	86
5.8	2D image display for 30mm wood; a) without internal defection, b) 5mm internal defection, c) 10mm internal defection.	87
5.9	Comparison between experiment value with predicted value for 40mm wood	88
5.10	2D image display for 40mm wood; a) without internal defection, b) 5mm internal defection, c) 10mm internal defection, d) 15mm internal defection.	89
5.11	Comparison between experiment value with predicted	90

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

	value for 50mm wood	
5.12	2D image display for 50mm wood; a) without internal defection, b) 10mm internal defection, c) 20mm internal defection	91
5.13	Wood to be scan	92
5.14	Wood width determination	93
5.14	2D image for first reading data	94
5.15	2D image for all reading data	95

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

TABLE	TITLE	PAGE
2.1	List of scanning method in wood inspection and the disadvantage	23
3.1	CCIR Band Designations	32
3.2	IEEE/MICROWAVE Industry Standards Bands	33
5.1	Comparison microwave attenuation for 30mm wood with and without immerse in water.	84
5.2	Data collection for wood	92

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF ABBREVIATIONS/SYMBOLS

I_p	-Maximun tunnel current
U_D	-Diffusion voltage
Z_L	-Wave impedance
C^*	-Capacitance per unit length
L^*	-Inductance per unit length
ε_r	-Dielectric constant
D	-Outer conductor
d	-Inner conductor
λ	-Wavelength microwave signal
λ_o	-Wavelength microwave in air
v_p	-Phase velocity of microwave signal
c_o	-Velocity of propagation of electromagnetic waves in free space

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

E	-Field strength
n_o	-Propagation microwave in free air
n_1	-Propagation microwave in wood
n_2	-Propagation microwave in wood defection
O_i	-Input layer of neurons
O_j	-Hidden layer of neurons
O_k	-Output layer of neurons
$f(net_j)$	–Sigmoid function
α	-Momentum term
η	-Learning rate
θ_j	-Input bias weight
θ_k	–Output bias weight
E_{min}	-Minimum error
δ_k	-The error signals that appear between the output and hidden layers
W_{kj}	-Weights between the output (O_k) and hidden layers (O_j).
w_{ij}	-Weight between hidden layers (O_j) and input layer (O_i)layer

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.0 Introducing Wood Scanning

The forest industry is one of the base industries in Malaysia and it covers all parts of the process from planting small trees to the refined end-products such as paper and lumber that will be used for various purposes. This proposal focus on the timber logs when they enter the saw mill, especially on the part of the process when solid wood is to be refined into lumber. This process involves a number of grading tasks where some kind of aid for the grading decision is of large interest. In addition to the grading the utilisation of the logs can be remarkably improved by deciding an optimal cutting strategy of the logs already at the line where they enter the sawmill. The optimisation strategy needs information about the dimensions as well as the inner structure of the logs in order to make the optimal cutting or grading decision. The optimisation criteria depend on the type of wood (Anders Kaestners 1999).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

The simplest aid is the visual inspection by a human operator using his eyes as the only information source to base the decision on. This inspection can be considered to be a surface scanning and can also be carried out with the help of cameras and laser-scanners. The direct human has some drawbacks that affect the results, varying experience and varying degrees of awareness of the information passing by and the judgments will therefore be subjective and varying with time. An automated scanning system performing the same task is always making the same decision when presented with identical information.

Scanning systems can be subdivided into two classes: namely surface and tomographic scanners. The surface scanner is only capable of gathering information from the surface of the log such as surface patterns and geometric dimensions, which is sufficient information for some purposes. If on the other hand, one is interested in the inner structure of the material, then the only possibility is to use a tomographic scanner that reveal the inner structure of the log in terms of variations in various physical properties. These two classes also have some what varying purposes; the surface scanners are more suited for grading sawn boards while the tomographic scanner is more suitable as provider of information to an optimisation system before the log is cut into lumber.

Another application in the sawmill is also related to optimisation, but does not involve a rotation of the log. The task in this application is to detect the presence of and determine the defection inside the wood using microwave signal.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.1 Project Background

Scanning wood for internal defects has been large interest in the research nowadays. Today there are varieties of scanning technologies available and from those the most interesting alternatives for an industrial application in a sawmill are:

- X-ray computed tomography
- Ultra sound tomography

The X-ray based system is the most commonly used scanning device for this type of applications delivers images and shows the variations in density within the material. The images are of high resolution and directly corresponding to the visible images if the log was entering at the selected position. This technology has some drawbacks though, the X-ray scanners are expensive and that the X-rays are high energy electromagnetic waves which are harmful for human beings.

The ultra sound system produces images that are based on the reflections of the sound waves in the material. Since ultra sound are mechanical waves working in the same frequency range as the harmonics of the mechanical vibration in the system the result is corrupted by a lot of noise. As a way to avoid the noise it has been suggested to immerse the logs in a fluid. However, this approach has some drawbacks such as the undesirable soaking of the log as well as the large amount of bubbles in the fluid that also interferes with the measurements (Anders Kaestners 1999). As a conclusion, this type of imaging system is not recommendable for log scanning purposes in an industrial environment even though it is inexpensive and harmless to human beings.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

As alternative to the previously mentioned two methods we purpose to use a scanning device based on attenuation of microwave signal. The microwaves are low energy electromagnetic waves that are emitted at very low intensity and are thus virtually harmless to human beings. Microwave tomography is a new technology which has enormous potential advantages in medicine, especially in areas of so called "physiologist imaging", such as in cardiology (Ruser and V. Magon, 1997). Nowadays the development of microwave tomography in industry increased recent years especially fluids or level measurement in large tank and vessels (Viktor S. Arefiev et al, 1997). This because the microwaves capable to penetrate non-metallic materials. Thus, its possible to penetrate the wall of pipes made of concrete, stoneware or plastics to inspect the state of the pipe surrounding. The Microwave signal also is applied to measure moisture content, density, weight, and grain angle of wood depends on the attenuation, phase shift and depolarization (A Plaskowski et al).

The aim of this proposal is to study the possibility of microwave in order to determine the internal characteristic of wood especially on defection inside the wood

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.2 Objective of Project

1) To understand the basic concept of tomography/ scanning process and microwave signal propagation.

2) To understand the basic concept of measurement of microwave attenuation when passed through the wood.

3) To select proper wood type for studied purpose.

4) To select the proper width size of wood for experiment purposed.

5) To locate the internal defection inside wood for experiment purposed

6) To determine the effect of microwave attenuation for undefective, defective, wood and undefective wood with moisture contains based on experiment results.

7) Analysis of data experiment based on extrapolation analysis.

8) Determine the preliminary results for possibility using microwave attenuation in wood scanning.

9) Use artificial neural network (ANN) that applied in Visual Basic to recognize the pattern voltage based on experiment data to develop 2D image and determine the internal characteristic of wood.

10) Purpose the solution from previous problem to be used in the future development and improvement.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.3 Scope of Work

1 Use the propagation of microwaves 14.5 GHz in wood tomography base on the attenuation of the microwave signal.

2 The experiment only focus on rubber wood as material under test (MUT)

3 To implement / set up simple hardware for testing/experiments in order to find the need amount of data for analysis.

4 Analysis of experiment data in order to determine the possibility to use microwave attenuation for wood tomography.

5 All of the results are based on analysis of experiment results.

6 Off-line 2D image reconstruction using Visual Basic based on experiment data. The image only constructed based on data measurement for wood without moisture content.

1.4 Thesis Outline

The thesis is divided into 6 chapters, which the first chapter is introduction of the project. The introduction is followed by chapter 2 that explained on literature review of the project. The basic properties of microwave include the basic theory of measurement of microwave signal are explained in chapter 3. The basic wood properties also discussed in this chapter. Chapter 4 provide explanation on project methodology include background on instrument used, experiment set-up, sample and software used for 2D off-line image reconstruction. The methodology chapter is followed by chapter 5, which describe the results of experiment results and analysis of results. Thesis conclusion and future recommendations is described in chapter 6

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

1. A. A. Vertiy, S. Gavrilov, S. Aksoy, "Imaging of Buried Object by Microwave Tomography Method in Condition of Low Reflection on Surface Medium", 2000 IEEE.

2. A. A. Vertiy, S.P GAvrilov, V.N. Stepanyuk, I. V. Voynovskyy, "Through-Wall and Wall Microwave Tomography Imaging", 2004 IEEE.

3. A.A. Vertiy, S. Gavrilov, S. Aksoy," Imaging Of Buried Objects By Microwave Tomography Method In Condition Of Low Reflection On Surface Medium, 2nd International Conference on Microwave and Millimeter Wave Technology Proceedings, (2000).

4. Anders Kaestners, "Polarimetry Based Wood Scanning Theory and Experiment", Thesis For The Degree Licentiate of Engineering, Department of Signal and Systems, Chalmers University of Technology, Sweden, 1999.

5. A Plaskowski, MS Beck, R Thorn, T Dyakowski, Imaging industrial flows "application of electrical process tomography".

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

6. Ch Pichot, J. Y. Dauvignac, C. Dourthe, I. Aliferis, E. Guilanton ,"Inversion Algoruthm and Measurement Systems for Microwave tomography of buried object", BP 93, 06902 Sophia Antipolis, France, 0-7803-5276-9/99, 1999 IEEE.

7. Ebbe Nyfors, Pertti Vainikainen, "Industrial Microwave Sensors", 1991 IEEE.

8. Frank Daschner, Micheal Kent, Reinhard Knochl, Ulla-Karin Berger. "Multi-parameter Microwave Sensors for Determining Composition or Condition of Substances", 2002 IEEE.

9. Fredrik Arnerup," Infrared Imaging of Scots Pine cross Sections: Automatic Heartwood Size Measurement," Master of Science Thesis, Royal institute of Technology, Sweden, 2002.

10. H. Ruser, V. Magon, "Sweep Linearization of Microwave FMCV Doppler Sensor By An Ultrasonic Reference", .IEEE frequency Control Symp, May 28-30, 1997.

11. J. Natterer and J. L. Sandoz, "5th Conference on Timber Engineering", August 17-20, 1998.

12. James, William L; Yen, You-Hsin; King, Ray J."A microwave method for measuring moisture content, density and grain angle of wood." Res. Note. FPL-RP-546. Madison, WI: U.S Department of Agriculture, Forest Service, Forest product Laboratory; 1985.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

13. Kristian C. Scads, Daniel L. Schmoldt, RobertJ.Jones, "Non-destrusive Methods for Detecting Defects in sofwood Logs" Res. Pap. FPL–RP-546. Madison, WI: U.S Department of Agriculture, Forest Service, Forest product Laboratory, 1996.

14. R. A. Williams, M. S. Beck, Process Tomography: principles, technique and application". 1st Edition.: Butterworth-Heinemann Ltd, 1995.

15. Robert N. Emerson, David G. Pollock, James A Kainz, Kenneth J. Fridly, David L McLean, and Robert JU. Ross., "Nondestructive Evolution Techniques For Timber Bridges", 1998.

16. Seichi Okamura and Zhihong Ma, " Moisture Content Measurement by Microwave Attenuation and Problems", Dept. of Electronic Engineering, Shizuoka University, Hamamatsu, Shizuoka, Japan. 0-7803-4308-5/98, 1998 IEEE.

17. Serguei Y. Semenov, Alexender E.Bulyshev, Alexander E. Souvoruv, Robert H Svenson, Yuri E. Sizov, Vladimir Y. Borisov, Vitaly G. Posukh, Igor M. Kozlov, Alexy G. NAzarov, and George P. Tatsis, "Microwave Tomography: Theoritical and Experimental Investigation of the Iteration Reconstruction Algorithm", 1998 IEEE.

18. Stephen C. Harsany, "Principle of Microwave Technology", Mt. San Antonio College.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

19. Yoo jinKim,Luis Jofre, Franco De Flaviis, Maria Q. Feng "Microwave Tomography Array for DamageDetection in Concrete Structures," University of California, Irvine, CA 92697, USA and Technical University of Catalonia, Barcelona, Spain.

20. You-Hsin Yen, William L. James, Ray J. King,' A microwave Method for Measuring Moisture content, Density, and Grain Angle". March 1985'

21. Viktor S. Arefiev, Andrew N. Starostian, Serguei Y. Semenov, "Microwave Tomography of High Dielectric Contrast Object. Gradient Method in Two-Dimensional Approach". 19th International Conference – IEE/EMBS Oct. 30-Nov.2, Chicago, IL. USA, 1997.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH