UNIVERSITI PUTRA MALAYSIA

COPLANAR UHF RFID TAG ANTENNA WITH U-SHAPED INDUCTIVELY COUPLED FEED FOR METALLIC APPLICATIONS

KARRAR NAJI SALMAN AL KHANJAR

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By

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

April 2016

DEDICATIONS

In the name of Allah, Most Gracious, Most Merciful
This thesis is dedicated to:

My parents
(Father & Mother)
My brothers & Friends

To every striving muhsin person who is constantly improving aspects of life...
To those who are compassionate towards achieving perfection...
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 Master of Science

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April 2016

Chair: Assoc. Prof. Alyani Binti Ismail, PhD
Faculty: Engineering

RFID stands for Radio Frequency Identification. The major purpose that RFID system is built for is to transfer data on a transponder (tag) that can be regained with a transceiver by means of a wireless connection. The contactless Identification (ID) system depends on data transmission by radio frequency electromagnetic (EM) signals, and accordingly, the whole functionality is weather independent and non-line-of-sight. These features for ID system copes the optical barcodes limitations, which are weather dependent, line-of-sight, and manual operation requirement. Most of RFID tags consisted of integrated circuit (IC) or a Chip and an antenna. The IC executes all of the data processing and is energized by extracting the power from the interrogation signal transferred by the RFID reader. The tag antenna controls 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 restrictions on the physical parameters of the readers antenna, such as being small or planar in size, these restrictions do stratify on the tags antenna. In a matter of fact, the tag miniaturizing in size 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 metallic applications. The introduced tag antennas are designed and fabricated to accomplish low tagging costs, good performance, as well as tagging metallic objects with small size tags.

First, high gain compact coplanar RFID tag antenna was designed and tested. In this design, a coplanar slim antenna is proposed and designed for metallic objects UHF RFID (860-960)MHz as First stage. The antenna structure etched on FR4

epoxy substrate. The slim antenna has been presented with proximity coupled feeding, two symmetrical coplanar ground layer, and transmission line fed by U-shaped inductively coupled feed. Furthermore, U-shaped inductive feeder consists of two opposing symmetrical U-shaped structures to feed the top radiator for antenna. The antenna size is $97.5 \times 50 \times 1.5$ mm^3 at 915 MHz. The peak gain and efficiency for the antenna reached to 5 dBi and 62% at 915 MHz respectively. The antenna bandwidth is 24.875 MHz (900.125-925) MHz (power reflection coefficient lower than -3 dB). The measurement result shows very good impedance matching due to the flexibility given by the U-shaped inductive feeder; moreover there is a very good agreement with simulations results. The design shows very high gain and good efficiency. 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.

The thesis presented a compact coplanar tag electrically small antenna (ESA) as Final stage. The antenna structure etched on polytetrafluorethylene (PTFE) as an upper layer substrate, whereas the bottom layer is FR4 epoxy substrate. This coplanar tag antenna gives us ultimate size reduction as well as better efficiency. The presented tag antenna designed with a proximity-coupled feed through, two symmetrical via-load coplanar grounds fed by U-shaped inductively coupled feed through embedded transmission line. This configuration led to antenna size to be $31. \times 19.5 \times 3.06$ mm^3 at 915 MHz, while the total gain and efficiency for the antenna are 0.12 dBi and 24% respectively. The vias-coplanar load gives and the U-Shaped inductive coupled feed the antenna flexible tuning for antenna impedance.The antenna realized gain bandwidth at half power bandwidth is 14.5 MHz (908- 922.5)MHz at 915 MHz. The impedance of the suggested antennas were simulated then measured to validate the design. At the same time, a figure of merit was applied for this proposed tag antenna and the results were exposed. This antenna measurement shows very good agreement with the simulation part. The presented RFID Tag antennas are low cost, compact, and with good efficiency and good gain that make it fit for tagging metallic applications. Finally, Figure of Merit was applied for Final stage of compact electrically small antenna (ESA) and comparison was presented to provide good validation for the proposed design. In this work, the proposed tag antenna was assessed throughout the study of the ESA performance. The tag antenna assessed with new Figure of Merit, namely, Normalized Bandwidth Gain product (NBG) and Normalized bandwidth Efficiency product (NBE). The presented comparison was carried out by (NBG) and (NBE). The results were calculated for both NBG and NBE where they are found to be 0.57 and 0.05 respectively.

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

TAG ANTENA UHF RFID SESATAH DENGAN SUAPAN INDUKTIF BERBENTUK U UNTUK APLIKASI LOGAM

Oleh

KARRAR NAJI SALMAN AL KHANJAR

April 2016

Pengerusi: Prof. Madya Alyani Binti Ismail, PhD
Fakulti: Kejuruteraan

RFID adalah berdiri untuk Pengenalan Frekuensi Radio. Tujuan utama sistem RFID dibina adalah untuk memindahkan data pada transponder (tag) yang dapat diperolehi semula dengan transceiver melalui sambungan tanpa wayar. Sistem Pengenalan(ID) tanpa sentuh bergantung kepada penghantaran data dengan isyarat frekuensi radio elektromagnet (EM), dan dengan itu, keseluruhan fungsi adalah cuaca bebas dan tanpa garis pejera. Ciri-ciri sistem ID ini dapat mengatasi kekurangan kod bar optik, yang bergantung kepada cuaca, garis pejera, dan keperluan operasi manual. Kebanyakan tag RFID terdiri daripada litar bersepadu (IC) atau Chip dan antena. IC melaksanakan semua pemprosesan data dan mendapatkan tenaga melalui pengekstrakan kuasa daripada isyarat soal siasat yang dikeluarkan oleh pembaca RFID. Tag antena mengawal jumlah kuasa yang dihantar daripada pembaca untuk tag dan memantulakn isyarat daripada tag kepada pembaca. Walau bagaimanapun tidak ada pembatasan yang diwujudkan kepada parameter fizikal antena pembaca, seperti bersaiz kecil atau berbentuk satah, pembatasan ini telah mengklasifikasikan antena tag ini. Pada hakikatnya, pengecutan tag dalam saiz adalah dihadkan oleh saiz tag antena.

Tesis ini melaporkan mengenai reka bentuk, fabrikasi, dan pengukuran tag antena (860-960 MHz) frekuensi ultra tinggi (UHF) RFID, yang boleh digunakan dalam aplikasi logam. Tag antena yang diperkenalkan and difabrikasi untuk mencapai kos tagging yang rendah, prestasi yang baik, dan penandaan logam dengan tag saiz kecil.

Pertamanya, tag antena RFID padat sesatah bergandaan tinggi telah direka dan diuji. Dalam reka bentuk ini, antena sesatah langsing telah dicadangkan dan direka untuk objek logam UHF RFID (860-960) MHz sebagai peringkat pertama.

Struktur antena terukir pada FR4 epoxy substrat. Antena langsing telah dibina bersama dengan penyuap proksimiti terganding, dua lapisan bumi sesatah yang simetri, dan talian penghantaran disambung dengan suapan induktif berbentuk-U. Tambahan pula, penyuap induktif berbentuk-U terdiri daripada dua struktur berbentuk- U bertentang yang simetri untuk menyuap radiator atas bagi antena. Saiz antena adalah 97.5×50×1.5 mm^3 pada 915 MHz. Gandaan puncak telah mencapai 5 dBi dan kecekapan untuk antena mencapai 62% pada 915MHz. Jalur lebar antena adalah 24.875 MHz (900.125-925) MHz (pekali pantulan kuasa lebih rendah daripada -3 dB). Hasil pengukuran menunjukkan padanan impedans yang sangat baik kerana fleksibiliti yang diberikan oleh penyuap induktif berbentuk-U. Tambahan pula, hasil pengukuran menunjukkan persamaan yang sangat baik dengan keputusan simulasi. Reka bentuk ini menunjukkan gandaan yang sangat tinggi dan kecekapan yang baik. Antena ini diperkenalkan untuk memenuhi keperluan bagi penandaan jarak panjang dan cagak untuk objek logam seperti penandaan tong minyak di kilang penapis petrol dan silinder gas.

Tesis telah megemukakan tag antenna elektrik padat sesatah kecil(ESA) sebagai peringkat akhir. Struktur antena terukir pada polytetrafluorethylene (PTFE) sebagai substrat lapisan atas, manakala lapisan bawah adalah FR4 epoxy substrat. Tag antena sesatah ini membolehkan pengurangan saiz secara muktamad serta kecekapan yang lebih baik. Tag antena yang dibentangkan telah direka dengan penyuap proksimiti terganding melalui dua muat sesatah bumi yang simetri disambung dengan penyuap induktif berbentuk-U melalui talian penghantaran terbenam. Konfigurasi ini menyebabkan saiz antena menjadi 31×19.5×3.065 mm^3 pada 915MHz, manakala jumlah gandaan adalah 0.12 dBi dan kecekapan untuk antena adalah 24%. Muat sesatah dan penyuap induktif berbentuk-U membolehkan pelarasan impedans antenna yang fleksibel. Gandaan jalur lebar yang diperolehi oleh antena pada jalur lebar setengah-kuasa 14.5 MHz (908-922.5) MHz pada 915 MHz. Impedans antena yang dicadangkan telah disimulasikan, kemudian diukur untuk mengesahkan reka bentuk yang dihasil. Pada masa yang sama, angka merit telah digunakan pada tag antena ini dan keputusan telah diperolehi. Ukuran antena menunjukkan prestasi yang selaras dengan ukuran dalam sebahagian simulasi. Tag antena RFID yang dibentangkan adalah berciri kos rendah, padat, berkecekapan yang baik dan gandaan yang baik. Ini menjadikan ia sesuai untuk tag aplikasi logam. Akhirnya, angka merit telah digunakan untuk antenna elektrik padat kecil(ESA) peringkat akhir dan perbandingan telah dibentangkan untuk mengesahkan reka bentuk yang dicadangkan. Dalam karya ini, tag antena yang dicadangkan telah dinilai sepanjang kajian prestasi ESA. Tag antena telah dinilai dengan angka merit, iaitu produk gandaan jalur lebar ternomal (NBG) dan produk kecekapan jalur lebar ternormal(NBE). Perbandingan yang dibentangkan telah dijalankan dengan (NBG) dan (NBE). Keputusan telah dikira mendapati bahawa NBG adalah 0.57 dan NBE adalah 0.05.

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I certify that a Thesis Examination Committee has met on 22 April 2016 to conduct the final examination of Karrar Naji Salman Al Khanjar on his thesis entitled "Coplanar UHF RFID Tag Antenna with U-Shaped Inductively Coupled Feed for Metallic 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 Master of Science.

Members of the Thesis Examination Committee were as follows:

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Date: 28 June 2016

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:

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Date:

Declaration by graduate student

I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- The research conducted and the writing of the thesis was under our supervision;
- Supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________________
Name of Chairman of Supervisory Committee: Assoc. Prof. Dr.Alyani binti Ismail

Signature: ______________________________
Name of Member of Supervisory Committee: Assoc. Prof. Dr. Raja Syamsul Azmir Raja Abdullah

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

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
CST	Computer Simulation Technology
EAS	Electronic Article Surveillance
EIRP	Equivalent Isotropic Radiated Power
PTFE	polytetrauorethylene
EM	Electromagnetic
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
PBG	Photonic Band Gap
PCB	Printed Circuit Board
PIFA	Planar Inverted F Antenna
PP	Polypropylene
PRC	Power Reflection Coefficient
PTC	Power Transmission Coefficient
RF	Radio Frequency
RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
SHF	Super High Frequency
SMA	Sub Miniature version A
SRD	Short Range Devices
UWB	Ultra-Wideband
VNA	Vector Network Analyzer

CHAPTER 1

INTRODUCTION

1.1 Background

Radio Frequency Identification (RFID) involves sending of a radio frequency query signal from a remote reader or interrogator to a tag or transponder and receiving the modulated signal scattered back from the tag. The tag encompasses information regarding the object it is attached to. The received signal decodes by the reader and sends the information of the object to unit which is called a central processing unit. This central processing unit is receiving from neighboring readers, situated at other locations communicating with neighboring tags. Hence a communication system is established by the means of any items, placed at different locations of a retail-store or a warehouse can be tracked and identified. The tag and the reader utilize the antenna for signal/power transfer and compose the back-bone of the system. The amount of power transferred from the reader to the tag and back from the tag to the reader is determined by the antennas. As a matter of fact, there are limitations in tag antenna design particularly in the tag miniaturization due to the small size of the antenna; however there are no restrictions on the physical parameters of the reader antenna such as small size and being planar.

1.2 Problem statement and motivation

The existence of RFID technology prolonged for many years, but it is only recently witness rapid 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 it's 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) has given for each tagged objects and this identifier having it's 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 requested to store the object information. All these factors open 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].

From inventory management to theft detection, RFID has been utilized in many areas such as in logistics and the automotive industry, as well as in retail stores and warehouses [2–6]. In many contexts, Passive RFID technology is widely embraced even quite remote from the canonical ones which are basically linked to logistics. RFID-based sensor data transmission [7–10] Identification of goods containing liquid or made of metal [11–15] platform tolerant tags [8, 16] are only a few of the many possible examples where tags customized for specific applications are required. Over the last few years, the electromagnetic scientific community has been an acknowledged for the necessity to 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 [7–15, 17–33].

Although RFID brings forward the advantage of efficient supply chain management, many challenges are demonstrated due to the increasing implementation of RFID technology. Among the major challenges are:

1. Degradation of RFID system performance and reliability in presence of metal objects.
2. RFID tagging costs.
3. Tagging smaller objects at item level.
4. Impedance matching between antenna and chip.

Overview discussions on RFID challenges can be found in the literature such as in [34–37].
To permit a comprehensive and full deployment of RFID, and to bring into realization the vision of tagging objects down to item level, practicable solutions must be drawn to meet these RFID challenges from all aspects. In this thesis, the main focus is on tackling the first challenge listed above, with the complex material of concern being metallic objects and structures. 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.

Meanwhile, the second and third challenges listed above (concerning cost and size respectively) should be emphasis on while tackling the first challenge. These second and third challenges become very important particularly when item level tagging is included. In order to lower the tags cost in comparison to the item to be tagged on, the tags should be made from inexpensive materials and simple to manufacture. Yet, the ohmic loss will increase with decreasing of size of the antenna [38], and thus the efficiency will decrease. Therefore, maintaining a balance between the tag performance, cost and size is a challenging task. A compact coplanar structure have been adopted throughout this this thesis for the purpose of good gain and thus good read range with size reduction. The further size reduction achieved by load-via patch integrated with coplanar transmission line technology. The proposed antennas are fabricated at low cost using polytetrafluorethylene (PTFE) and Flame Retardant (FR4) substrate.
This thesis also itemizes on the fourth challenge listed above which is of an essential importance for proper tag antenna design. Chips vendors manufacture variety of Application Specific Integrated Circuits (ASIC) that are available in the market with different impedance values. Most microchips founded in market todays

exhibit an input reactance roughly ranging from -100 to - 400 while the real part is smaller. Thus, Antenna designers should stick to these values which are already produced, where in most cases; they are not free to select the desired antenna size to accomplish the desired task. With good impedance matching can lead to ensure maximum power transfer between it's antenna and the chip increasing the read range.

1.3 Aim and Objectives of Research

The main goal for this work is to design different structure for coplanar tag antenna designed technology, HIS-conventional technique, the load-via patch construction fed by U-shaped inductively coupled feed. This design is aimed for metallic objects.

The research is focused on the following four main objectives:

1. To design coplanar RFID tag antenna and investigate the coplanar feature on RFID performance in presence of metallic objects.
2. To improve the radiation efficiency and thus, the antenna gain for high gain coplanar tag antenna and compact coplanar electrically small tag antenna .
3. To conduct measurement in order to validate the performance of the designed high gain coplanar tag antenna and compact coplanar electrically small tag antenna.
4. To validate the performance of the designed tag antennas through figure of merit for Electrically Small Antennas (ESA's) .

1.4 Scope of Research

The scope of this thesis is to design a new coplanar transmission line for RFID applications integrated with U-shaped inductive feeder to improve their performance characteristics. The designed antennas used two type of planar transmission line which is considered newly utilized in RFID. The Coplanar tag antenna introduced together with via-load patch and HIS-structures. The flow of this study is demonstrated in Figure 1.1. The continuous-lines represent the direction followed in this thesis to achieve the objectives, while the dashed-lines are referring to other related research areas that are outside the scope of this work.

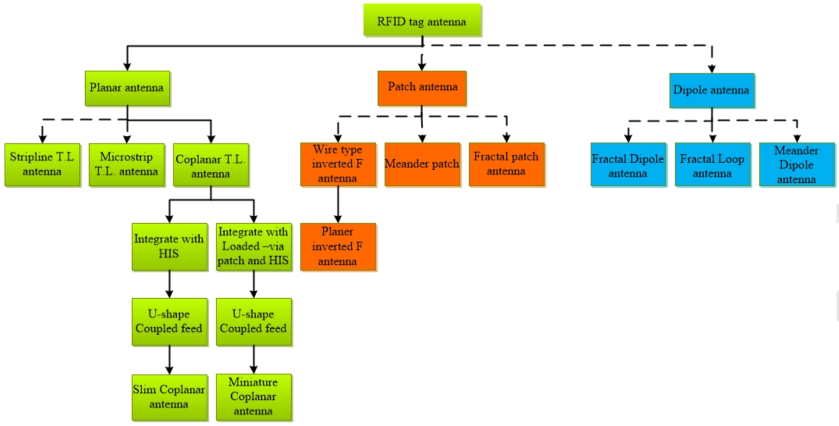

Figure 1.1: Scope of Research

1.5 Overview of Research Methodology

Firstly, to accomplish the objectives of this work, comprehensive research on RFID tag antennas, coplanar transmission line was utilized and integrated with Loaded-via patch, HIS technology and U-shaped inductively coupled feed to give understanding prospective to their fundamentals. In addition, understand how these types of materials can be integrated with antennas. Next, inexpensive materials are located for antenna construction with suitable chips after identifying antenna parameters and obtaining used chip impedance. Then, a 3D full-wave electromagnetic simulator (CST Microwave Studio, Version 2013 [39]) was used to simulate the structures. Afterwards, unique methods of integration have been applied between the tag antennas after it was successfully designed for RFID applications. Finally, measurements have been performed on the RFID tag antennas to validate the design methods. The developed methodology for designing RFID tag antennas is illustrated in the flow chart depicted in Figure 1.2.

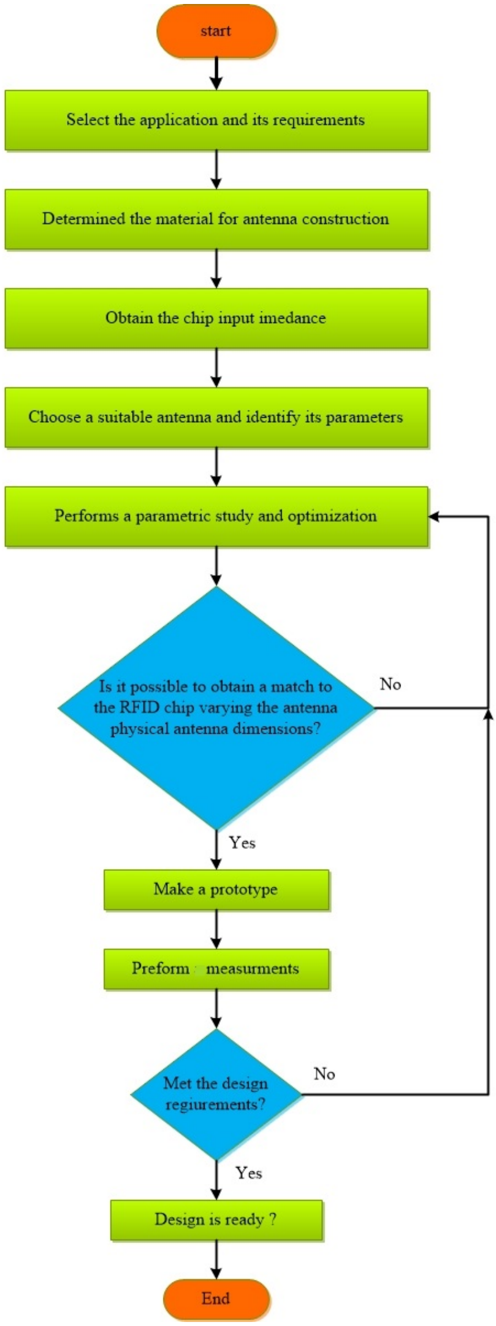

Figure 1.2: Methodology Design Flowchart of RFID Tag Antennas

1.6 Organization of the Thesis

This thesis is organized into six chapters, which are summarized as follows:

Chapter 1 provides a general introduction to the research area, and identifies the current problems in designing RFID tag antennas that motivated this research. It also introduces the goal, objectives, methodology, scope of research as well as the organization of thesis writing.

Chapter 2 presents a literature review on RFID system and RFID tag antennas. It first provides a background of RFID technology and some details about their classes and types. Then some details are provided about RFID tag antenna design considerations as well as some recent designs and applications. Finally, a summary ends the chapter.

Chapter 3 describes the methodology used to design the Coplanar transmission line structures that are used in antenna designs in Chapters 4 and 5 in an attempt for antenna gain enhancement. The performance of U-shaped inductively coupled feed behavior is investigated in terms of the lumped element equivalent circuits, and discusses effects of the feeder parameters to frequency resonant. Loaded-via patch and HIS technology were studied well in addition to the Parameters affecting for coplanar structure as well. Methodology is finally summarized.

Chapter 4 contains a description on new design of slim Coplanar tag antenna with gain enhancement for metallic objects which is based on the coplanar transmission line technology structure. Some antenna parameters are studied showing their effects on antenna self-resonant frequency. The effective parameters for U-shaped inductive feeder were investigated well compatible with coplanar parameters. Content is reviewed at the end of the chapter. This chapter considered as the first stage for the proposed tag antenna design

Chapter 5 elaborates on a novel design of miniaturized metal mount double-layered for RFID applications. The tag antenna integrated with loaded-via patch, HIS technology and U- shaped feeder to achieve the gain enhancement. In addition, parametric study is also shown for different antenna parameters. Comprehensive analyses were done throughout the chapter concerning theoretical and simulation validation as well as the design techniques adopted. A study for Merit of Figure for ESA was introduced throughout this chapter. Furthermore, an equivalent circuit for the proposed antenna was designed. Finally, a summary on the chapter is reviewed at the end. This chapter considered as the final stage for the proposed tag antenna design

In Chapter 6, the entire thesis is summarized and concluded, followed by discussion of the major contributions of the work. Eventually, potential ideas for future work are suggested.

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