UNIVERSITI PUTRA MALAYSIA

MINKOWSKI FRACTAL TAG ANTENNAS INTEGRATED WITH SPLIT RING RESONATORS AND COMPLEMENTARY SPLIT RING RESONATORS FOR RADIO FREQUENCY IDENTIFICATION APPLICATIONS

ALI SADEQ ABDULHADI JALAL

FK 2013 63

MINKOWSKI FRACTAL TAG ANTENNAS INTEGRATED WITH SPLIT RING RESONATORS AND COMPLEMENTARY SPLIT RING RESONATORS FOR RADIO FREQUENCY IDENTIFICATION APPLICATIONS

By

ALI SADEQ ABDULHADI JALAL

Thesis Submitted to the School Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

August 2013

DEDICATION

To my altruistic and beloved wives…

To my lovely sons (Hussain and Mustafa)…

To my supportive siblings…

To every striving muhsin person who is constantly improving aspects of life…

To those who are compassionate towards achieving perfection (ihsaan)…

To the consistent pursuers of knowledge aiming for positive change…

A special contribution to my home country Iraq and to Malaysia;

With lots of gratitude…

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

MINKOWSKI FRACTAL TAG ANTENNAS INTEGRATED WITH SPLIT RING RESONATORS AND COMPLEMENTARY SPLIT RING RESONATORS FOR RADIO FREQUENCY IDENTIFICATION APPLICATIONS

By

ALI SADEQ ABDULHADI JALAL

August 2013

Chairman: Assoc. Prof. Alyani Binti Ismail, PhD

Faculty: Engineering

RFID stands for Radio Frequency Identification. The main goal of an RFID system is to carry data on a transponder (tag) that can be retrieved with a transceiver through a wireless connection. The contactless Identification (ID) system relies on data transmission via radio frequency electromagnetic (EM) signals, and consequently, the whole operation is non-line-of-sight and weather independent. These advantages overcome the limitations of optical barcodes, which are line-of-sight and weather dependent and need manual operation. Most RFID tags are comprised of an antenna and integrated circuit (IC). The IC performs all of the data processing and is powered by extracting power from the interrogation signal transmitted by the RFID reader. The tag antenna determines the amount of power transferred from the reader to the tag and back from the tag to the reader. Though there are no constraints on the physical parameters of the reader's antenna, such as

being planar or small in size, these constraints do apply on the tag's antenna. In fact, the tag miniaturizing is limited by the tag antenna size.

This thesis reports on the design, fabrication, and measurement of Ultra High Frequency (UHF) RFID tag antennas (860 to 960 MHz), which can be used in various applications. The proposed tag antennas are designed and fabricated to achieve low tagging costs, tagging of small objects at item level, as well as tagging metallic objects with miniaturized tags.

First, it presents three different types of planar fractal RFID tag antenna designs integrated with square Split Ring Resonators (SRR) in an attempt to improve their performance characteristics at low cost. Three fractal iterations are considered to perform size reduction. Each antenna design was etched on FR4 epoxy substrate with an evident compact size. The antenna sizes are: $82 \times 88.59 \times 1.6$ mm^3 for *AN1*; $72 \times 78.59 \times 1.6$ mm^3 for *AN2* and $66.5 \times 73.09 \times 1.6$ mm^3 for *AN3*. The modified Minkowski fractal structure has been adopted to perform size reduction in three different iteration designs. Return loss results show that the integration of SRRs with antennas performs a frequency down-shift of the antenna resonant frequency thereby achieving further size reduction over the original fractal structure that was aimed for size reduction. The impedance of the designed antennas were simulated then measured to validate the design. The experiment results showed that the maximum read range of the proposed tag antennas, *AN1*, *AN2* and *AN3* is about 2.10 m, 1.10 m and 0.75 m respectively with 4.0 W EIRP radiation power of the RFID reader. The proposed RFID Tag antennas are compact, low cost, and with good reading range

that make them suitable for RFID applications. They are used for tagging objects other than metals or liquids.

Second, two metal mount fractal tag antennas are designed and tested. The two antennas are integrated with square Complementary SRRs (CSRR) in a floating intermediate conductive copper layer. This floating layer achieves down shift to the antenna resonant frequency and enhances its gain due to the added capacitance from the CSRR structure. The size of the proposed tag antennas is 36.7×18.1×3.165 mm^3 for antenna *N1* and 35.3×17.4×3.165 mm^3 for antenna *N2*. Very small and compact tag antennas are achieved with good agreement between measured and simulated impedance results. The read range measurements showed that the maximum read range of *N1*, and *N2* is about 0.82 m and 0.48 m respectively, obtained when the two tags are placed on a square metallic sheet. The proposed RFID tag antennas offer attractive design for metallic objects identification such as gas cylinders and oil barrels tagging in petrol refineries.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

ANTENA LABEL PECAHAN MINKOWSKI BERSEPADU DENGAN PENYALUN GELANG-BELAH DAN PENYALUN PELENGKAP GELANG-BELAH UNTUK APLIKASI PENGENALAN FREKUENSI RADIO

Oleh

ALI SADEQ ABDULHADI JALAL

Ogos 2013

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD

Fakulti: Kejuruteraan

RFID adalah singkatan kepada *Radio Frequency Identification* iaitu sistem pengenalan identiti menggunakan frekuensi gelombang radio. Tujuan utama sistem RFID ini adalah untuk membawa data pada transponder (Label) supaya ia dapat diperolehi semula menggunakan alat pemancar-penerima melalui hubungan tanpa wayar. Sistem ID tanpa sentuhan ini bergantung kepada penghantaran data melalui isyarat frekuensi radio elektromagnetik (EM) dan ini bermakna, seluruh operasi adalah bukan secara garis lurus dan bebas dipengaruhi cuaca. Kelebihan-kelebihan tersebut mampu mengatasi kelemahan dari kod bar optik di mana sistem tersebut memerlukan penghantaran isyarat secara garis lurus dan mudah dipengaruhi cuaca serta perlu dilaksanakan secara manual. Kebanyakan label RFID terdiri daripada antena dan litar bersepadu (IC). IC melaksanakan semua pemprosesan data dan dikuasakan dengan menyaring kuasa daripada oleh isyarat yang dipancarkan oleh

pembaca RFID. Manakala antena label menentukan jumlah kuasa yang dihantar daripada pembaca ke label dan kembali kepada pembaca dari label. Walaupun tiada sebarang kekangan pada parameter fizikal antenna pembaca, seperti berbentuk satah ataupun bersaiz kecil, kekangan ini nyata digunakan pada rekabentuk antena. Bahkan, pengecilan label adalah terhad berikutan saiz antena tersebut.

Tesis ini melaporkan kaedah rekabentuk, proses fabrikasi dan pengukuran terhadap label antena berfrekuensi ultra tinggi (UHF) (860 sehingga 960 MHz) di mana ia boleh digunakan untuk pelbagai aplikasi. Label antena yang dicadangkan telah direkabentuk dan difabrikasi untuk mendapatkan kos yang rendah, melabelkan objek-objek kecil pada aras barangan, dan juga melabelkan objek logam dengan label yang telah dikecilkan.

Pertama sekali, tesis ini akan menerangkan tiga jenis rekabentuk antena label RFID bersepadu dengan penyalun segiempat sama gelang –belah sebagai satu kaedah untuk membaiki ciri–ciri prestasi antena tersebut. Tiga lelaran akan diambil kira sebagai percubaan untuk pengecilan saiz antena. Setiap rekabetuk antena telah dipunarkan pada substratum epoksi FR4 dengan saiz yang lebih kompak. Saiz setiap antena adalah seperti berikut: 82 × 88.59 × 1.6 mm^3 untuk *AN1*; 72 × 78.59 × 1.6 mm^3 untuk *AN2* and 66.5 × 73.09 × 1.6 mm^3 untuk *AN3.* Struktur Pecahan Minkowski terubahsuai telah diguna pakai untuk melaksanakan pengecilan saiz terhadap rekabentuk tiga lelaran yang berbeza. Hasil dari kehilangan kembali menunjukkan bahawa antena bersepadu dengan penyalun segiempat sama gelang-belah (SRR) memberikan anjakan penurunan frekuensi pada frekuensi salun antena mengakibatkan pengecilan saiz berbanding dengan struktur pecahan yang asal

dimana tujuan utama adalah untuk mendapatkan saiz yang lebih kecil. Anjakan penurunan frekuensi daripada SRR berlaku ekoran daripada penambahan regangan daripada SRR tersebut terhadap galangan antena yang asal. Seterusnya, galangan antena telah disimulasi dan diukur untuk pengesahan rekabentuk. Hasil eksperimen menunjukkan julat bacaan maksima untuk antena label yang dicadangkan, *AN1*, *AN2*,dan *AN3* adalah pada 2.10m, 1.10m and 0.75m dengan kuasa radiasi EIRP sebanhyak 4.0W pada pembaca RFID. Antena Label RFID yang dicadangkan adalah kompak, kos yang lebih rendah serta julat bacaan yang baik membuatkan antena ini sesuai untuk aplikasi RFID. Antena ini boleh digunakan untuk melabel objek-objek selain besi atau cecair.

Seterusnya, dua jenis antena label pecahan bercagak logam telah direka dan diuji. Kedua-dua antena tersebut disepadukan dengan penyalun pelengkap gelang –belah (CSRR) pada lapisan pertengahan beraliran kuprum yang terapung. Lapisan terapung ini dapat mencapai anjakan penurunan terhadap frekuensi salun antenna dan juga mampu meningkatkan gandaan antena kerana penambahan kemuatan daripada struktur CSRR. Berikut merupakan saiz untuk antena label yang dicadangkan: 36.7×18.1×3.165 mm^3 untuk antena *N1* dan 35.3×17.4×3.165 mm^3 untuk antena *N2*. Antena label yang sangat kecil dan kompak telah dicapai dengan kesepadanan galangan hasil daripada keputusan simulasi dan juga ujikaji. Pengukuran julat bacaan diperolehi apabila dua label diletakkan pada kepingan segiempat logam dan ia menunjukkan julat bacaan maksima bagi *N1* adalah 0.82, dan *N2* ialah 0.48m. Antena Label RFID yang dicadangkan ini mampu memberikan rekabentuk yang menarik untuk pengenalan objek logam seperti penanda untuk gas silinder dan tong minyak dalam industri petroleum.

ACKNOWLEDGEMENTS

Of all that exists in the entire universe, my sheer gratitude is dedicated to no other than the Most Compassionate Allah S.W.T. Who had Generously Bestowed me a golden chance to further my doctorate degree in Universiti Putra Malaysia.

I am too touched being fated an ardently obliging beloved family members who are incessantly empowering my drive towards completing the painstaking processes throughout the tribulations of the study. In addition to the dynamic spur of enthusiasm, which is inexplicably bursting from the fierce love I deeply feel for my lovely sons – towards the betterment of our future life. So goes to other inspiring family members.

Anyhow, all the way through, I am truly indebted to my flexible but efficient supervisor: Associate Professor Dr. Alyani binti Ismail for her clear-cut style of supervision yet promoting students' freedom of ideas expression to stand upright with her securing offer of unwavering support – really, I am among the lucky few. In addition, I wish to express my appreciation to the members of my committee, Professor Dr. Mohamad Adzir Bin Mahdi, Professor Dr. Nor Kamariah Noordin, and Associate Professor Dr. Mohamad Fadlee A. Rasid for offering their valuable time and comments. I would also like to thank the SENSTECH SDN BHD (728289-X), Kuala Lumpur, Malaysia, and those others that have helped in the thesis work directly or indirectly.

I certify that a Thesis Examination Committee has met on 23 August 2013 to conduct the final examination of Ali Sadeq Abdulhadi Jalal on his thesis entitled "Minkowski Fractal Tag Antennas Integrated with Split Ring Resonators and Complementary Split Ring Resonators for Radio Frequency Identification Applications" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

Members of the Thesis Examination Committee were as follows:

M. Iqbal bin Saripan, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Roslina binti Mohd Sidek, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Borhanuddin bin Mohd Ali, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Hussain Al-Rizzo, PhD
Professor
University of Arkansas at Little Rock
United States
(External Examiner)

NORITAH OMAR, PhD
Associate Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 19 September 2013

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Alyani Binti Ismail, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamad Adzir Bin Mahdi, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Nor Kamariah Noordin, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohamad Fadlee A. Rasid, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

BUJANG BIN KIM HUAT, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

ALI SADEQ ABDULHADI JALAL

Date: 23 August 2013

TABLE OF CONTENTS