Design of High Performance RFID Systems for Metallic Item Identification

by

Mun Leng Ng

B.E. (Electrical & Electronic, First Class Honours),
The University of Adelaide, Australia, 2003.

Thesis submitted for the degree of

Doctor of Philosophy

in

School of Electrical and Electronic Engineering
The University of Adelaide, Australia

July 2008

THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

To my parents

Contents

Abstract

Although the origins of Radio Frequency Identification (RFID) technology can be traced back for many years, it is only recently that RFID has experienced rapid growth. That growth is mainly due to the increasing application of this technology in various supply chains. The widening of the implementation of RFID technology in supply chains has posed many challenges and one of the biggest is the degradation of the RFID system performance when tagging metallic objects, or when the RFID system operates in a metallic environment. This thesis focuses on tackling the issue of having metallic objects in an Ultra High Frequency (UHF) RFID system.

The work presented in this thesis contributes to the research on UHF RFID systems involving metallic objects in several ways: (a) the development of novel RFID tags that range from a simple tag for general applications to tags suitable for metallic object identification; (b) the tag designs target the criteria of minimal tag size and cost to embrace the vision of item level tagging; and (c) the analysis of the performance (through theoretical predictions and practical measurements) of an RFID tag near metallic structures of various shapes and sizes.

The early part of this thesis provides a brief introduction to RFID and reviews the background information related to metallic object identification for UHF RFID systems. The process of designing a basic tag, and additional information and work done related to the process, are outlined in the early part of this thesis. As part of this fundamental research process, and before proceeding to the designing of tags specifically for metallic objects, a small and low cost RFID tag for general applications was developed. Details of the design of this tag, with the application of this tag for animal identification, are presented.

In the later parts of the work, different tag design approaches were explored and this has generated three rather different RFID tags suitable for attaching to metallic objects. The aim of this research is not just to design tags for metallic objects but also to tackle the constraints of having tags that are small in size, cost effective and suited in size

to some familiar objects. Hence, in the later part of this research, the work took a step further where one of the three tags designed for metallic objects addressed the challenge of identifying individual small metallic beverage cans.

RFID involves tagging of different types of objects and a tag may be required to be located in a depression of a metallic object. In the final part of this research, the read range performance of one of the RFID tags designed for metallic objects was analysed when the tag was located in metallic depressions of various shapes and sizes. The analysis was performed from a combination of theoretical calculation and simulation perspectives, and also through practical real-life measurements.

Metallic objects are very common around us. Their presence is unavoidable and so to identify them, having the appropriate RFID tags suitable for operation on metallic surfaces is essential. Frequently the tags must be small in size and low in cost to allow identification at item level of individual small metallic objects. Understanding and being aware of the potential effects of metallic structures of various shapes and sizes on the tag performance is thus important. The research in this thesis into all the above can bring the industry further towards full deployment of RFID down to item level tagging.

Statement of Originality

This work contains no material that has been accepted for the award of any other degree or diploma 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.

I give consent to this copy of the thesis, when deposited in the University Library, being available for loan, photocopying and dissemination through the library digital thesis collection.

The author of this thesis acknowledges that copyright of published work contained within this thesis (as listed in the publications page) resides with the copyright holder(s) of that work.

Signed

Date

Acknowledgments

First of all, I would like to express my sincere gratitude to my research principal supervisor, Professor Peter H. Cole, for his constant guidance and support throughout my Ph.D candidature. I am immensely grateful for all the time that he has dedicated for discussions on my work. I would also like to deeply thank my research co-supervisor, Associate Professor Christopher J. Coleman, for reviewing my research progress from time to time and providing fruitful insights during our discussions. I truly appreciate them.

Many thanks to Mr. Alfio R. Grasso for communicating and arranging projects with industrial partners. I would also like to thank the members and colleagues of the Auto-ID Laboratory at Adelaide for the constructive technical discussions that we have had. Special thanks to Mr. David M. Hall for his willingness to share his technical expertise and experience on RFID from an industrial practice aspect.

I would also like to thank the staff of the School of Electrical and Electronic Engineering at the University of Adelaide, particularly Mr Geoffrey W. Pook and Mr. Pavel Simcik for providing technical services for some of my antenna fabrications. I also appreciate all the support given by the administration and workshop staff.

Thanks to the University of Adelaide and once again to Professor Peter H. Cole for offering me a Divisional Scholarship for my Ph.D study. A sincere appreciation also goes to Pork CRC for providing the funding for one of my projects.

For my parents who brought me up with all their love and have been unconditionally supporting me to reach my every goal and ambition, thank you very much. I could not be more proud as your daughter. Last but not least, I would like to thank my fiancé, research partner and also best friend, Kin Seong, who is always standing by me and willing to go through thick and thin together with me.

Mun Leng Ng (June 2008)

Conventions

Typesetting

This thesis is typeset using the LaTeX2e software.

The fonts used in this thesis are Times New Roman and Sans Serif.

Referencing

The referencing and citation style adopted in this thesis are based on the Institute of Electrical and Electronics Engineers (IEEE) Transaction style [1].

For elecronic references, the last accessed date is shown at the end of a reference.

Units

The units used in this thesis are based on the International System of Units (SI units) [2].

Prefixes

In this thesis, the commonly used numerical prefixes to the SI units are "p" (pico; 10^{-12}), "n" (nano; 10^{-9}), "μ" (micro; 10^{-6}), "m" (milli; 10^{-3}), "k" (kilo; 10^{3}), "M" (mega; 10^{6}) and "G" (giga; 10^{9}).

Phasors

Where phasors are used to represent sinusoidal quantities, peak value phasors rather than r.m.s. phasors are used.

Spelling

The Australian English spelling is adopted in this thesis.

Illustrations

The illustrations in this thesis are drawn using the CorelDRAW 11 software.

Publications

Book Chapter

[1] M. L. Ng, K. S. Leong, and P. H. Cole, "RFID tags for metallic object identification," in *RFID Handbook: Applications, Technology, Security, and Privacy*, S. Ahson and M. Ilyas, Eds. CRC Press, 2008.

[2] K. S. Leong, M. L. Ng, and P. H. Cole, "RFID reader synchronisation," in *RFID Handbook: Applications, Technology, Security, and Privacy*, S. Ahson and M. Ilyas, Eds. CRC Press, 2008.

Journal

[1] K. S. Leong, M. L. Ng, A. R. Grasso, and P. H. Cole, "Dense RFID reader deployment in Europe using synchronization," *Journal of Communications*, vol. 1, no. 7, pp. 9–16, 2006.

Conference

[1] M. L. Ng, K. S. Leong, and P. H. Cole, "Design and miniaturization of an RFID tag using a simple rectangular patch antenna for metallic object identification," in *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii, 2007.

[2] M. L. Ng, K. S. Leong, and P. H. Cole, "A small passive UHF RFID tag for metallic item identification," in *21st International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC)*, vol. 2, Chiang Mai, Thailand, 2006.

[3] M. L. Ng, K. S. Leong, D. M. Hall, and P. H. Cole, "A small passive UHF RFID tag for livestock identification," in *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE)*, Beijing, China, 2005.

[4] M. L. Ng, K. S. Leong, and P. H. Cole, "Analysis of constraints in small UHF RFID tag design," in *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE)*, Beijing, China, 2005.

[5] K. S. Leong, M. L. Ng, and P. H. Cole, "HF and UHF RFID tag design for pig tagging," in *11th Biennial Conference of the Australasian Pig Science Association (APSA)*, Brisbane, Australia, 2007.

[6] K. S. Leong, M. L. Ng, and P. H. Cole, "Investigation on the deployment of HF and UHF RFID tag in livestock identification," in *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii, USA, 2007.

[7] K. S. Leong, M. L. Ng, and P. H. Cole, "Miniaturization of dual-frequency RFID antenna with high frequency ratio," in *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii, USA, 2007.

[8] K. S. Leong, M. L. Ng, and P. H. Cole, "Investigation of RF cable effect on RFID tag antenna impedance measurement," in *IEEE Antennas and Propagation Society International Symposium*, Honolulu, Hawaii, USA, 2007.

[9] K. S. Leong, M. L. Ng, and P. H. Cole, "Investigation of the threshold of second carrier sensing in RFID deployment," in *International Symposium on Applications and the Internet (SAINT) - Workshop - RFID and Extended Network: Deployment of Technologies and Applications*, Hiroshima, Japan, 2007.

[10] K. S. Leong, M. L. Ng, and P. H. Cole, "Dual-frequency antenna design for RFID application," in *21st International Technical Conference on Circuits/Systems, Computers and Communications (ITC-CSCC)*, vol. 2, Chiang Mai, Thailand, 2006.

[11] K. S. Leong, M. L. Ng, and P. H. Cole, "Operational considerations in simulation and deployment of RFID systems," in *17th International Zurich Symposium on Electromagnetic Compatibility*, Singapore, 2006.

[12] K. S. Leong, M. L. Ng, A. R. Grasso, and P. H. Cole, "Synchronisation of RFID readers for dense RFID reader environments," in *International Symposium on Applications and the Internet (SAINT) - Workshop - RFID and Extended Network: Deployment of Technologies and Applications*, Phoenix, Arizona, USA, 2006.

[13] K. S. Leong, M. L. Ng, and P. H. Cole, "Positioning analysis of multiple antennas in a dense RFID reader environment," in *International Symposium on Applications and the Internet (SAINT) - Workshop - RFID and Extended Network: Deployment of Technologies and Applications*, Phoenix, Arizona, USA, 2006.

[14] K. S. Leong, M. L. Ng, and P. H. Cole, "The reader collision problem in RFID systems," in *IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications (MAPE)*, Beijing, China, 2005.

[15] D. C. Ranasinghe, M. L. Ng, K. S. Leong, and P. H. Cole, "Small UHF RFID label antenna design and limitations," in *IEEE International Workshop on Antenna Technology: Small Antennas and Novel Metamaterials*, New York, USA, 2006.

[16] D. C. Ranasinghe, K. S. Leong, M. L. Ng, D. W. Engels, and P. H. Cole, "A distributed architecture for a ubiquitous RFID sensing network," in *Intelligent Sensors, Sensor Networks and Information Processing Conference (ISSNIP)*, Melbourne, Australia, 2005.

[17] D. C. Ranasinghe, K. S. Leong, M. L. Ng, D. W. Engels, and P. H. Cole, "A distributed architecture for a ubiquitous item identification network," in *Seventh International Conference on Ubiquitous Computing*, Tokyo, Japan, 2005.

Non-refereed

[1] M. L. Ng, K. S. Leong, and D. W. Engels, "Prospects for ubiquitous item identification," in *Auto-ID Labs Workshop*, Zurich, 2004.

[2] K. S. Leong, and M. L. Ng, "A simple EPC enterprise model," in *Auto-ID Labs Workshop*, Zurich, 2004.

[3] K. S. Leong, M. L. Ng, and D. W. Engels, "EPC network architecture," in *Auto-ID Labs Workshop*, Zurich, 2004.

List of Figures

List of Tables