

Analysis, Design and Optimisation of Various Antenna Types Based on Equivalent Magnetic-Current Concept

by

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B. Engineering (Electrical and Electronic, Honours),
University of Adelaide, Australia, 2013

Thesis submitted for the degree of

Doctor of Philosophy

in

Electrical and Electronic Engineering,
Faculty of Engineering, Computer and Mathematical Sciences
The University of Adelaide, Australia

January, 2017

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Abstract

The field equivalence principle is a classical technique, simple to use but remarkably effective to analyse aperture antennas. For most of thin planar structures, the aperture can be approximated as perfect magnetic conductor. Thus, the field equivalence principle typically yields a well-approximated equivalent problem that is much easier to solve than the original geometry. Inspired by this principle, a wide range of novel antenna structures are proposed in this thesis. These structures are further developed, optimised and tailored for various practical applications. Three main types of antennas are investigated, including travelling-wave antennas, low-profile monopolar antennas and reconfigurable antennas, corresponding to three major parts of this dissertation.

The first part examines various realisations of travelling-wave half-mode substrate-integrated waveguide (HMSIW) antennas and their optimisations. This type of antenna is equivalent to a magnetic dipole. In this part, the core contribution is a generalised semi-analytical model to effectively analyse continuous-source travelling-wave antennas, based on which different optimisation techniques for bandwidth and radiation patterns are proposed. An optimisation procedure that includes parameter uncertainties is also demonstrated.

The second part focuses on a type of low-profile monopolar antennas that can be interpreted as magnetic-current loops using the field equivalence principle. The main contributions are different configurations of symmetrical radiating slots that act as additional magnetic-current loop sources.

The last major part covers a wide range of reconfigurable antennas targeting various applications. These includes a family of stub-loaded substrate-integrated antennas, a circular resonant cavity, and low-profile monopolar antennas that have been introduced in the second major part. These antennas not only cover three main application types of reconfigurable antennas, i.e. frequency-, polarisation-, and pattern-tunability, but also combine those in a single device. Moreover, significant improvements in performances compared to antennas available in the literature are demonstrated.

Abstract

Overall, the thesis provides different frameworks to design many types of antennas. The analytical models, using the field equivalence principle as a common fundamental technique, provide not only thorough understandings on antennas' radiation mechanisms but also an effective means for rapid antenna optimisations.

Statement of Originality

I certify that this work contains no material which has been accepted for the award of any other degree or diploma in my name, in any university or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text. In addition, I certify that no part of this work will, in the future, be used in a submission in my name, for any other degree or diploma in any university or other tertiary institution without the prior approval of the University of Adelaide and where applicable, any partner institution responsible for the joint-award of this degree.

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Acknowledgments

I would like to express my sincere gratitude to all people and organisations whose support, skills and encouragement are crucial to the successful completion of this thesis.

First and foremost, I would like to convey my deep gratitude to my principal supervisor, **Prof. Christophe Fumeaux** for his constant support throughout my research time at the University of Adelaide. His encouragement, constructive feedback, critical comments, travel funds and responsiveness are all essential factors that lead me throughout my candidature. He has not only inspired in me the passion for research but also helped me to balance it with social life and professional development. To me, he is a wonderful research supervisor and mentor whose advice I always trust.

Second, I would like to mention my co-supervisors, **Dr Thomas Kaufmann** and **Dr Leonard Hall**. I am thankful to have Dr Thomas Kaufmann as my lecturer in the Engineering Electromagnetic Course. He was the one who brought me to the field of electromagnetic. After working through the summer research under his excellent supervision, I gained and started to build up my research skills and experiences. I am also strongly indebted to Dr. Leonard Hall, who has offered me much useful feedback on my designs as well as advices in the professional engineering life. Thanks to him, I have also learned and appreciated the importance of the fabrication procedures.

In addition, I wish to express my gratitude to the technical staffs at the School of Electrical and Electronic Engineering Workshop, who have done excellent jobs on fabricating the devices presented in this thesis. Thanks to their guidance, I have also learned many different fabrication techniques. I would like to specially mention here Mr Alban O'Brien and Mr Pavel Simcik who have been patiently helping me fabricate multiple antenna designs until the prototypes are successful. I also thank Mr Brandon Pullen and Mr Danny Di Giacomo for their assistance on fabrication and material ordering.

My PhD research would not be possible without the assistance from the University of Adelaide and the School of Electrical and Electronic, from which I received financial support and technical instruments for my research. I would like to thank the administrative

Acknowledgments

team, Mrs Ivana Rebellato, Mrs Rose-Marie Descalzi, Ms Jodie Schluter, Ms Laura McNamara, Ms Deborah Koch and Ms Daphne Zammit who have helped me through administrative work in the most efficient way. I would also like to acknowledge the Vietnam Ministry of Education and Training who allowed me to continue my study in Australia after four year of undergraduate sponsorship.

Throughout my PhD candidature, I have received valuable help from many friends and colleagues. I would like to thank all of group members in the Applied Electromagnetic Groups, including Dr Withawat Withayachumnankul, Dr Ali Horestani, Dr Zahra Shaterian, Dr Amir Ebrahimi, Dr Cheng Zhao, Sree Pinapati, Shengjian Chen, Wendy Lee, Chengjun Zou, Jack Gao, Andrew Udina, Deshan Govender, Siti Nailah Zainarry and Ali Makatooni for their constructive feedback on my presentations as well as their willingness to help me in any occasion. I have had a great time doing research at the University thanks to their constant support and friendship. I also especially thank Lachlan James Gunn who has always been eager to help me on designing Printed Circuit Boards (PCB) despite of being extremely busy for his own thesis. I also thank Duong Nguyen and Thanh Bui, two of my Vietnamese friends in the School, who have helped me in multiple occasions and shared great times together with me.

I wish to give my deep appreciation to my dear fiancée, Ms Phuong-Tu Nguyen, who has always been by my side in any situations and supported me unconditionally. Her love, patience and continuous support has guided me through this challenging journey. Last but not least, I would like to give my endless love and appreciation to my father, my mother and my brother, who have been caring for and encouraging me infinitely.

Nghia Nguyen-Trong,
January 2017,
Adelaide

Thesis Conventions

The following conventions have been adopted in this thesis:

Typesetting

This document was compiled using L^AT_EX2e. TeXstudio were used as text editor interfaced to L^AT_EX2e. Inkscape was used to produce schematic diagrams and other drawings.

Referencing

The IEEE style has been adopted for referencing.

System of units

The units comply with the international system of units recommended in an Australian Standard: AS ISO 1000–1998 (Standards Australia Committee ME/71, Quantities, Units and Conversions 1998).

Spelling

Australian English spelling conventions have been used, as defined in the Macquarie English Dictionary (A. Delbridge (Ed.), Macquarie Library, North Ryde, NSW, Australia, 2001).

Publications

Note: Articles with an asterisk (*) are directly relevant to this thesis. Articles with a hash (#) are related to this thesis but the work was carried out before the candidature and are not part of original contributions.

Journal Articles

1. **N. Nguyen-Trong**, L. Hall, T. Kaufmann and C. Fumeaux, "Wideband Millimeter-Wave Antennas With Magnetic-Dipole Patterns Integrated in Metallic Structures," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 11, pp. 4877-4882, Nov. 2016. *
2. **N. Nguyen-Trong**; A. Piotrowski; L. Hall; C. Fumeaux, "A Frequency- and Polarization-Reconfigurable Circular Cavity Antenna," *IEEE Antennas and Wireless Propagation Letters*, 2016, in print, DOI: 10.1109/LAWP.2016.2616128. *
3. **N. Nguyen-Trong**; A. Piotrowski; T. Kaufmann and C. Fumeaux, "Low-Profile Wideband Monopolar UHF Antennas for Integration Onto Vehicles and Helmets," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 6, pp. 2562-2568, June 2016. *
4. **N. Nguyen-Trong**; L. Hall and C. Fumeaux, "A Frequency- and Pattern-Reconfigurable Center-Shorted Microstrip Antenna," *IEEE Antennas and Wireless Propagation Letters*, 2016, in print, DOI: 10.1109/LAWP.2016.2544943. *
5. **N. Nguyen-Trong**, L. Hall and C. Fumeaux, "Transmission-Line Model of Nonuniform Leaky-Wave Antennas," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 3, pp. 883-893, March 2016. *

Publications

6. A. Kouassi, N. **Nguyen-Trong**, T. Kaufmann, S. Lalléchère, P. Bonnet and C. Fumeaux, "Reliability-Aware Optimization of a Wideband Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 2, pp. 450-460, Feb. 2016. *The two first authors contributed equally to the work.* *
7. N. **Nguyen-Trong**, L. Hall and C. Fumeaux, "A Frequency- and Polarization-Reconfigurable Stub-Loaded Microstrip Patch Antenna," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 11, pp. 5235-5240, Nov. 2015. *
8. N. **Nguyen-Trong**, T. Kaufmann, L. Hall and C. Fumeaux, "Analysis and Design of a Reconfigurable Antenna Based on Half-Mode Substrate-Integrated Cavity", *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 8, pp. 3345-3353, Aug. 2015. *
9. N. **Nguyen-Trong**, T. Kaufmann, L. Hall and C. Fumeaux, "Variational Analysis of Folded Substrate-Integrated Waveguides", *IEEE Microwave and Wireless Components Letters*, vol. 25, no. 6, pp. 352-354, June 2015. *
10. N. **Nguyen-Trong**, T. Kaufmann and C. Fumeaux, "A Semi-Analytical Solution of a Tapered Half-Mode Substrate-Integrated Waveguide With Application to Rapid Antenna Optimization", *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 6, pp. 3189-3200, June 2014. #
11. N. **Nguyen-Trong**, T. Kaufmann, and C. Fumeaux, "A wideband omnidirectional horizontally polarized travelling-wave antenna based on Half-mode Substrate Integrated Waveguide", *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 682-685, 2013. **First Prize winner for the IEEE Australian Council Paper Contest for undergraduate students.** #

Conference Articles

1. N. **Nguyen-Trong**, C. Fumeaux, A. Kouassi, S. Lalléchère and P. Bonnet, "Reliability-aware optimization for the sidelobe level of leaky-wave antennas," *2016 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cairns, Australia, 2016, pp. 708-711. *

2. **N. Nguyen-Trong**, L. T. Hall and C. Fumeaux, "Pattern synthesis with angular mask for leaky-wave antennas," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, Montreal, QC, 2016, pp. 1-2. *
3. **N. Nguyen-Trong**, L. T. Hall and C. Fumeaux, "Impedance matching of a frequency- and pattern-reconfigurable antenna," *2016 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM)*, Montreal, QC, 2016, pp. 1-2. *
4. **N. Nguyen-Trong**, C. Fumeaux, S. Gupta and C. Caloz, "Pulse radiation from a leaky-wave antenna," *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, Fajardo, 2016, pp. 87-88.
5. **N. Nguyen-Trong**, L. Hall and C. Fumeaux, "A reconfigurable quarter-wave patch antenna employing a folded loading stub," *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, Fajardo, 2016, pp. 831-832. *
6. **N. Nguyen-Trong**, L. Hall and C. Fumeaux, "Reconfigurable antennas based on stub-loaded substrate-integrated circuits," *10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, 2016, pp. 1-4. *
7. **N. Nguyen-Trong**, T. Kaufmann and C. Fumeaux, "Perturbation method for near-elliptical Half-Mode cavity antennas," *10th European Conference on Antennas and Propagation (EuCAP)*, Davos, Switzerland, 2016, pp. 1-3.*
8. **N. Nguyen-Trong**, L. Hall and C. Fumeaux, "A biasing technique for varactor-loaded reconfigurable antennas," *2016 IEEE 2nd Australian Microwave Symposium (AMS)*, Adelaide, SA, 2016, pp. 23-24. *
9. **N. Nguyen-Trong**, L. Hall and C. Fumeaux, "On the tuning range of a reconfigurable half-mode substrate-integrated cavity antenna," *International Symposium on Antennas and Propagation (ISAP)*, Hobart, TAS, 2015, pp. 1-4. *
10. **N. Nguyen-Trong**, T. Kaufmann, L. Hall and C. Fumeaux, "Optimization of Leaky-Wave Antennas Based on Non-Uniform HMSIW", presented at *IEEE MTT-S International Conference on Numerical Electromagnetic and Multiphysics Modeling and Optimization (NEMO)*, 2015. **First prize winner student paper competition.** *

Publications

11. **N. Nguyen-Trong**, T. Kaufmann, L. Hall and C. Fumeaux, "Investigation of parasitic effects from feed and termination on the far-field pattern of leaky-wave antennas based on HMSIW", *Loughborough Antennas and Propagation Conference (LAPC)*, pp. 72-76, 10-11 Nov. 2014. *
12. **N. Nguyen-Trong**, T. Kaufmann and C. Fumeaux, "Near-field characteristics of a wideband travelling-wave antenna based on a tapered Half-Mode Substrate-Integrated Waveguide", *International Workshop on Antenna Technology (iWAT)* pp. 300-303, 4-6 March 2014. **Best student paper award.** #
13. **N. Nguyen-Trong**, T. Kaufmann, and C. Fumeaux, "Wideband transition from coaxial cable to Half-mode Substrate Integrated Waveguide", *Asia-Pacific Microwave Conference Proceedings (APMC)*, pp.110-112, 5-8 Nov. 2013. #

Papers Accepted or under Review

1. **N. Nguyen-Trong**, A. Piotrowski, and C. Fumeaux, "A Frequency-Reconfigurable Dual-Band Low-Profile Monopolar Antenna", submitted to *IEEE Transactions on Antennas and Propagation*, under review. *
2. **N. Nguyen-Trong**, A. Piotrowski, L. Hall, C. Fumeaux, "Concept of a Beam-Steerable Cavity-Fed Antenna with Magnetic-Dipole Coupling Elements", accepted for presentation at *11th European Conference on Antennas and Propagation (EuCAP)*, Paris, France, 2017. *
3. **N. Nguyen-Trong**, L. Hall, C. Fumeaux, "Conformal Integration of Traveling-Wave Slot Antennas in Millimeter-Wave Regime", accepted for presentation at *International Workshop on Antennas and Propagation (iWAT)*, Athens, Greek, 2017. *
4. **N. Nguyen-Trong**, L. Hall, C. Fumeaux, "Variational Analysis of Substrate-Integrated Waveguides with Longitudinal Slot", accepted for presentation at *Applied Computational Electromagnetics Society Conference Firenze*, Italy, 2017. *

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