# Solutions for Hard-to-Tag Objects in UHF RFID Systems

by

**Zhonghao Hu**

B.E. (Electrical & Electronic),
Northwestern Polytechnical University, China, 2006.

Thesis submitted for the degree of

**Doctor of Philosophy**

in

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

March 2011

*To my parents*

# Contents

# Abstract

Radio frequency identification (RFID) is an auto-identification technology realised by radio waves. The ultimate goal of RFID is the item-level tagging of all kinds of products in supply chains. This goal challenges industry and academia in many aspects.

Passive UHF RFID systems, when compared with other RFID systems, are believed to possess advantages in achieving that goal. However, UHF RFID systems possess two serious disadvantages: (i) the relatively large antenna size, and (ii) the sensitiveness to the metallic items on which a tag is mounted. Those two deficiencies make a large number of small size objects and metallic objects hard to tag. In addition, different applications also bring special requirements or limitations in adopting UHF RFID systems, such as in the case of a container seal, the requirement for tags to have a physical security function, and in other cases such as pallet shipping, the requirement for detecting massive numbers of items densely stacked together. Finally, of course, cost is one of the key limitations if one intends to apply his or her design down to item-level tagging commercially. Hence each of the inherent deficiencies of the system itself and the limitations caused by the application, or a combination of all or some of the deficiencies and limitations make a large number of items hard to tag and impedes the item-level tagging target.

The research in this thesis aims, by antenna design and electromagnetic wave analysis, to provide feasible and affordable solutions for some of those hard-to-tag objects in UHF RFID systems, and the thesis can be divided into five parts.

In detail, the first part of the thesis gives the motivations, contributions and structure of this thesis. In addition it also provides a brief introduction to RFID systems and about how they are operated, developed, classified, regulated and standardised.

The second part of this thesis presents basic terminologies and design criteria in tag antenna design, transponder IC design and reader design. Factors which limit the operating range of UHF RFID systems are discussed. Following this discussion, a novel method making use of a scattering matrix for evaluating the operating range of a UHF RFID system deployed in an arbitrary environment is proposed.

In the third part, concerning the meander line dipole antenna (MDA), one of the approaches to minimising tag antenna size is analysed in terms of its resonant frequency, size reduction contributors, radiation pattern and efficiency. An analytic formula for calculating the resonant frequency of an MDA on a dielectric substrate as an RFID tag antenna is established. Based on the analysis, a novel tag antenna with a physical security function (an electronic seal) for protecting shipping containers was designed and experimentally verified.

The fourth part of this thesis puts emphasis on metallic item detection. The reason of why common dipole based tag antennas cannot work well in close proximity to metal is given. Previous solutions and their own demerits in solving this problem are summarised. Then, a low profile, simple structure, compact size solution is introduced via the artificial magnetic conductor concept. Furthermore, a general DVD disc contains a very thin metal layer inside for the purpose of reflecting laser. That layer may not bring many troubles in identifying a single DVD by a UHF RFID system, but if thousands of DVDs were stacked, the role the metal component plays in degrading the detection of each DVD in the stack should be investigated. An approach in detecting a large number of DVDs (up to 2000) densely stacked is thus presented.

Conclusions of the work in this thesis are drawn as the last part of the thesis. Besides conclusions the last part also includes some recommendations for future work and the description of the original contributions of this thesis.

The potential benefits of item-level tagging in supply chains are enormous. The existence of a large number of hard-to-tag objects is one of the main challenges in achieving item-level tagging. The studies in this thesis extend the scope of the detectable objects and this extension makes item-level tagging more realisable.

# 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.

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Signed

Date

# Acknowledgments

First and foremost, I must recognise my principal supervisor Prof. Peter H. Cole for his constant and patient guidance during the period of my Ph.D study. His meticulous approach to learning and tolerance towards others will influence me for the rest of my life. Talking with him not only in professional areas but also in music and culture has always been enjoyable and beneficial. In addition, many thanks to him for generously providing my living allowance.

I would also like to wholeheartedly thank my co-supervisors Dr Christophe Fumeaux and Dr Christopher Coleman for providing valuable suggestions to my research.

Sincere thanks to my colleagues and also to successful graduates in the Auto-ID Lab, Adelaide for their unselfish help in extending my knowledge. They are Behnam Jamali, David Hall, Damith Ranasinghe, Ng Mun Leng and Kin Seong Leong. Thanks also to Mr Alfio R. Grasso for arranging projects with industrial partners.

I am indebted for the work done by the staff in the School of Electrical and Electronic Engineering, particularly, Mr Pavel Simcik and Mr Brandon Pullen who fabricated most of my designs, and Associate Professor Michael Liebelt, Associate Professor Cheng Chew Lim and Mr Stephen Guest who managed my scholarship and travelling issues. Of course thanks to the four kind ladies in the school office.

Many thanks to my friends, specifically Thomas McLean, Matthew Trinkle, Yang Ruiting, Guo Bin, Wang Yuexian in Adelaide and also Liu Tan, Wu Xiao, Ye Yang in China for their constant support and encouragement during my Ph.D studies.

I am grateful to my parents who dedicate their love to me. Since I first entered primary school, all through my educational journey of twenty years, their love has always accompanied me. Last but not least, thanks for the unconditional love and encouragement from my girlfriend Xin Xia. Without her, I could not imagine how I could have accomplished this work.

*Zhonghao Hu (September 2010)*

# Conventions

## Typesetting

This thesis is typeset using the LaTeX2e software.

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

## Referencing

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

For electronic 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].

## Spelling

The Australian English spelling is adopted in this thesis.

# Publications

## Book Chapter

[1] P. H. Cole, L. Turner, Z. Hu, and D. Ranasinghe, "The Future of RFID," in *Unique Radio Innovation for the 21st Century*, D. Ranasinghe, M. Sheng, and S. Zeadally, Eds. Springer, 2010.

## Book Chapter Accepted

[1] P. H. Cole and Z. Hu, "Operating Range Evaluation of UHF RFID Systems," in *Advances in RFID Tags*. Vienna, Austria: InTech, 2010.

[2] Z. Hu, P. H. Cole, and C. Fumeaux, "Analysis and Design of Meander Line Dipole Antennas," in *Chipless Radio Frequency Identification: Systems for Ubiquitous Tagging*, N. Karmakar, Ed. Hershey, USA: IGI Global, 2011.

## Journal Accepted

[1] Z. Hu, P. H. Cole, and A. Grasso, "Compact solution for metallic item detection in RFID systems by means of artificial magnetic conductor," *International Journal of Radio Frequency Identification Technology and Applications (IJRFITA)*, 2010.

[2] Z. Hu and P. H. Cole, "Detection of Massive Numbers of DVDs by a UHF RFID system," *Progress In Electromagnetics Research B (PIER-B)*, 2010.

## Conference

[1] Z. Hu, P. H. Cole, and L. Zhang, "A method for calculating the resonant frequency of meander-line dipole antenna," in *4th IEEE Conference on Industrial Electronics and Applications, ICIEA 2009*, Xi'an, China, May 2009, pp. 1783–1786.

[2] Z. Hu and P. H. Cole, "Detection of DVDs in a stack by an RFID system," in *Asia-Pacific Symposium on Electromagnetic Compatibility, APEMC 2010*, Beijing, China, April 2010.

[3] Z. Hu and P. H. Cole, "The Slitted Decouple Design for Metallic Item Detection in UHF RFID Systems," in *Asia-Pacific Symposium on Electromagnetic Compatibility, APEMC 2010*, Beijing, China, April 2010.

[4] Z. Hu and P. H. Cole, "Bottle Packaged Wine Product Detection By UHF RFID Systems," in *International Conference on Electromagnetics in Advanced Applications, ICEAA 2010*, Sydney, Australia, Septermber 2010.

# Non-refereed

[1] P. H. Cole and Z. Hu, "Solving the Water and Metal Problem," *RFID Journal*, April 2009. [Online]. Available: http://www.rfidjournal.com/article/view/4755 [29 July 2010].

[2] P. H. Cole and Z. Hu, "Every DVD Tells a Story," *RFID Journal*, July 2010. [Online]. Available: http://www.rfidjournal.com/article/view/7717 [29 July 2010].

# Abbreviations

**AC** Alternating Current

**ACMA** Australia Communications and Media Authority

**AMC** Artificial Magnetic Conductor

**ASK** Amplitude Shift Keying

**BOPP** Biaxially Oriented Polypropylene

**BTA** Bow Tie Antenna

**CMOS** Complementary Metal Oxide Semiconductor

**CPS** Coplanar Strip

**CST** Computer Simulation Technology (a commercial simulation software)

**DC** Direct Current

**DVD** Digital Video Disc

**DVD R** Recordable Digital Video Disc

**DVD-ROM** Digital Video Disc-Read Only Memory

**EAS** Electronic Article Surveillance

**EAN** European Article Numbering

**EBG** Electromagnetic Band Gap

**EEPROM** Electrically Erasable Programmable Read Only Memory

**EIRP** Equivalent Isotropic Radiated Power

**EPC** Electronic Product Code

**ERP** Effective Radiated Power

**ETSI** European Telecommunications Standards Institute

**FCC** Federal Communications Commission

**FDA** Folded Dipole Antenna

**FEM** Finite Element Method

**FeRAM** Ferroelectric Random Access Memory

**FHSS** Frequency Hopping Spread Spectrum

**FSS** Frequency Selective Surfaces

**GA** Genetic Algorithms

**GS1** Global Standards 1

**HF** High Frequency

**HFSS** High Frequency Structural Simulator (a commercial simulation software)

**IC** Integrated Circuit

**IEC** International Electrotechnical Commission

**IFA** Inverted F Antenna

**IPICO** Intellectual Property and Innovation Company

**ISM** Industrial, Scientific and Medical (frequency range)

**ISO** International Organization for Standardization

**LBT** Listen Before Talk

**LF** Low Frequency

**MDA** Meander Line Dipole Antenna

**MOM** Method Of Moments

**PBG** Photonic Band Gap

**PIE** Pulse Interval Encoding

**PP** Polypropylene

**PSK** Phase Shift Keying

**PZT** Lead Zirconate Titanate

**RAM** Random Access Memory

**RCS** Radar Cross Section

**RF** Radio Frequency

**RFID** Radio Frequency Identification

**SAW** Surface Acoustic Waves

**SBT** Strontium Bismuth Tantalate

**SHF** Super High Frequency

**SMA** Sub-Miniature version A

**UCC** Uniform Code Council

**UHF** Ultra High Frequency

**UID** Ubiquitous Identification

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