UNIVERSITI PUTRA MALAYSIA

SPLIT-RING RESONATOR-BASED ANTENNA WITH PHOTONIC BAND GAP FOR UHF RFID TAG

FUAD NAIM AHMED ERMAN

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By

FUAD NAIM AHMED ERMAN

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

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DEDICATION

This thesis is dedicated to:

The sake of Allah, my Creator and my Master,

My great teacher and messenger, Mohammed (May Allah bless and grant him), who taught us the purpose of life,

My homeland Palestine, the warmest womb;

Universiti Putra Malaysia; my second magnificent home;

My great parents, who never stop giving of themselves in countless ways,

My beloved brothers and sisters; particularly my dearest brother, Qutayba who stands by me when things look bleak,

The symbol of love and giving, my friends who encourage and support me,

All the people in my life who touch my heart,

I dedicate this thesis.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

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October 2016

Chair: Assoc. Prof. Alyani bt. Ismail, PhD

Faculty: Engineering

RFID system is to transfer data on a transponder (tag) that can be retrieved with a transceiver by means of wireless connection. The whole operation is weather independent and non-line-of-sight. These features for ID system overcome the limitations of optical barcodes. RFID tags are comprised of integrated circuit (IC) and an antenna. The IC executes 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 transmitted from the reader to the tag and the reflect signal from the tag to the reader. Nevertheless, there are no constraints on the physical parameters of the reader's antenna, such as being planar or small in size, these constraints do stratify on the tags 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 for 860 to 960 MHz which can be used in metallic applications. The presented tag antennas are designed and fabricated to accomplish low tagging costs, good performance, for tagging metallic objects.

Split-ring resonator-based tag antenna with regular ground plane was designed and tested. In this design, a compact antenna is proposed and designed for metallic objects UHF RFID (860-960) MHz. The antenna structure etched on polytetrafluorethylene (PTFE) substrate. The slim antenna has been proposed with proximity coupled feeding, two split ring structure mounted to each side of the tag chip and it is fed by two symmetrical C-shaped resonators with outer strip lines. The antenna size is $83.7\times62.8\times1.57\ \text{mm}^3$ at operating frequency. The peak gain and read range of the antenna reached to -1.445 dBi and 0.5 m respectively when it is placed on $400\times400\ \text{mm}^2$ metallic surface. The antenna bandwidth is 20 MHz (power reflection coefficient lower than -3 dB). This antenna introduced to fill up the need for tagging for long range and mounted for metallic objects such as oil barrels tagging in petrol refineries and gas cylinders

Photonic band gap (PBG) structure integrated to enhance the gain. The PBG structure formed by etching a periodic pattern of circles in the ground plane. The total gain and read range of this design are -0.72 dBi and 0.53 m respectively when it is mounted on $400 \times 400\ mm^2$ metallic plate. The percent of gain improvement is around 49.76% when PBG integrated in the design. The antenna bandwidth at half power bandwidth is 17.8 MHz. The impedance of the suggested antennas was simulated then measured to validate the design. The presented RFID tag antennas are low cost, compact, and with good gain that make it fit for tagging metallic applications.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

Antena Berdasarkan Bentuk Bulatan Terpisah yang Berganda dengan Penghalang Jurang Fotonik untuk UHF RFID TAG

Oleh

FUAD NAIM AHMED ERMAN

Oktober 2016

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD

Fakulti: Kejuruteraan

RFID adalah sistem untuk memindahkan data pada transponder (tag) yang boleh didapatkan semula dengan penerima melalui proses sambungan tanpa wayar. Keseluruhan operasi bergantung kepada persekitaran semasa dan bukan melalui pandangan terus. Ciri-ciri sistem ID dapat mengatasi kekurangan pada teknologi kod bar optik. Tag RFID terdiri daripada litar bersepadu dan antena (IC). Litar Bersepadu melaksanakan semua pemprosesan data dan memperolehi bekalan kuasa dengan mengekstrak kuasa dari isyarat pengenalan diri yang dihantar oleh tag antena pembaca RFID. Tag antena mengenal pasti jumlah kuasa yang dipancar dari pembaca kepada tag dan memantulkan isyarat dari tag kepada pembaca. Selain itu, tiada kekangan dari segi parameter fizikal antena pembaca, seperti menjadi satah atau bersaiz kecil, dimana ianya bergantung kepada saiz antena. Pembuatan tag bergantung kepada saiz tag antena.

Tesis ini melaporkan mengenai reka bentuk, pembuatan, dan pengukuran Kuasa Frekuensi Tinggi (UHF) RFID tag antena untuk julat 860 kepada 960 MHz yang boleh digunakan dalam aplikasi logam. Tag antena yang direka untuk mencapai kos pembuatan rendah, prestasi yang baik, untuk pengesanan objek logam.

Tag antena yang berasaskan reka bentuk "Resonator Split-ring" dengan permukaan pembumian biasa telah direka dan diuji. Dalam reka bentuk ini, antena yang kecil dicadangkan dan direka untuk objek logam UHF RFID (860-960) MHz. Struktur antena dihasilkan melalu proses kimia dalam larutan polytetra fl uorethylene (PTFE). Antena tipis telah dicadangkan dengan ruangan untuk penerimaan isyarat, dua struktur "Split Ring" dipasang untuk setiap sisi tag cip dan ia disertakan ruangan penerimaan isyarat yang berbentuk Cpada garisan jalur yang paling luar. Saiz antena adalah 83.7 × 62.8 × 1.57 mm^3 padaoperasi frekuensi. Kuasa yang tertinggi dan jarak pembacaan mencapai 0.5 m -1,445 dBi dan apabila ia diletakkan pada 400 × 400 mm^2 permukaan logam. Jalur lebar antenn adalah 20 MHz (pekali kuasa pantulan lebih rendah daripada -3 dB) . Antena ini diperkenalkan bagi memenuhi keperluan tag untuk jarak yang lebih jauh dan boleh

diletakkan pada permukaan logam seperti tong minyak di pusat penyulingan minyak mentah dan tong gas cecair.

Jurang jalur Fotonik (PBG) struktur bersepadu untuk meningkatkan prestasi. Struktur PBG dihasilkan melalui proses rendaman dalam larutan kimiamenghasilkan bentuk bulatan yang pada permukaan pembumian. Prestasi dan jarak pembacaan bagi reka bentuk ini adalah 0.53 m -0,72 dBi apabila ia dipasang pada permukaan logam bersaiz 400 × 400 mm^2. Peratus peningkatan prestasi adalah sekitar 49.76% apabila PBG bersepadu digunakan dalam reka bentuk ini. Kapasiti jalur lebar antena pada kuasa separuh adalah 17.8 MHz. Jumlah rintangan untuk antena yang direka bentuk telah menjalani ujian simulasi dan keputusan telah. RFID tag antena yang dicadangkan adalah kos rendah, kompak, dan dengan prestasi yang baik yang menjadikan ianya sesuai untuk tag aplikasi logam.

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FUAD NAIM AHMED ERMAN

I certify that a Thesis Examination Committee has met on 27 October 2016 to conduct the final examination of Fuad Naim Ahmed Erman on his thesis entitled "UHF RFID Tag Antenna Using Split-ring Resonator-based Antenna with Inductive Outer Strip Lines for Metallic Objects" 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

Fazirulhisyam Hashim, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Maryam Mohd Isa, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Zahriladha bin Zakaria, PhD
Associate Professor
Universiti Teknikal Malaysia Melaka
Malaysia
(External Examiner)

ZULKARNAIN ZAINAL, PhD
Professor and Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 26 January 2017

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

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

Raja Syamsul Azmir Raja Abdullah, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

ROBIAH BINTI YUNUS, PhD
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Declaration by graduate student

I hereby confirm that:

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This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
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Supervisory Committee: Assoc. Prof. Alyani bt. Ismail

Signature: ____________________________
Name of Member of
Supervisory Committee: Assoc. Prof. Raja Syamsul Azmir b. Raja Abdullah

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LIST OF ABBREVIATIONS

AIDC	Auto Identification and Data Capture
AUT	Antenna Under Test
AMC	Artificial Magnetic Conductor
ASIC	Application Specific Integrated Circuit
BW_p	Percentage Bandwidth
BW_r	Ratio Bandwidth
CSRR	Complementary Split Ring Resonators
CST	Computer Simulation Technology
DNG	Double Negative
DPS	Double Positive
EAS	Electronic Article Surveillance
EIRP	Equivalent Isotropic Radiated Power
EM	Electromagnetic
ENG	Epsilon-Negative
EPC	Electronic Product Code
ERP	Effective Radiated Power
GHz	Gigahertz
HDPE	High Density Polyethylene
HF	High Frequency
HFSS	High Frequency Structure Simulator
HIS	High Impedance Surface
HPBW	Half-Power Beamwidths
IC	Integrated Circuit
ID	Identification
IFF	Identification of Friend or Foe
ISM	Industrial Scientific and Medical
LF	Low Frequency
MHz	Megahertz
MNG	Mu-Negative
PBG	Photonic Band Gap
PCB	Printed Circuit Board
PP	Polypropylene
PRC	Power Reflection Coefficient
PTC	Power Transmission Coefficient
PTFE	Polytetrafluoroethylene
RF	Radio Frequency
RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
SHF	Super High Frequency
SMA	Sub Miniature Version A
SRD	Short Range Devices
SRR	Split Ring Resonator
VNA	Vector Network Analyzer

CHAPTER ONE

INTRODUCTION

1.1 Introduction

Radio Frequency Identification (RFID) system composed of a transponder or tag, an RFID reader or interrogator and a central processing unit. RFID technology uses electromagnetic waves to scatter back and forth between the RFID interrogator and the tag. The tag contains the ID information of the object, which is amounted onto. The RFID interrogator extracts the data from the transponder by decoding the scattering signal and send the information of the object to a central processing unit. The central processing unit acts as interface between the RFID system and its users. The communication system is commonly used for asset tracking and identifying. The power transfer is determined by tag and the reader antennas. The antennas is the main part of the system. There are no restrictions on the physical parameters of the reader antenna such as small size and being planar. In fact, a good impedance matching between tag antenna components could improve the functionality power of the chip; consequently, it improves the gain.

The existence of RFID technology prolonged for many years, but it is only recently experienced growth which has arisen from application of this technology in different supply chains. The stimulus to the growth of RFID came after the introduction of the Electronic Product Code (EPC) concept by which each tagged object can have its information stored in a database elsewhere instead of in the tags attached to them. A unique identifier (due to the unique EPC in each tag) for each tagged object and this identifier have its information stored in a database. This information associated with each of the physical objects which can be accessed and updated anytime and anywhere, thus allowing easy trace and track of physical objects all over supply chains. Moreover, this kind of tags have low cost due to no large memories are required to store the object information. All these factors raise the possibility of wide implementation of RFID technology by tagging and identifying every single physical object (or product) in supply chains for total visibility within those supply chains. The vision that led to expand the RFID technology to item level tagging can be summarized by giving each specific item a unique identifier number rather than the method of pallet and level tagging [1] .

The implementations of RFID tag in the ultra-high frequency band are growing substantially with many features, especially passive ones. Its application in supply chain management, transportation system, security, general detection systems, disease prevention, logistics systems, access point system, road tolling, and business transaction system [2-5]. Passive RFID technology is applied increasingly in many contexts, even in the canonical ones related to logistics. Identification of goods containing liquid or made of metal [6-8], RFID-based sensor information transmission [9, 10], and platform tolerant tags [11, 12], only a few of the many possible examples where tags customized for specific applications are required. This necessity has been acknowledged by the electromagnetic scientific community which, over the last few years, has put a great deal of effort into RFID projects. The resultant rapid breed of scientific works on tag design and optimization is an obvious fact [13-16].

1.2 Problem statement and Motivation

In spite of the fact that RFID presents advantages to the supply chain management, numerous challenges are demonstrated due to the increasing implementation of RFID technology. Among the major challenges are [17]:

1. Degradation of RFID system performance and reliability because of the vicinity of metals;
2. RFID tagging costs;
3. Small tag antenna with low efficiency; and
4. Impedance matching between the antenna and the IC chip.

Overview discussions on RFID challenges can be found in the literature such as in [17].

To allow a thorough and full deployment of RFID, and to bring into realization the vision of tagging objects down to item level, feasible solutions must be drawn to meet these RFID challenges from all aspects. One of the major RFID implementation problem is the degradation in performance when tagging metallic objects or operating in an environment containing metallic structures. The tagging of objects at pallet, case, and even item levels will most likely involve metallic objects.

Concerning size of the tag antenna should be emphasis on while designing the prototype. This challenge becomes very important particularly when item level tagging is included. Yet, the ohmic loss will increase with decreasing of size of the antenna, and thus the efficiency will decrease [18]. Therefore, maintaining a balance between the tag performance and size is a challenging task. Metamaterial-based tag antenna has been adopted throughout this thesis works for the purpose of good gain and thus good reader range with comparable size. Further gain enhancement is achieved through etching of a periodic pattern of circles in the ground plane of the design. The proposed antennas are fabricated using Polytetrafluoroethylene (PTFE) substrate.

This thesis also itemizes on the challenge listed which are important for proper tag antenna design. Chips vendors produce a variety of Application Specific Integrated Circuits (ASIC) chip that are available in the market with different impedance values. Antenna designers should stick to these values, where in most cases; they are not free to choose the desired antenna size to achieve the desired task. Murata RFID MAGICSTRAP LXMS31ACNA-011 tag chip is used in this research.

1.3 Research Aim and Objectives

The primary goal of this study is to design UHF metamaterial-based tag antenna using split-ring resonator and integrating PBG structure to achieve higher gain for mounted metallic objects.

The research is focused on the following four main objectives:

1. To design split-ring resonator-based tag antenna with regular ground for metallic applications;
2. To improve the tag antenna performance by integrating PBG structure for metallic objects identification; and

3. To validate the performance of the designed tag antennas via measurements of their complex impedance and read range.

1.4 Scope of Research

The scope of this research is to design new metamaterial-based antennas for RFID metallic applications to enhance the performance characteristics. The split ring resonator-based antenna with regular ground plane and PBG structure is proposed for RFID implementations. The PBG integrated in the design to enhance its performance characteristics. Figure 1.1 illustrated the flow of this study. The direction followed to achieve the objectives is presented by the continuous-lines.

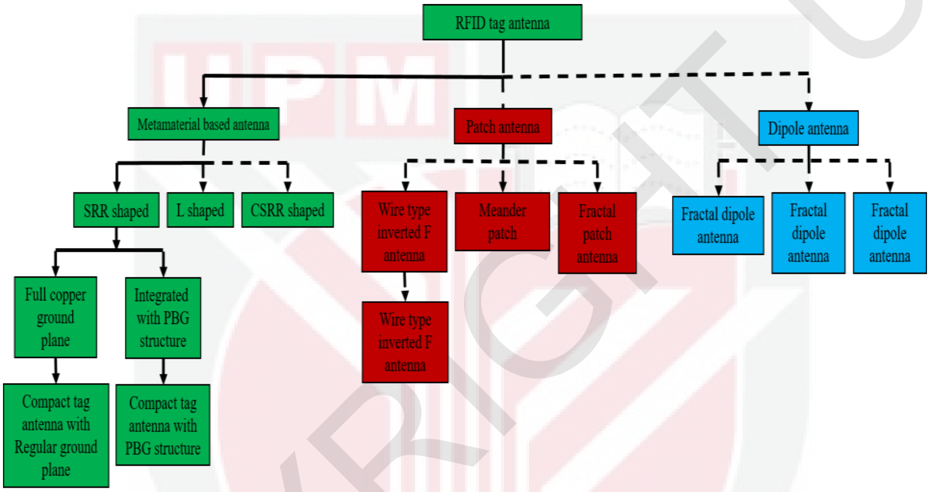

Figure 1.1 Scope of Research

1.5 Overview of Research Methodology

Firstly, to achieve the objectives of this research, extensive research on RFID tag antennas and metamaterial-based antenna was performed to understand their fundamentals and how these types of antennas can be used for RFID applications. Determining the inexpensive material was next for the antenna construction with convenient chips after identifying the antenna parameters and getting the chip impedance, which were used in the design. Then, the performance of RFID tag antennas was experimented and analyzed through using a 3D full-wave electromagnetic simulator [19]. Thereafter, integrating PBG structure was applied with tag antenna after it was successfully designed with regular ground for RFID applications. Finally, to validate the design technique on the RFID tag antennas, the measurements were performed. The methodology of designing RFID tag antennas is exhibited in Figure 1.2.

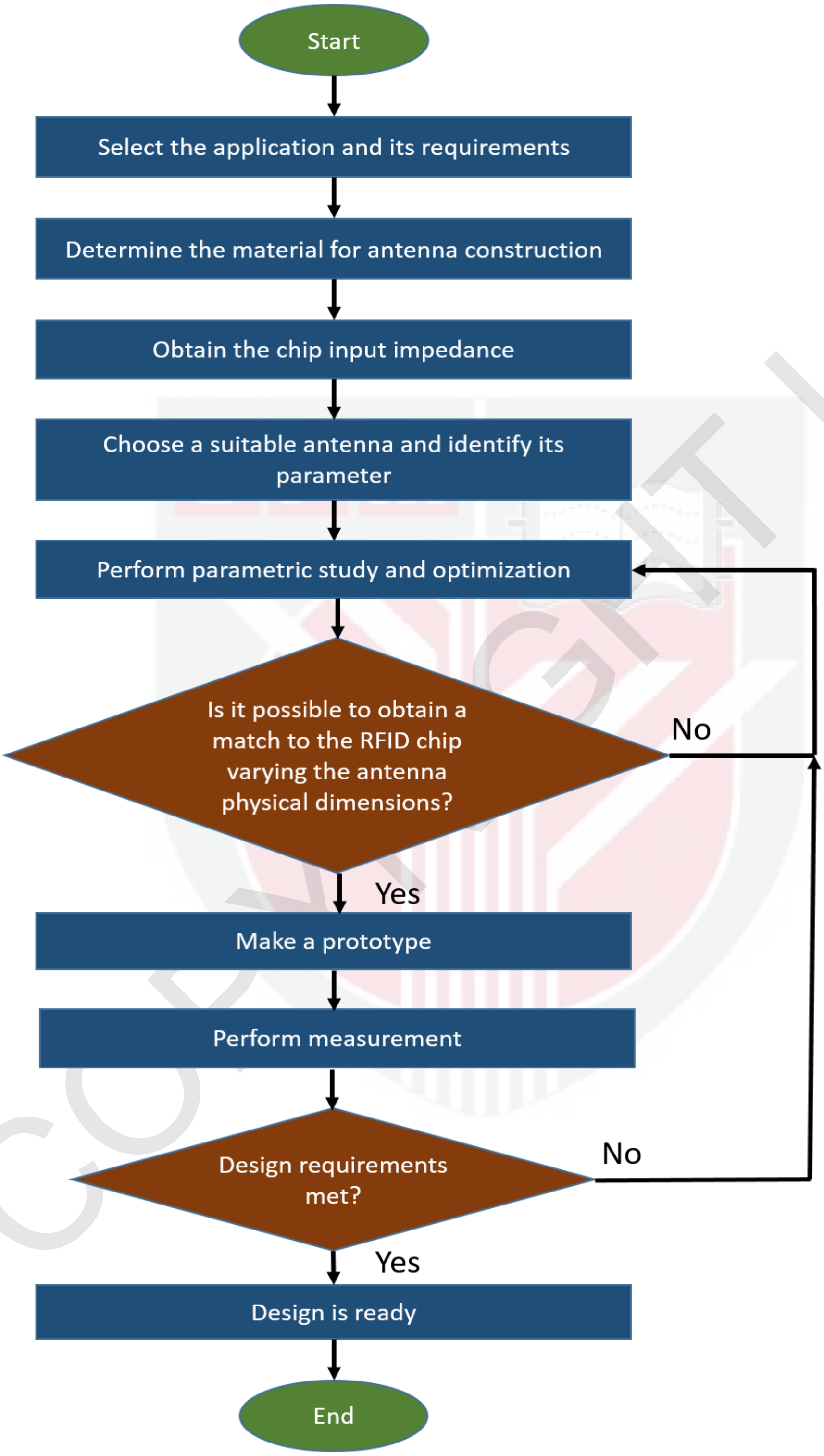

Figure 1.2. Methodology Design Flow of RFID Tag Antennas

1.6 Organization of the Thesis

This research is organized into five chapters, which are summarized as follows:

Chapter one provides a background of the research, and identifies the current reason, which motivated this present research to design RFID tag antennas. It also introduces the goal, objectives, methodology, scope of the research as well as the organization of thesis writing.

Chapter two presents the literature review on RFID system and metamaterials. It first provides a background and history of RFID technology and some details about their classes and design considerations. Then it further details the salient electromagnetic features of the metamaterials as well as their recent applications. Finally, a summary of previous work is included.

Chapter three describes the methodology used to design split ring resonator-based antenna structure that are used in antenna designs in Chapters 4 in an attempt for achieving high gain. The performance of split-ring resonator based tag antennas is investigated in terms of achieving impedance matching and the effects of integrating PBG structure on antenna performance are discussed. Parameters affecting resonance frequency are included as well as the research methodology.

Chapter four elaborates on a novel design of split-ring resonator-based RFID tag antennas. The research explicitly emphasizes on first tag antenna with regular ground plane and second tag antenna integrated with PBG structure to enhance the gain. Parametric study is also illustrated for various antenna parameters. The performance characteristics in terms of reflection coefficient, gain, resonance frequency and bandwidth are shown. Comprehensive analyses for simulated and measured results are done for validation. Finally, a summary on the chapter is included at the end.

Chapter five is allocated for the research conclusions followed by discussion of the major contributions of the research. Eventually, recommendations for further research are listed.

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LIST OF PUBLICATIONS

Journal Article

Fuad Erman, Alyani Ismail, Raja Syamsul Azmir Raja Abudullah, Adam Reda Hasan Alhawari, Arafat Shabaneh, Noor Mohammad " High Gain Metal-mounted RFID Tag Antenna Using Split-ring Resonators with Inductive Outer Strip Lines". (submitted)

Conference

Erman, F. N., et al. "UHF RFID split-ring resonator tag antenna inductively coupled feed for metallic object." *Communications (MICC), 2015 IEEE 12th Malaysia International Conference on*. IEEE, 2016.

Erman, Fuad, et al. " UHF RFID Split Ring Resonator-Based Tag Antenna with Photonic Bandgap Structure for Metallic Objects." 3rd International Conference on Defence & Security Technology, Putrajaya, Malaysia, 2017.

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