

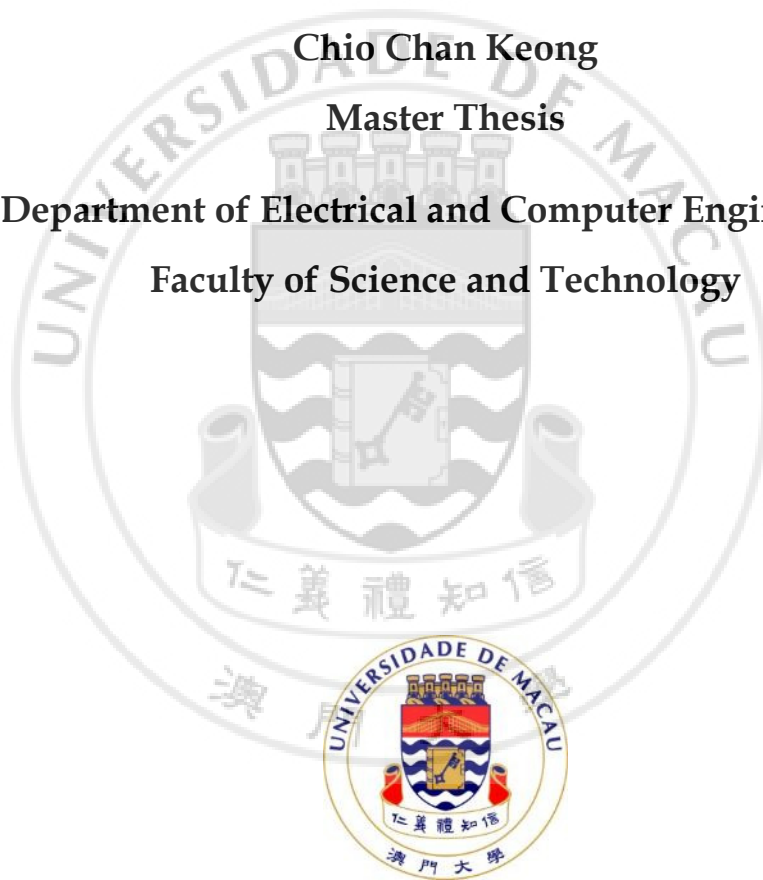
Analysis of Radiation from Wireless Communication Systems Using Parallel Electromagnetic Simulation

Chio Chan Keong

Master Thesis

Department of Electrical and Computer Engineering

Faculty of Science and Technology



University of Macau

Analysis of Radiation from Wireless Communication Systems Using Parallel Electromagnetic Simulation

Chio Chan Keong

A thesis submitted in partial fulfillment of the requirements for
the degree of
Master of Electrical and Electronics Engineering



Supervisor: Dr. Ting Sio Weng
Faculty of Science and Technology
University of Macau

2013

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at the University of Macau, I agree that the Library and the Faculty of Science and Technology shall make its copies freely available for inspection. However, reproduction of this thesis for any purposes or by any means shall not be allowed without my written permission. Authorization is sought by contacting the author at

Telephone: +853-66685694

E-mail: ryanchio@gmail.com



Signature: _____

Date: _____

Abstract

Considering the continuous increasing deployment of wireless communication system, the radiation level and communication quality are always highly concerned. Compared to the conventional approach for radiation and communication quality assessment based on electromagnetic field measurement, the use of computational method can better help to find out the field strength at locations where measurement is difficult to be undertaken, and even helps to forecast the change of the field distribution due to any adjustment of the base-station antennas and propagation environment. For achieving the objective of analyzing the radiation and communication quality of wireless communication systems in a city or a region in a city using computational electromagnetics, the structure to be simulated includes buildings with dielectric materials and base-station antennas. Usually, this kind of full-wave electromagnetic simulation belongs to electrically-large problem.

In this thesis, analyzing method based on parallel MoM with higher order basis functions for various wireless communication networks is proposed. As the Method of Moments (MoM) has advantages in accuracy for electrically-large computational electromagnetic simulation and high computation efficiency among different computational electromagnetics methods. It can be used to support the optimization by the evaluation of the field distribution, signal quality, pilot pollution, and the radiation safety level of the communication environment. For Wi-Fi and GSM network, the field strength will be simulated and compared with the on-site measurement to provide analysis of the communication quality and radiation safety. For UMS network, both the field strength and signal to interference ratio will be calculated to provide analysis on UMS network. In addition, signal quality and pilot pollution problem are

also analyzed. All the electromagnetic simulations above have 0.3 to 0.5 million unknowns which are considered as electrically large problems.

For base-station antenna modeling, 6 base-station antennas and 2 Wi-Fi antennas will be designed and techniques in improving the performances of the antenna were proposed. All the base-station antennas are directional antennas and the classification of them bases on their operation frequency, antenna gain, horizontal and vertical bandwidth etc. The Wi-Fi antennas include directional antenna and omni-directional antenna.

In addition, order reduction technique will be studied for increasing computation efficiency while the accuracy is kept. In this technique, the model will be rebuilt and the order of the basis functions in MoM with HOBs will be reduced for some shadowed regions or transition regions. In the example being studied, the proposed order reduction technique successfully decreases the computation time by 45.12% and the memory requirement is reduced by 34.38% while the simulation accuracy is almost kept.

All the corresponding techniques in modeling of antennas and building structures, analysis and detail discussions will be given in the following chapters. Moreover, simulation and experimental comparison are given to verify the correctness of the proposed analyzing model.

To this end, the above studies have been summarized in the following technical papers:

1. C.-K. Chio, S.-W. Ting, X. W. Zhao, K.-W. Tam, "Prediction model for radiation from base-station antennas using electromagnetic simulation," 2012 Asia-Pacific Microwave Conference, Dec 2012, pp. 1082-1084.
2. C.-K. Chio, S.-W. Ting, K.-W. Tam, "Prediction model for radiation from base-station antennas using MoM with high order basis functions and order reduction technique," 13th IEEE HK/Macau AP/MTT Postgraduate Conference, Oct 2012.
3. C.-K. Chio, S.-W. Ting, K.-W. Tam, "Radiation analysis for co-existing GSM900 and UMTS900 networks," 2013 IEEE International Symposium on Antennas and Propagation, July 2013.

4. C.-K. Chio, S.-W. Ting, K.-W. Tam, "Coverage analysis of outdoor public Wi-Fi hotspot using full-wave electromagnetic simulation," 2013 IEEE International Symposium on Antennas and Propagation, July 2013.
5. C.-K. Chio, S.-W. Ting, E.-H. Lim, K.-W. Tam, "Compact dual-band quasi-elliptic bandpass filter with transmission-zero control," 2012 IEEE MTT-S Int. Microwave Symp. Dig., June 2012.
6. C.-K. Chio, S.-W. Ting, K.-W. Tam, "Compact Dual-Band Quasi-Elliptic Bandpass Filter with Improved Upper-Stopband Performance," APMC2013, Dec 2012.
7. C.-K. Chio, S.-W. Ting, E.-H. Lim, K.-W. Tam, "Novel Reconfigurable Multiple-Band Quasi-Elliptic Bandpass Filter using Defected Ground Structure," 2013 IEEE MTT-S Int. Microwave Symp. Dig., June 2013.



Acknowledgement

I would like to show my sincere gratitude to my supervisor, Dr. Sio-Weng Ting, whose expertise, understanding, and patience. I would not have considered a graduate career in computational electromagnetics without his motivation and encouragement. Also, I would like to express my deep appreciation to Dr. Xun-Wang Zhao. He provided me with direction, technical support when using the simulator and theory of the Method of Moments. It was though his persistence, understanding and kindness that I completed my Master degree. Without them, this thesis could not have been accomplished.

I must also acknowledge to my colleague and friend, Mr. Chi-Hou Chio, for his assistance and help in server setup and useful suggestions. Without him, the work can hardly be completed. I would also like to thank my friends, colleagues and Professors in Wireless Communication Laboratory, especially for Prof. Kam-Weng Tam, Dr. Wai-Wa Choi and Dr. Shaodan Ma, Mr. BinKai Ou, Mr. Wen-Yao Zhung, Mr. Li Yang and Mr. Pedro Cheong.

Also, I would like to thank the Science and Technology Development Fund, Macao SAR Government and University of Macau under projects: FDCT/033/2010/A2, MYRG147 (Y1-L2)-FST11-TSW and SRG008-FST11-TSW.

Last but not the least, I would also like to thank my family for the support they provided me through my entire life and in particular.

Table of Contents

Table of Contents

Abstract	i
Acknowledgement	iv
Table of Contents	v
List of Tables	xii
Glossary	xiii
1 MOBILE COMMUNICATION NETWORK OVERVIEW AND OPTIMIZATION.....	1
1.1 MOBILE COMMUNICATION NETWORK OVERVIEW.....	1
1.1.1 GSM NETWORK (2G).....	1
1.1.2 UMTS NETWORK (3G)	3
1.2 METHODOLOGY OF NETWORK OPTIMIZATION.....	6
1.2.1 Significance of Drive Test and Walk Test.....	8
1.2.2 Software / Tools used in Drive Test and Walk Test.....	9
1.2.3 Hardware / Equipment used in Drive Test and Walk Test.....	10
SUMMARY	13
REFERENCES.....	14
2 COMPUTATIONAL ELECTROMAGNETICS OVERVIEW AND ENHANCEMENT OF MOM.....	15
2.1 INTRODUCTION OF COMPUTATIONAL ELECTROMAGNETICS (CEM).....	15
2.1.1 Finite- Difference Time- Domain Method (FDTD).....	16
2.1.2 Finite Element Method (FEM).....	16
2.1.3 Method of Moments (MoM).....	17
2.2 THE METHOD OF MOMENTS	18
2.2.1 Basic Algorithm	18

2.2.2	Electric Field Integral Equation (EFIE)	19
2.2.3	The Triangular Patch Basis Functions (RWG)	20
2.3	ENHANCEMENT OF MOM	22
2.3.1	Higher Order Basic Functions.....	26
2.3.2	Parallel Processing.....	27
2.3.3	Modeling of NURBS Surfaces	28
2.4	PILOT RESEARCH I - ELECTROMAGNETIC SIMULATION OF MICROWAVE FILTERS.....	30
2.5	PILOT RESEARCH II - ELECTROMAGNETIC SIMULATION OF Wi-Fi NETWORK USING HIGH ORDER MoM	34
2.5.1	Radiation Safety Assessment at the Lotus Square	35
2.5.2	Radiation Safety Assessment at Feira Do Carmo.....	39
2.6	SUMMARY.....	43
	REFERENCES.....	44
3	BASE-STATION ANTENNA MODELING	46
3.1	MODELING OF GSM ANTENNAS.....	46
3.2	MODELING OF UMTS ANTENNAS.....	51
3.3	WIFI ANTENNA MODELING	56
3.3.1	Modeling of Directional Antenna.....	56
3.3.2	Modeling of Omni-Directional Antenna	58
	SUMMARY	60
	REFERENCES.....	61
4	ANALYZING MODELS FOR RADIATION FROM GSM BASE-STATION ANTENNAS USING ELECTROMAGNETIC SIMULATION	62
4.1	INTRODUCTION.....	62
4.2	CASE STUDY I - GSM ANTENNA AND ANALYZING MODEL FOR AN APARTMENT	64
4.2.1	GSM Antenna.....	64
4.2.2	Model for Apartment	65

4.2.3	Measurement and Analyzing Model Comparison.....	66
4.3	CASE STUDY II – CORRIDOR OF A BUILDING IN UNIVERSITY OF MACAU.....	68
4.3.1	GSM Antenna	68
4.3.2	Model for a Corridor	68
4.3.3	Measurement and Analyzing Model Comparison.....	69
4.4	SUMMARY.....	70
	REFERENCES.....	71
5	ANALYSIS OF COMMUNICATION QUALITY AND RADIATION SAFETY IN UMTS NETWORK	72
5.1	INTRODUCTION.....	72
5.2	SIMULATION MODEL.....	73
5.3	MEASUREMENT SETUP.....	74
5.4	MEASUREMENT AND SIMULATION COMPARISON AND ANALYSIS.....	75
5.4.1	Measurement and Simulation comparison	75
5.4.2	Field Intensity and Communication Analysis	78
5.5	SUMMARY.....	84
	REFERENCES.....	85
6	ORDER REDUCTION TECHNIQUE FOR MoM WITH HIGH ORDER BASIS FUNCTIONS.....	86
6.1	INTRODUCTION OF ORDER REDUCTION TECHNIQUE.....	86
6.2	CASE STUDY	87
6.3	PERFORMANCE OF ORDER REDUCTION	88
6.4	SUMMARY.....	92
	REFERENCES.....	93
7	CONCLUSIONS AND PROSPECTIVE FOR FUTURE WORK	94
7.1	CONCLUSIONS	94
7.2	PROSPECTIVE FOR FUTURE WORK	96

APPENDIX A – E-Field Measurement Procedures of NEMO Handy97

APPENDIX B – Seibersdorf Field Nose Measurement 101

APPENDIX C – Datasheet of Base-Station Antennas..... 102

APPENDIX D – List of Publications..... 103



List of Figures

Figure 1.1 – Structure of GSM Network.....	2
Figure 1.2 – Basic Architecture of UMTS Network	5
Figure 1.3 – The distribution of base-station antennas in the South area of Macau	6
Figure 1.4 – Optimization Workflow.....	7
Figure 1.5 – NOKIA N80, NOKIA 6680 and NOKIA C5	10
Figure 1.6 – NEMO Handy	12
Figure 2.1 – Cluster System Structure	28
Figure 2.2 – Dual-band bandpass filter using DGS	31
Figure 2.3 – Control mechanism of the transmission zeros in the filter	32
Figure 2.4 – Circuit Structure of Filter-A and Filter-B.....	33
Figure 2.5 – The Lotus Square	35
Figure 2.6 – The Feira do Carmo	35
Figure 2.7 – The model of the Lotus statue.....	36
Figure 2.8 – Locations of the measurement points with respect to the lotus statue and the Wi-Fi antennas.	38
Figure 2.9 – The simulated E-field distribution of the Lotus Square model.	39
Figure 2.10 – Model of the Feira do Carmo Structure.....	40
Figure 2.11 – Locations of the measurement points and the Wi-Fi antennas with respect to the Feira do Carmo Structure.	41
Figure 2.12 – The simulated E-field distribution of the Feira do Carmo model.....	42
Figure 3.1 – The GSM base-station antenna Type-A	47
Figure 3.2 – The 3D radiation pattern of the antenna model	48
Figure 3.3 – (a) Horizontal and (b) Vertical pattern of the GSM antenna Type-A	48
Figure 3.4 – The model and GSM base-station antenna Type-B.....	49
Figure 3.5 – (a) Horizontal and (b) Vertical pattern of the GSM antenna Type-B.....	50
Figure 3.6 – The model and GSM base-station antenna Type-C.....	51

Figure 3.7 – (a) Horizontal and (b) Vertical pattern of the GSM antenna Type-C	51
Figure 3.8 – Measured spectrum shows the radiation exposure due to a coexistence of GSM and UMTS at around 900 MHz.....	52
Figure 3.9 – The model and UMTS base-station antenna Type-B	53
Figure 3.10 – (a) Horizontal and (b) Vertical pattern of the UMTS antenna Type-B	53
Figure 3.11 – The model and UMTS base-station antenna Type-C.....	54
Figure 3.12 – (a) Horizontal and (b) Vertical pattern of the UMTS antenna Type-C.....	55
Figure 3.13 – The model and UMTS base-station antenna Type-D.....	56
Figure 3.14 – (a) Horizontal and (b) Vertical pattern of the UMTS antenna Type-D.....	56
Figure 3.15 – The model of Wi-Fi directional antenna and its simulated 3D radiation pattern.	57
Figure 3.16 – The simulated radiation patterns of the directional antenna at 2.4 GHz (a) vertical and (b) horizontal.....	58
Figure 3.17 – The model of the Omni-directional antenna and its simulated 3D radiation pattern.....	59
Figure 3.18 – The simulated radiation patterns of the Omni-directional antenna at 2.45 GHz (a) vertical and (b) horizontal, in comparison with the manufacture specification.....	59
Figure 4.1 – Relative location of the GSM antennas and their main beam directions with respect to the apartment.....	64
Figure 4.2 – Dimensions of the apartment model.....	65
Figure 4.3 – E-field distribution of the analyzing model.....	67
Figure 4.4 – Model of the corridor structure and the base-station antenna.....	68
Figure 4.5 – The simulated E-field distribution inside the corridor at 944 MHz.....	69
Figure 4.6 – Comparison between simulation and measurement at 944 MHz.....	69
Figure 5.1 – UMTS communication situation in the proximity of the Lotus Square	74
Figure 5.2 – Measurement point located around the Lotus Square	75
Figure 5.3 – Field distribution in a range of ± 10 meters apart from the Lotus Statue	79
Figure 5.4 – Field distribution in a wider range apart from the Lotus Statue	79
Figure 5.5 – E_c/N_0 distribution in a range of ± 10 meters apart from the Lotus Statue	81
Figure 5.6 – E_c/N_0 distribution in a wider range apart from the Lotus Statue	81

Figure 5.7 - E_c/N_0 distribution for different base-station antenna.....83

Figure 6.1 - A bilinear surface defined by four vertices.87

Figure 6.2 - Dimensions and different views of the apartment (a) top view (b) bottom view...88

Figure 6.3 - E-field distribution of the analyzing model (a) normal order (b) with order reduction (unit: V/m).89

Figure 6.4 - The comparison of gain for the model with order reduction technique: (a) in vertical and (b) horizontal direction.90



List of Tables

Table 2.1 – Comparison between simulation and measurement results for the case of the Lotus Square.....	39
Table 2.2 – Comparison between simulation and measurement results for the case of Feira do Carmo.	42
Table 3.1 – GSM Antenna Type-A specification and Simulation Comparison.....	48
Table 3.2 – GSM antenna Type-B specification and Simulation Comparison.....	49
Table 3.3 – GSM antenna Type-C specification and Simulation Comparison	50
Table 3.4 – UMTS antenna Type-B specification and Simulation Comparison	53
Table 3.5 – UMTS antenna Type-C specification and Simulation Comparison.....	54
Table 3.6 – UMTS antenna Type-D specification and Simulation Comparison	55
Table 3.7 – Parameters of the directional antenna model in comparison with the manufacturer specification.....	57
Table 3.8 – Parameters of the Omni-directional antenna model in comparison with the manufacturer specification.....	58
Table 4.1 – Comparison of Simulated and Measured Electric field	67
Table 5.1 – Simulated and Measured RSCP and E_c/N_0 comparison of SC133.....	76
Table 5.2 – Simulated and Measured RSCP and E_c/N_0 comparison of SC260.....	77
Table 5.3 – Simulated and Measured RSCP and E_c/N_0 comparison of SC348.....	77
Table 5.4 – Simulated and Measured RSCP and E_c/N_0 comparison of SC385.....	78
Table 5.5 – The simulated pilot pollution locations in wider range apart from the Lotus structure	82
Table 6.1 – Comparison of Memory and CPU time.....	90
Table 6.2 – Comparison of Simulated and Measured Electric field	91

Glossary

3D	Three Dimensions
CEM	Computational Electromagnetics
DT	Drive Test
Ec/No	Energy per modulating bit to the noise spectral density
EFIE	Electric Field Integral Equation
FDDE	Frequency Domain Differential Equation
FDIE	Frequency Domain Integral Equation
FDMA	Frequency-Division Multiple Access
FDTD	Finite- Difference Time- Domain Method
FEM	Finite Element Method
GSM	Global System for Mobile Communications
GTD	Geometrical Theory of Diffraction
HOBs	Higher-Order Basis Functions
HOBBIES	Higher Order Basis Based Integral Equation Solver
ICNIRP	International Commission on Non-Ionizing Radiation Protection
MLFMA	Multilevel Fast Multipole Algorithm
MoM	Method of Moments
NURBS	Non-Uniform Rational B-spline
PO	Physical Optics
RSCP	Received Signal Code Power
RSSI	Received Signal Strength Indication
RWG	Rao-Wilton-Glisson
TDDE	Time Domain Differential Equation
TDIE	Time Domain Integral Equation
UMTS	Universal Mobile Telecommunications System
WCDMA	Wideband Code Division Multiple Access