



**UNIVERSITI PUTRA MALAYSIA**

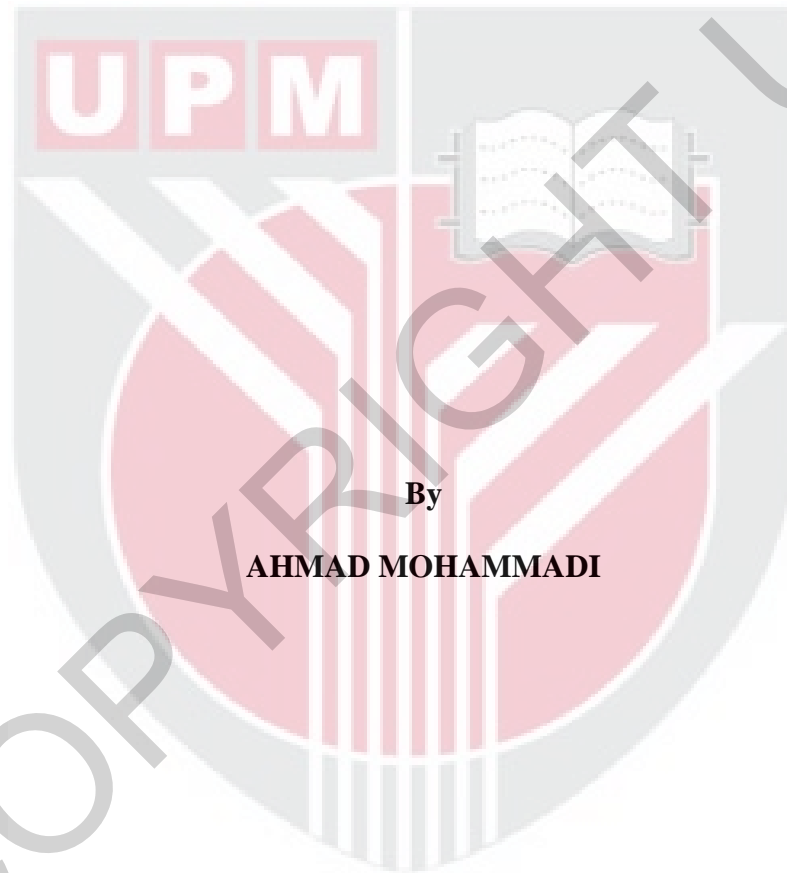
***CARBON NANOTUBE - BASED MICROWAVE RESONANT  
SENSOR FOR ORGANIC CONTAMINANTS DETECTION***

**AHMAD MOHAMMADI**

**FK 2014 10**



**CARBON NANOTUBE - BASED MICROWAVE RESONANT SENSOR FOR  
ORGANIC CONTAMINANTS DETECTION**



By

**AHMAD MOHAMMADI**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**June 2014**

## COPYRIGHT

All material contained within the thesis, including without limitation text, logos, icons, photographs and all other artwork, is copyright material of Universiti Putra Malaysia unless otherwise stated. Use may be made of any material contained within the thesis for non-commercial purposes from the copyright holder. Commercial use of material may only be made with the express, prior, written permission of Universiti Putra Malaysia.

Copyright © Universiti Putra Malaysia



**DEDICATED**

**To**

**This thesis is dedicated to my beloved wife, Mahtab Mohammadi, to my dear mother Zahra, my dear father Ramazan that I owe them all of success in my life.**



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in  
Fulfilment of the Requirement for the Degree of Doctor of Philosophy

**CARBON NANOTUBE - BASED MICROWAVE RESONANT SENSOR FOR  
ORGANIC CONTAMINANTS DETECTION**

By

**AHMAD MOHAMMADI**

**June 2014**

**Chairman: Associate Professor. Alyani Ismail, PhD**

**Faculty: Engineering**

Organic contaminants are one of the most important kinds of environment pollutions which have been raised over the last century. Conventionally organic contaminants are measured using various methods which require extraction, cleaning procedures and organic solvent. These methods are time consuming and expensive. Fast and accurate detection of organic compounds is the important key to protect the environment and human health safety. Napropamide and phenolic compounds are two kinds of organic contaminants in the Malaysian environment which are chosen to be investigated in this thesis.

This thesis describes the design of proximity coupled feed patch antenna as an organic contaminates sensor. This sensor system consists of a two-layer Flame Retardant (FR-4) patch antenna coated with Multi Walled Carbon Nanotubes (MWCNTs) and Polypyrrole-Chitosan (PPy-CHI) for absorbing organic contaminates. Proximity coupled feeding was chosen to feed the patch antenna and the feeding is from the ground plane side without any physical contact to the material under test. The best design of patch antenna and feed line position in 5 GHz resonant frequency are chosen based on simulation results using full-wave electromagnetic simulator Computer Simulation Technology (CST) Microwave studio. The performance of the fabricated patch antenna was tested using Vector Network Analyzer (VNA) and the results are then be compared with simulations results.

Multi Walled Carbon Nanotubes (MWCNTs) and Polypyrrole-Chitosan (PPy-CHI) as a sensing layer were coated on the top of antenna using electric field deposition. Atomic Force Microscopy (AFM) was used to ensure successful coating result on the top of the antenna. Chemical interaction between applied materials to the sensing layer was investigated by Fourier Transform Infrared Spectroscopy (FT-IR).

The whole system after coating and fabrication was tested using different amounts of phenol, 2-4 Dichlorophenol (24DCP), commercial napropamide and napropamide at room temperature (25oC). Changes in resonant frequency of patch antenna before and after applying phenol, 2-4 Dichlorophenol (24DCP), commercial napropamide and napropamide were measured. Based on measurement results, FR-4 patch antenna coated with MWCNTs and PPy-CHI are capable to detect small concentration of measured materials down to 0.5 ppm. At this operating frequency (5 GHz), the technique can be used in wireless network sensor systems to measure organic pollutions vapour in shielded area for future research.



Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Doktor Falsafah.

**TIUBNANO KARBON - BERDASARKAN GELOMBANG MIKRO  
PENDERIA UNTUK PENGESAN PENCEMARAN ORGANIK**

Oleh

**AHMAD MOHAMMADI**

Jun 2014

**Pengerusi: Profesor Madya. Alyani Ismail, PhD**

**Fakulti: Kejuruteraan**

Pencemaran organik adalah salah satu daripada ciri-ciri utama pencemaran persekitaran yang meningkat sejak beberapa abad yang lalu. Pengesanan terhadap sebatian organik yang pantas dan tepat merupakan kunci utama di dalam melindungi persekitaran dan keselamatan manusia. Pada kebiasaannya, sebatian organik diukur dengan menggunakan pelbagai kaedah dimana ia memerlukan kaedah pengekstrakan pembersihan, larutan organik dan kaedah ini amat mahal dan memakan masa. Sebatian napropamide and phenolic adalah dua jenis pencemaran organik yang terdapat di dalam Malaysia dan dipilih untuk dibuat kajian di dalam tesis ini. Tesis ini menerangkan tentang reka bentuk gandingan dua struktur antenna yang digunakan sebagai penderia bagi organik yang tercemar. Sistem penderia ini mengandungi dua lapis (FR – 4) struktur antenna yang dilapisi oleh 'Multi Walled Carbon Nanotubes' (MWCNTs) dan 'Polypyrrole-Chitosan' (PPy-CHI) untuk diserap oleh bahan organik yang tercemar. Saluran pendua yang berhampiran dipilih untuk di salurkan kepada struktur antenna. Penyaluran adalah dari bahagian pembumian sentuhan fizikal kepada bahan yang dikaji. Reka bentuk struktur antenna yang terbaik dan posisi garis saluran dalam 5GHz frequency saluran dipilih berdasarkan kepada keputusan simulasi dengan menggunakan gelombang penuh simulator 'Computer Simulation Technology (CST) Microwave Studio'. Pelaksanaan fabrikasi struktur antenna diuji dengan menggunakan 'Vector Network Analyzer' (VNA) dan berdasarkan hasil fabrikasi di buat perbandingan hasil simulasi. 'Multi Walled Carbon Nanotubes' (MWCNTs) mempunyai ketebalan 5-10  $\mu\text{m}$  dan 'Polypyrrole-Chitosan' (PPy-CHI) adalah lapisan penderia yang telah dilapisi antenna di bahagian atas dengan menggunakan pemendapan medan elektrik. 'Atomic Force Microscopy' (AFM) digunakan untuk menjayakan keputusan lapisan di bahagian atas antenna. Interaksi kimia antara bahan yang digunakan dan lapisan penderia telah dikaji dengan menggunakan 'Fourier Transform Infrared Spectroscopy' (FT-IR). Keseluruhan sistem setelah dilapisi dan difabrikasi telah diuji

oleh phenol, 2-4 Dichlorophenol (24DCP), komersial napropamide dan napropamide dengan menggunakan kuantiti yang berbeza pada suhu bilik (25°C). Perubahan di dalam frekuensi salun pada struktur antena sebelum dan selepas menggunakan phenol, 2-4 Dichlorophenol (24DCP), komersial napropamide and napropamide telah diukur. Berdasarkan kepada hasil pengukuran, FR-4 struktur antena yang dilapisi dengan MWCNTs dan PPy-CHI berupaya menegesan kepekatan kecil bahan yang diukur dibawah paras 0.5 ppm. Pada frekuensi operasi ini (5 GHz), teknik ini boleh digunakan dalam sistem jarinaqn penderia tanpa wayar di dalam pengukuran pencemaran wap organik dalam kawasan penghadang untuk penyelidikan yang akan datang.





## ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my supervisor, Associate Professor Dr. Alyani Ismail for her continual intellectual guidance and advice during this research. Her encouragement, moral and technical support made this work possible.

I am also grateful to members of my supervisory committee, Professor Dr. Mohd Adzir Bin Mahdi, Associate Professor Dr. Raja Syamsul Azmir Bin Raja Abdullah and Dr Maryam Binti Mohd Isa for their advice and helpful discussion during this period of study.

I am very grateful to my dear lecturers in UPM and also kind staffs thought my student time in UPM.

I would also like to thank:

- Mr. Mohd. Hisham bin Ali who has provided technical support in the Laboratory.
- All the staff in KKK department, UPM for the co-operation given to me throughout my work.
- The Universiti Putra Malaysia for research fellowship.
- All my lovely friends in Malaysia for enjoyable social life in a wonderful country.

Last but not least, I wish to express my gratitude to my family for the support they gave throughout my studies.



I certify that a Thesis Examination Committee has met on 27 June 2014 to conduct the final examination of Ahmad Mohammadi on his thesis entitled "Carbon Nanotube-Based Microwave Resonant Sensor for Organic Contaminants Detection" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

**Abd. Rahman bin Ramli, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Roslina binti Mohd Sidek, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Mohd Nizar bin Hamidon, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Internal Examiner)

**Khalil Hassan Sayidmarie**

Professor  
University of Mosul  
Iraq  
(External Examiner)



---

**NORITAH OMAR, PhD**  
Associate Professor and Deputy Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date: 18 August 2014

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

**Alyani Ismail, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Chairman)

**Mohd Adzir Bin Mahdi, PhD**

Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Raja Syamsul Azmir Bin Raja Abdullah, PhD**

Associate Professor  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

**Maryam Binti Mohd Isa, PhD**

Lecturer  
Faculty of Engineering  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BIN KIM HUAT, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia

Date:

## DECLARATION

### Declaration by graduate 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: \_\_\_\_\_

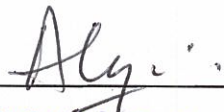
Name and Matric No.: \_\_\_\_\_



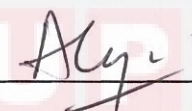
## Declaration by Members of Supervisory Committee

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 **Prof. Madva Dr. Alyani Ismail**  
Chairman of  
Supervisory  
Committee: Department of Computer & Communication Systems Engineering  
Faculty of Engineering  
Universiti Putra Malaysia

Signature:   
Name of **Mohd Adzir Mahdi, Ph.D**  
Member of  
Supervisory  
Committee: Jabatan Kejuruteraan Sistem Komputer dan Komunikasi  
Fakulti Kejuruteraan  
Universiti Putra Malaysia

Signature:   
Name of **Prof. Madya Dr. Alyani Ismail**  
Member of  
Supervisory  
Committee: Department of Computer & Communication Systems Engineering  
Faculty of Engineering  
Universiti Putra Malaysia

Signature: \_\_\_\_\_  
Name of \_\_\_\_\_  
Member of  
Supervisory  
Committee: \_\_\_\_\_

## TABLE OF CONTENTS

	<b>Page</b>
<b>DEDICATION</b>	
<b>ABSTRACT</b>	i
<b>ABSTRAK</b>	iii
<b>ACKNOWLEDGEMENTS</b>	v
<b>APPROVAL</b>	vi
<b>DECLARATION</b>	viii
<b>LIST OF TABLES</b>	xiii
<b>LIST OF FIGURES</b>	xiv
<b>LIST OF ABBREVIATIONS</b>	xviii
<b>LIST OF SYMBOLS</b>	xx
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	
1.1 Introduction	1
1.2 Organic Contaminations	1
1.3 Microwave Measurement	2
1.4 Procedure Scheme of Measuring Organic Contaminants	3
1.5 Problem Statement	4
1.6 Aim and Objectives	5
1.7 Research Scope	5
1.8 Outline of the Thesis	6
<b>2 LITERATURE REVIEW</b>	
2.1 Carbon Nanotubes	8
2.1.1 Synthesis and Purification of Carbon Nanotubes	9
2.1.2 Structure and Properties of Carbon Nanotubes	10
2.1.3 Microwave Devices using Carbon Nanotubes	13
2.1.4 Microwave Sensors Based Carbon Nanotubes	15
2.1.5 Carbon Nanotube Coating Methods	18
2.1.6 Related Works in Detection Napropamide and Phenolic Compounds	21
2.2 Antenna	22
2.2.1 Microstrip Antenna	22
2.2.2 Circular Microstrip Patch Antennas	23
2.2.3 Microstrip Substrate Materials	23
2.2.4 Circular Microstrip Patch Antennas Feeding Methods	25

<b>3</b>	<b>THEORETICAL BACKGROUND</b>	
3.1	Properties of Materials in electric field	29
3.1.1	Microwave – Materials Interaction	29
3.1.2	Microwave Interaction with Wet materials	32
3.2	Measurement using Microwave Techniques	33
3.2.1	Non Resonant Methods	33
3.2.2	Resonators Method	35
3.3	Methods of Analysis	36
3.3.1	Methods of Analysis of Microstrip Antenna	37
3.3.2	The Cavity model	37
3.3.3	Stripline Parameter	40
3.4	Theory of Resonant Method Measurement using Circular Patch	42
3.4.1	Plane Wave Reflection	42
3.4.2	Reflection and Transmission at Multiple Interfaces	43
3.4.3	System Signal Flow Graph	44
<b>4</b>	<b>METHODOLOGY</b>	
4.1	General Description of the System	46
4.2	Microstrip Disk Resonator Method	48
4.2.1	Disk Resonator Design	48
4.2.2	Feedline Design	48
4.2.3	Electromagnetic Simulation	49
4.2.4	Fabrication and Performance Tests of Resonator	51
4.3	Coating Method	52
4.3.1	Preparation of Gold Layer	52
4.3.2	Preparation of Carbon Nanotube, Polypyrrole and Chitosan Layer	53
4.3.3	Fabrication process of Coating Carbon Nanotube	53
4.3.4	Testing Coated Layer by Atomic Force Microscopy	55
4.3.5	Testing Chemical Interaction between Organic Contaminant and Coated Layers by Fourier Transform Infrared Spectroscopy (FT-IR)	56
4.3.6	Final Fabrication of Microstrip Disk Resonator Sensor	56
4.4	Samples Preparation	58
4.5	Performance of Fabricated Microstrip Disk Resonator for Organic Contaminant Detection	59
<b>5</b>	<b>RESULTS AND DISCUSSION</b>	
5.1	The Performance of Antenna	60
5.1.1	Antenna Parameters	61
5.1.2	Resonant Frequency	61
5.1.3	Input Impedance	62
5.1.4	Voltage Standing Wave Ratio (VSWR), Radiation Pattern and Gain	63
5.2	Fourier Transform Infrared Spectroscopy (FT-IR) Results	65
5.2.1	FT-IR Spectra of FR-4 Patch Antenna with Napropamide	66

5.2.2	FT-IR Spectra of FR-4 Patch Antenna with Commercial Napropamide	67
5.2.3	FT-IR Spectra of FR-4 Patch Antenna with some Phenolic Compounds	68
5.3	Experimental Results of FR-4 Patch Antenna as a Organic Compounds Sensor	69
5.3.1	Performance Tests of Coated and Fabricated FR-4 Patch Antenna	69
5.3.2	Experimental Results of FR-4 Patch Antenna to Detect Napropamide	70
5.3.3	Sensitivity Measurement of FR-4 Patch Antenna to Detect Napropamide	71
5.3.4	Experimental Results of FR-4 Patch Antenna to Detect and Sensitivity Measurement of Commercial Napropamide	72
5.3.5	Experimental Results of FR-4 Patch Antenna to Detect and Sensitivity Measurement of Phenolic Compounds	75
5.4	Selectivity of FR-4 Patch Antenna as Organic Compounds Sensor	77
5.5	Comparison between Sensitivity Results of FR-4 Patch Antenna Coated By MWCNTS-PPY-CHI Layer and Microwave Disk Resonator Coated by CNT	78
<b>6</b>	<b>CONCLUSION AND SUGGESTION</b>	
6.1	Conclusion	79
6.2	Recommendations for Future Work	80
6.2.1	Portable Design	80
6.2.2	Wireless Sensor Systems to Measure Organic Pollutions Vapour	80
6.2.3	Using other Polymers in Sensing Layer	81
6.2.4	Measuring other Kind of Pollutions	81
	<b>REFERENCES</b>	82
	<b>BIODATA OF STUDENT</b>	89
	<b>LIST OF PUBLICATIONS</b>	90