Planar Electromagnetic Sensors for Environmental Monitoring

A thesis presented in partial fulfilment of the requirements for the degree of
Doctor of Philosophy in Electrical Engineering
at Massey University, Palmerston North, New Zealand

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2011

To my wife

Norsyidah binti Khairul Anuar

Abstract

Water is the essence of life and an important nutrient for every living thing. Therefore, ninety six novel planar electromagnetic sensors based on the combination of meander sensor and interdigital sensor have been designed, fabricated, and tested for the application of water quality monitoring. Experiments were conducted to obtain the impedance characterization for each sensor, and the results were used to estimate the important parameters that influence the performance of the sensors based on the equivalent electrical circuits. The best sensors were selected based on the design with the highest electrical parameters (total effective capacitance and effective inductance). Intensive modelling and simulation of the selected best sensors are also discussed where the results were compared with the simulation results. Furthermore, the best sensors have been tested to detect nitrates contamination in distilled water using sodium nitrate ($NaNO_3$) and ammonium nitrate (NH_4NO_3) solutions with different concentrations. The sensor that consists of the series combinations of spiral meander planar sensor (with five turns) with the interdigital sensor (with large negative electrode): SECS22_1 is the best sensor to detect the presence of nitrate added into distilled water and can estimate the concentration level. Furthermore, the sensor was tested with various kinds of prepared samples and natural water samples taken from natural sources around New Zealand. The outcomes have shown a very good correlation of contamination level, translated from the qualitative and quantitative results. Using the SECS22_1 sensor, a method to estimate nitrate contamination in natural water sources using Independent Component Analysis (*ICA*) has been explained and demonstrated. This model can accurately estimate nitrate in a natural water source as shown by the results. A low-cost system has been developed based on SECS22_1, a microcontroller, a waveform circuit, signal conditioning circuits, and *LabView*. The results from the experiment have shown the low-cost system has the potential to be used as a tool for nitrate detection and water sources quality monitoring in remote places such as farms. Finally, the work and improvement for future consideration are also discussed in this research.

Acknowledgements

Praise to Allah S.W.T., the Most Gracious and the Most Merciful, whose blessing and guidance have helped me to present this thesis. There is no power nor strength save in Allah, the Highest and the Greatest. Peace and blessing of Allah be upon our Prophet Muhammad S.A.W. who has given light to mankind.

I would like to express my deepest gratitude to my supervisors Associate Professor Dr. Subhas Chandra Mukhopadhyay and Dr Gardiyawasam Amal Darshana Punchihewa for their support and supervisions. This research would not have been successful without their invaluable guidance, constant help as well as constructive criticisms and opinions throughout the research.

I would like to express my sincere thanks to my colleagues who provided guidance and assistance during the research. Also to Dr Gourab Sen Gupta, Mr Collin Plaw, and Bruce Collins, your assistance and support during my research were most appreciated.

Special thanks to my mother, wife, father, brothers, sisters, families, and Libo for their wishes, assistance, sedulous guidance, and patience. Also, thanks to all my friends and syabab, whose sacrifices had made everything is possible for me.

Last but not least, special thanks to the Ministry of Higher Education (MOHE) of Malaysia and Universiti Teknologi Malaysia for providing me with the financial support and granting leave to pursue my Ph.D degree.

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Abbreviations

NO_3^-	nitrate ion
SSCPXX_V	SSCP is the code for the meander sensor and interdigital sensor that are placed side by side and connected in parallel. XX is the number of the variation from 1 to 24. V is the version number of the sensors which is 1.
SSCSXX_V	SSCS is the code for the meander sensor and interdigital sensor that are placed side by side and connected in series. XX is the number of the variation from 1 to 24. V is the version number of the sensors which is 1.
SECPXX_V	SECP is the code for the meander sensor that is enclosing the interdigital sensor and the sensors are connected in parallel. XX is the number of the variation from 1 to 24. V is the version of the sensors which is 1.
SECSXX_V	SECP is the code for the meander sensor that is enclosing the interdigital sensor and the sensors are connected in series. XX is the number of the variation from 1 to 24. V is the version of the sensors which is 1.
$\vec{H}$	the magnetic field intensity
$\vec{E}$	the electric field intensity
$\vec{B}$	the magnetic flux density
$\vec{D}$	the electric flux density
$\vec{J}$	the current density
$\vec{J}^e$	the external current density
σ	the electric conductivity
v	the velocity of the conductor
ρ	the electric charge density
ε_0	the permittivity of vacuum which sets to be 8.854×10^{-2} F/m
μ_0	the permeability of vacuum equals to $4\pi\times10^{-7}$ H/m
χ_e	the electric susceptibility
χ_m	the magnetic susceptibility
ε_r	the relative permittivity
μ_r	the relative permeability
ε	the permittivity
μ	the permeability

V	the electric scalar potential
$\vec{A}$	the magnetic vector potential
Ψ	the gauge variable
ω	the angular frequency
$\widetilde{A}$	the modified magnetic vector potential
$\widetilde{V}$	the modified electric scalar potential
$NaNO_3$	Sodium Nitrate
NH_4NO_3	Ammonium Nitrate
HCl	Hydrochloric acid
NaOH	Sodium hydroxide base
MLR	Multilinear regression method
ICA	Independent component analysis
FastICA	Fixed point independent component analysis algorithm
$(NH_4)_2HPO_4$	Diammonium Phosphate
PCB	Printed circuit board