

Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.

**NOVEL SENSOR DESIGN FOR DETECTION OF
DANGEROUS CONTAMINATED MARINE
BIOTOXINS**

A Thesis submitted in fulfilment of the
requirements for the Degree of

Master of Engineering

in

INFORMATION AND TELECOMMUNICATION ENGINEERING

By

MOHD SYAIFUDIN BIN ABDUL RAHMAN



SCHOOL OF ENGINEERING AND ADVANCED TECHNOLOGY

MASSEY UNIVERSITY

PALMERSTON NORTH

NEW ZEALAND

March 2009

To my parents:

Abdul Rahman Bin Daud

and

Mariah Binti Abdul Rahman

Abstract

Planar electromagnetic sensing system has been used as one of the NDT methods to evaluate the material properties i.e., to evaluate near-surface properties such as conductivity, permeability and dielectric properties. The applications of planar electromagnetic sensors will depend on both the characteristic of the sensor type chosen and also the characteristic of material under test. Conventional planar interdigital sensors and novel planar interdigital sensors have been designed, fabricated and tested for detection of dangerous marine biotoxins in seafood. Our main objective is to sense the presence of dangerous contaminated acid in mussels and other seafoods. Initial studies were conducted with three peptide derivatives namely Sarcosine, Proline and Hydroxylproline. These three chemicals are structurally closely related to our target molecule (domoic acid). The initial results have shown that all sensors respond very well to the chemicals and it is possible to discriminate the different chemicals from the output of the sensor. Novel interdigital sensors have shown better sensitivity measurement compared to conventional interdigital sensors. The novel interdigital sensors were then being tested with three seafood products. Results from the analysis have shown that novel interdigital sensor with configuration #1 (Sensor_1) has better sensitivity compared to other sensors. Sensor_1 has been chosen for experiment using proline and mussels. The changes in sensor sensitivity were analysed with mussels before and after adding the proline. The presence of proline on the mussel surface and also injected proline to the mussel samples were clearly detected by Sensor_1. Further experiment was conducted with small amount of domoic acid (0.5 μg to 5.0 μg) injected to a mussel and it was found that Sensor_1 was able to detect small amount of domoic acid (1.0 μg) injected into the mussel sample. Sensor_1 was able to detect approximately 12.6 $\mu\text{g/g}$ of domoic acid in mussel meat. Three threshold levels of particular sample thickness have been established for detection of domoic acid. The first prototype of a low cost sensing system known as SIT (Seafood Inspection Tool) has been developed. The outcomes from the experiments provide chances of opportunity for further research in developing a low cost miniature type of sensors for reliable sensing system for commercial use.

Acknowledgements

First of all I would like to thank God, for giving me the strength and time to complete this research work. I am indebted to Associate Professor Dr. Subhas Mukhopadhyay, my research supervisor for his passionate interest in the subject and supervising my research work. I thank him for providing valuable advice, expert guidance and the friendly way that he teaches.

I would like to express my gratitude to my families, friends and colleagues who have helped and giving advice during the experiments and the preparation of the thesis. In particular I would like to thank my wife, Nina for her continual support during my studies at Massey University. I would like to thank Malaysian Agricultural Research and Development Institute (MARDI) for providing me the financial support to pursue my studies.

Special thanks to Dr. Krishanthi Jayasundera from the Institute of Fundamental Science, Massey University for her help and guidance related to chemistry and marine biotoxins. I would like to thank Dr. Gourab Sen Gupta for his help and guidance on microcontroller programming. I would like to acknowledge Mr. Nathan Eichler for his help on the software part of the embedded system. I also would like to acknowledge the help of Mr. Ken Mercer, Mr. Collin Plaw and Mr. Bruce Collins for their help on technical matters and invaluable comments to improve the experimental works in the laboratory.

And finally I would like to thank my beloved parents for their unconditional love and support. Thank you for all the sacrifices you made to give me a better chance in life.

Contents

Abstracts	iii
Acknowledgements	iv
Table of Contents	v
List of Figures	viii
List of Tables	xii
Chapter 1: Introduction	1
1.1 Introduction to Sensor	1
1.2 Sensors and Non-destructive Testing (NDT)	2
1.3 Planar Electromagnetic Sensor	4
1.3.1 Background of Planar Electromagnetic Sensors Research Works at Massey University.....	4
1.3.2 Planar Meander and Mesh Sensor	4
1.3.3 Planar Interdigital Sensor	6
1.3.4 Applications Planar Interdigital Sensors	7
1.4 Organization of the Thesis	12
Chapter 2: Introduction to Seafood Poisoning	13
2.1 Seafood Poisoning	13
2.2 Paralytic Shellfish Poisoning (PSP) Toxins	15
2.3 Diarrhoeic Shellfish Poisoning (DSP) Toxins	16
2.4 Neurotoxic Shellfish Poisoning (NSP) Toxins	16
2.5 Azaspiracid Shellfish Poisoning (AZP) Toxins	16
2.6 Ciguatera Fish Poisoning (CFP) Toxins	16
2.7 Amnesic Shellfish Poisoning (ASP) Toxins	17
2.7.1 Domoic Acid (DA)	17
2.8 Conclusion	18
Chapter 3: Existing Methodology of Seafood Inspection	19
3.1 Introduction	19
3.2 Chromatography technique	20
3.3 Surface Plasmon Resonance (SPR)	22
3.4 Enzyme-linked Immunosorbent Assay (ELISA)	22
3.5 Conclusion	23

Chapter 4: Development of Planar Interdigital Sensor	24
4.1 Introduction to Planar Interdigital Sensors	24
4.2 Sensor Design and Fabrication	27
4.2.1 Design and Fabrication Process	27
4.2.2 Conventional Interdigital Sensors	27
4.2.3 Novel Planar Interdigital Sensors	29
4.3 Conclusion	31
Chapter 5: Theoretical and Field Analysis	32
5.1 Introduction	32
5.2 Analysis of Conventional Sensors	35
5.2.1 The Equivalent Circuit for Conventional Sensors	35
5.2.2 Circuit Analysis	37
5.3 Analysis for Novel Interdigital Sensors	40
5.3.1 The Equivalent Circuit for Interdigital Sensors	40
5.3.2 Circuit Analysis	42
5.4 Modelling using COMSOL Multiphysics	45
5.4.1 Modelling for Conventional Sensors	47
5.4.2 Modelling for Novel Sensors	49
5.5 Conclusion	52
Chapter 6: Experimental Results and Discussions	53
6.1 Introduction	53
6.2 Experimental Setup and Measurement Method Sensor	53
6.3 Initial Studies with Chemical Samples	55
6.3.1 Experimental Results with Conventional Sensors	57
6.3.2 Experimental Results with Novel Sensors	59
6.4 Experiments with Seafood Products	61
6.4.1 Experimental Results with Seafood Products	61
6.5 Experiments with Mussels and Proline	67
6.5.1 Experimental Results with Mussels and Proline	68
6.6 Experiments with Mussels and Domoic Acid	75
6.6.1 Experimental Results with Mussels and Domoic Acid	76
6.7 Conclusion	80

Chapter 7: Development of A Low Cost Sensing System	81
7.1 Introduction	81
7.2 Interfacing with Microcontroller	81
7.2.1 Initialisation of Important Parts of Microcontroller	83
7.3 Electronics and Signal Processing Circuit for the Low Cost Sensing System.	85
7.3.1 Smooth Sine Wave Generation	88
7.3.2 Signal Rectification and Amplification	89
7.4 Calibration, Sensitivity Threshold and Signal Definitions	91
7.5 Power Supply for A Low Cost Sensing System	93
7.6 Prototype of Seafood Inspection Tool (SIT)	94
7.7 Conclusion	95
Chapter 8: Conclusion	96
Chapter 9: Future Work	100
Chapter 10: References	102
Publications and Awards	108

List of Figures

1.1:	Market impact of all sensor types by industries	2
1.2:	Configuration of planar electromagnetic sensors; (a) Mesh-type sensor and (b) Meander-type sensor	5
1.3:	Structure of the sensor	6
1.4:	Experimental setup to determine fat content in pork meat	8
1.5:	Sensor and different sections of a tenor and alto saxophone reeds	9
1.6:	Sensor, modified microscope, low-loss cables, and network analyzer used to test the reeds	9
1.7:	Experimental setup using the interdigital sensor	9
1.8:	Experimental setup to access the quality of leather	10
1.9:	Experimental setup using mesh type sensor and a network analyser	11
2.1:	Global increase of marine algal toxins incidence	14
2.2:	Chemical structure of Domoic Acid	17
4.1:	Electric field lines of (a) Parallel plate capacitors (b) Planar interdigital sensor	24
4.2:	Configuration of conventional planar interdigital sensor	25
4.3:	Fringing electric field of interdigital sensor	25
4.4:	Electric field formed between positive and negative electrodes for different pitch lengths, (l_1 , l_2 and l_3)	26
4.5:	Sensing possibilities to detect various characteristic of samples	26
4.6:	Representation of conventional interdigital sensor with configuration #1	28
4.7:	Conventional sensor with (a) Configuration #2 and (b) Configuration #3.....	28
4.8:	The fabricated conventional interdigital sensors compared to 20¢ New Zealand coin	29
4.9:	Representation of Sensor_1 configuration	30
4.10:	Sensor_2 and Sensor_3 with different configurations	30
4.11:	The fabricated novel interdigital sensors	31
5.1:	Equivalent circuit diagram of interdigital sensor	32
5.2:	Experiment setup for sensor analysis	33
5.3:	Impedance characteristic of interdigital sensor	35
5.4:	Equivalent circuit of conventional interdigital sensor (a) configuration #1 (b) configuration #2 and (c) configuration #3	37

5.5:	Signal waveform of sensor with configuration #1 (Din_10mil)	37
5.6:	Signal waveform of sensor with configuration #2 (Din_20mil)	38
5.7:	Signal waveform of sensor with configuration #3 (Din_40mil)	38
5.8:	Impedance characteristic of conventional interdigital sensor	39
5.9:	Phase difference characteristic of conventional interdigital sensor	39
5.10:	The equivalent representation of different sensors; (a) Sensor_1 with electrodes configuration 1-11-1 (b) Sensor_2 with electrodes configuration 1-5-1-5-1 and (c) Sensor_3 with electrodes configuration 1-3-1-3-1-3-1	41
5.11:	Variation of equivalent capacitance within each sensor geometry	42
5.12:	The signal waveform of Sensor_1.....	43
5.13:	The signal waveform of Sensor_2.....	43
5.14:	The signal waveform of Sensor_3.....	43
5.15:	Impedance characteristic of novel interdigital sensor	44
5.16:	Phase difference characteristic of conventional interdigital sensor	45
5.17:	Measurement of electric field intensity	46
5.18:	Electric field distribution of sensor configuration #1 (Din_10mil)	47
5.19:	Electric field distribution of sensor configuration #2 (Din_20mil)	47
5.20:	Electric field distribution of sensor configuration #3 (Din_40mil)	47
5.21:	Electric field intensity of conventional sensors	48
5.22:	Electric field distribution of Sensor_1	50
5.23:	Electric field distribution of Sensor_2	50
5.24:	Electric field distribution of Sensor_3	50
5.25:	Electric field intensity of novel sensors	51
6.1:	The experimental setup	54
6.2:	Full wave signal rectification circuit	54
6.3:	Sarcosine, Proline and Hydroxyproline molecules used for initial studies	55
6.4:	Three chemical samples prepared for the experiments	56
6.5:	The sample on the sensor of measurement	56
6.6:	The relationship between sensitivity and sensor configuration	58
6.7:	The relationship between sensitivity and chemical samples	58
6.8:	Comparison of sensors' sensitivity with different configurations	60
6.9:	Comparison of sensors' sensitivity with different samples	60
6.10:	10 samples of fish prepared for the experiment	61

6.11:	Comparison of sensors' sensitivity with fish samples	63
6.12:	10 samples of mussel prepared for the experiment	63
6.13:	Comparison of sensors' sensitivity with mussel samples	65
6.14:	10 samples of squid prepared for the experiment	65
6.15:	Comparison of sensors' sensitivity with squid samples	67
6.16:	The samples were cut from each mussel	68
6.17:	The sample (mussel) on the sensor of measurement	68
6.18:	Sensor sensitivity with sample before and after adding proline	70
6.19:	Results of mussel samples from different locations (before + proline)	71
6.20:	The relationship between sensor sensitivity with sample thickness (before +proline)	71
6.21:	Sensor sensitivity with sample before and after injected by proline	73
6.22:	Sensor sensitivity with different amount of injected proline	74
6.23:	Linearity of sensor sensitivity with injected proline	75
6.24:	The chemical structure of DA	76
6.25:	Domoic acid used for the experiments	76
6.26:	Sensor sensitivity with injected DA to a sample	77
6.27:	Sensor sensitivity with water and different concentrations of DA injected to the mussels	78
6.28:	Sensitivity threshold levels for normal samples and samples injected with DA of different thickness	79
7.1:	A SiLab C8051F020 microcontroller board	82
7.2:	Experimental setup of a low cost sensing system	82
7.3:	Fabricated electronic circuit for signal processing	87
7.4:	Sine-wave smoothing circuit	88
7.5:	Sine-wave generated by the micro-controller before and after the smoothing circuit	88
7.6:	Signal conditioning circuit diagram	89
7.7:	Ideal output signal of full wave rectifier. From bottom to top, the waveforms show VIN (CH1), VHALF (CH2), and VOUT (CH3)	90
7.8:	Signal from the sensor output feed to full wave signal rectification circuit	90
7.9:	Half wave signal	90
7.10:	Full-wave rectification after introduce gain of 8.2	91

7.11: A negative voltage from a single positive supply	93
7.12: Fabricated electronic circuit to power the sensing system	94
7.13: Seafood Inspection Tool (1 st prototype)	94

List of Tables

2.1:	Main marine toxins, their source organisms, and infected organisms and countries where their presence has been revealed	14
3.1:	Toxin properties: areas of common occurrence, toxicity, and regulatory action levels	20
3.2:	Chromatographic detection procedures for ASP	21
4.1:	Conventional interdigital sensor parameters	28
4.2:	Novel interdigital sensor parameters	30
5.1:	Relationship between excitation voltage, sensing voltage, current, impedance and capacitance for each conventional sensor	38
5.2:	Relationship between excitation voltage, sensing voltage, current, impedance and capacitance for novel sensors	44
5.3:	Capacitance calculated from the modelling using COMSOL for conventional sensors	48
5.4:	Capacitance calculated from the modelling using COMSOL for novel sensors	51
6.1:	Prices of different chemicals in the market	56
6.2:	Measurement data of conventional sensors	57
6.3:	Measurement data of novel sensors	59
6.4:	Measurement data of Sensor_1 for fish samples	62
6.5:	Measurement data of Sensor_2 for fish samples	62
6.6:	Measurement data of Sensor_3 for fish samples	62
6.7:	Measurement data of Sensor_1 for mussel samples	64
6.8:	Measurement data of Sensor_2 for mussel samples	64
6.9:	Measurement data of Sensor_3 for mussel samples	64
6.10:	Measurement data of Sensor_1 for squid samples	66
6.11:	Measurement data of Sensor_1 for squid samples	66
6.12:	Measurement data of Sensor_1 for squid samples	66
6.13:	Measurement data of sample before and after adding proline on the sample surface	69
6.14:	Measurement data of samples before and after injected with 0.7 mg proline	72

6.15:	Measurement data of samples before and after injected with 0.7 mg, 1.4 mg and 2.1 mg of proline	74
6.16:	Sample prepared for the experiment with domoic acid	77
6.17:	Measurement data of samples injected with domoic acid	77
6.18:	Sensitivity threshold level with respect to sample thickness	79