DESIGN AND DEVELOPMENT OF RFID READER FRONT-END AND CHIPLESS TAG USING ULTRA WIDE BAND TECHNOLOGY

BY

A. K. M ZAKIR HOSSAIN

A thesis submitted in fulfillment of the requirement for the degree of Doctor of Philosophy (Engineering)

Kulliyyah of Engineering
International Islamic University Malaysia

NOVEMBER 2017

ABSTRACT

The invention of the Radio Frequency Identification (RFID) has introduced many advantages in the product tagging, object tracking and supply chain management comparing with the barcode system. Allocation of the UWB frequency range has given the RFID researchers another edge to include more bits for the inscription due to the wideness of the band and nowadays research on RFID is at the forefront to replace the barcode system. Often, it has been seen from literature that in the RFID system, the main focus is on the tag and how it can be read. Many researchers tried to read the backscattered data from the passive UWB tag with highly sophisticated test instrumentations such as, vector network analyzers (VNA), spectrum analyzers etc. In the UWB RFID readers, that can successfully read the microstrip resonator type tag, the generation of the chirp signal (and also in the tag space) limits the inclusion of more bits to the system. Inclusion of more bits needs more bandwidth which leads to the difficulties to design large bandwidth chirp signal. In literature it is also found that there are very little emphasis given on the development on the reader while developing a RFID system and how to make it simple and energy efficient. UWB RFID system is totally dependent on the constant chirp generation from the UWB RFID reader. With respect to the design of the tag, the bits can be spread over the entire bandwidth (BW) which goes up to 5 GHz. To detect the bits, the entire bandwidth needs to be swept while the only concerning frequencies are needed for detection and rest of the BW will be idle. From the theory of the mixer topology it is well known that with the fundamental frequency, two different main tones can be generated. These two tones are totally separate frequencies and can operate individually by separating them with narrow band pass filters. With this idea, by cascading as many mixer-filter configurations eight different frequencies are generated from 5 to 7 GHz. The generation is only limited on those concerning frequencies which the bits are allocated on a microstrip resonator type tag. A duty cycle of 50% is kept while switching different frequencies. Since the generated interrogation signal is a ‘chirp and hold’ signal, in this process the entire BW sweep is not necessary. Due to 50% on time, the EIRP of the reader is doubled and consequently the reading range is increased. The reader is also made less complex and easy to design. A new type of linear resonator for the UWB passive tag also designed and developed to fit with the designed reader front-end. The result shows the 8-bit tag’s resonator section occupies 19.22 mm^2/bit. The new design has reduced the area/bit upto 20% from the recent research.

خلاصة البحث

قدم اختراع تقنية تحديد الهوية باستخدام موجات الراديو (RFID) العديد من المزايا في وضع العلامات على المنتج وتتبع الكائن وإدارة سلسلة الإمداد مقارنة بنظام الشفرة الخيطية. أعطى توزيع نطاق الترددات UWB حداً آخر للباحثين في RFID ليشمل المزيد من البت لإدخال البيانات بسبب اتساع النطاق، والبحوث على RFID في الطليعة في الوقت الحاضر لتحل محل نظام الشفرة الخيطية. لقد لوحِظَ من البحوث السابقة أن التركيز الرئيسي في نظام RFID هو على العلامة وكيف يمكن قراءتها. حاول العديد من الباحثين قراءة البيانات المشتتة من علامة UWB بأدوات اختبار متطورة للغاية مثل أجهزة تحليل الشبكات المتجهة (VNA)، تحليل الطيف، إلخ. في قارئ UWB RFID الذي يمكن أن يقرأ بنجاح علامة نوع رنان شريط النقل الكهربائي، يحدّ توليد إشارة chirp (وأيضا في حيّز العلامة) من إدراج المزيد من البت للنظام. يحتاج إدراج المزيد من البت إلى المزيد من عرض النطاق الترددي مما يؤدي إلى صعوبات في تصميم إشارة نطاق ترددي كبير لِ chirp. وُجد أيضاً في البحوث السابقة أن هناك القليل من التركيز على التطوير بالقارئ في الوقت الذي يتم فيه تطوير نظام RFID وكيفية جعله بسيطاً وذات كفاءة في توفير الطاقة. يعتمد نظام UWB RFID كلّياً على جيل chirp الثابت من قارئ UWB RFID. وفيما يتعلق بتصميم العلامة، يمكن توزيع البتّات على عرض النطاق الترددي بأكمله (BW) والذي يصل إلى 5 غيغاهرتز. للكشف عن البتّات، يجب أن يتم فحص عرض النطاق الترددي بأكمله في حين أن هناك حاجة فقط للترددات اللازمة لعملية الكشف وسيكون بقية BW خاملاً. من المعروف جيداً من نظرية طوبولوجيا الخلاط أنه يمكن توليد اثنين من الترددات الرئيسية المختلفة مع التردد الأساسي. هاتان الإشارتان هما ترددات منفصلة تماماً ويمكنهما العمل بشكل فردي عن طريق فصلهما بمرشحات تمرير نطاق ضيق. بهذه الفكرة، يتم إنشاء ثمانية ترددات مختلفة من 5 إلى 7 غيغاهرتز من خلال تتالي العديد من تكوينات mixer-filter. يقتصر الجيل فقط على الترددات التي تخصّصها البتّات على علامة نوع رنان شريط النقل الكهربائي. يتم الاحتفاظ بدورة العمل بنسبة 50٪ أثناء تبديل الترددات المختلفة. بما أن إشارة الاستجواب المولّدة هي إشارة "‘chirp and hold "، فإن فحص BW الكامل ليس ضرورياً في هذه العملية. نظراً إلى 50٪ في الوقت المحدد، يتم مضاعفة EIRP من القارئ، وبالتالي يتم زيادة نطاق القراءة. جُعِل القارئ أيضاً أقل تعقيداً وسهل التصميم. صُمّم وطُوّر نوع جديد من الرنان الخطي للعلامة السلبية UWB ليتناسب مع القارئ الأمامي المُصمّم. تظهر النتيجة أن قسم رنان العلامة 8-بت تشغل 19.22 مم2/بت. خَفّض التصميم الجديد من المساحة لكل بت لتصل إلى 20٪ من البحوث الأخيرة.

APPROVAL PAGE

The thesis of Student's Name has been approved by the following:

Muhammad Ibn Ibrahimy
Supervisor

S. M. A Motakabber
Co-Supervisor

Ma'mun Ibne Reaz
Internal Examiner

Mashkuri Yaacob
External Examiner

S. M. Abdul Quddus
Chairman

DECLARATION

I hereby declare that this dissertation is the result of my own investigations, except where otherwise stated. I also declare that it has not been previously or concurrently submitted as a whole for any other degrees at IIUM or other institutions.

A. K. M Zakir Hossain

Signature .... Date ....

INTERNATIONAL ISLAMIC UNIVERSITY MALAYSIA

DECLARATION OF COPYRIGHT AND AFFIRMATION OF FAIR USE OF UNPUBLISHED RESEARCH

DESIGN AND DEVELOPMENT OF RFID READER FRONT-END AND CHIPLESS TAG USING ULTRA WIDE BAND TECHNOLOGY

I declare that the copyright holders of this dissertation are jointly owned by the student and IIUM.

No part of this unpublished research may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise without prior written permission of the copyright holder except as provided below

1. Any material contained in or derived from this unpublished research may be used by others in their writing with due acknowledgement.

2. IIUM or its library will have the right to make and transmit copies (print or electronic) for institutional and academic purposes.

3. The IIUM library will have the right to make, store in a retrieved system and supply copies of this unpublished research if requested by other universities and research libraries.

By signing this form, I acknowledged that I have read and understand the IIUM Intellectual Property Right and Commercialization policy.

Affirmed by A. K. M Zakir Hossain

……..……………………..   ………………………..

Signature   Date

ACKNOWLEDGEMENTS

Firstly, it is my utmost pleasure to dedicate this work to my dear parents and my family, who granted me the gift of their unwavering belief in my ability to accomplish this goal: thank you for your support and patience.

I wish to express my appreciation and thanks to those who provided their time, effort and support for this project. To the members of my dissertation committee, thank you for sticking with me.

Finally, a special thanks to Dr. Muhammad Ibn Ibrahimy and Dr. S.M.A Motakabber for their continuous support, encouragement and leadership, and for that, I will be forever grateful.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure No. Page No.

LIST OF ABBREVIATIONS

2D	2 Dimensional
ADC	Analogue-To-Digital
ADS	Advanced Design System
AIDC	Automatic Identification and Data Capture
ASIC	Application-Specific Integrated Circuits
ASK	Amplitude Shift Keying
Auto-ID	Automatic Identification
BAP	Battery Assisted Passive
BPF	Band Pass Filter
BPSK	Binary Phase Shift Keying
BW	Band Width
CNR	Complex-Natural-Resonance
CPW	Co-planar Waveguide
CST MWS	Computer Simulation Technology Microwave Studio
CW	Continuous Wave
DFT	Discrete Furiour Transform
DPS	Density of Coding Per Surface
EAS	Electronic Article Surveillance
EIRP	Effective Isotropic Radiated Power
EM	Electromagnetic
EU	European Union
FCC	Federal Communications Commission
FD	Frequency Division
FMCW	Frequency Modulated Continuous Wave
FSS	Frequency-Selective Surface
GHz	Giga Hertz
HF	High Frequency
HIS	High-Impedance Surface
IC	Integrated-Circuit
ID	Identification
IEEE	Institute of Electrical and Electronics Engineers
IR-UWB	Impulse Radio- ultra wide band
ISM	Industrial, Scientific and Medical Radio
ISO	International standards Organizations
ITU	International Telecommunication Union

KHz	Kilo Hertz
LF	Low Frequency
LH	Left-Handed
LNA	Low Noise Amplifier
LOS	Line-of-Sight
MHz	Mega Hertz
PA	Power Amplifier
RF	Radio Frequency
RFID	Radio Frequency Identification
R_X	Receiver
SAW	Surface Acoustic Wave
SEM	Singularity Expansion Method
SSI	Selective Spectral Interrogation
STMPM	Short-Time Matrix Pencil Method
TD	Time Division
TDR	Time-Domain Reflectometry
T_X	Transmitter
UHF	Ultra High Frequency
UWB	Ultra Wide Band
VCO	Voltage Controlled Oscillator
VNA	Vector Network Analyser
WPAN	Wireless Personal Area Networks

LIST OF SYMBOLS

+	Plus
-	Minus
$>$	Greater Than
$<$	Smaller Than
$\leq$	Smaller Than or Equal
S	Spectral Density
P_t	Transmitted Power (Reader Antenna)
G_r	Antenna Gain (Reader)
π	Pi
r	Radius
P_a	Power At Tag Antenna
λ	Lamda (Wavelength)
A_e	Effective Aperture
G_t	Antenna Gain (Tag)
P_{rx}	Backscattering Received Signal
L_T	Total Distributed Inductance
C_T	Total Capacitance of Spiral
R	Resistance
f_{res}	Resonant Frequency
C_0	Total Distributed Capacitance of One Turn Spiral
r_m	The Mean Radius
R_{in}	Inner Radius
R_{out}	Outer Radius
Ls	Self-Inductance of The Spiral
M	The Mutual Inductance Between Turns of The Spiral
$y(\theta, \varphi, t)$	Response in Complex Frequency Plane
$R_i(\theta, \varphi)$	Radius of Complex Amplitude
j	Complex Parameter
ω	Angular Frequency
α_i	Damping Factor
s_i	The Poles
$\sum_{i=1}^{M} R_i$	Summation
θ	Phase Angle

φ	Amplitude

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

RFID (Radio frequency identification) is mainly a technique of transmitting and receiving necessary data between an RFID tag and reader which uses radio frequency for detection. It comes from one of the branches of the term called 'Automatic Identification (Auto-ID)' named by the organization called Automatic Identification and Data Capture (Su, Chu, Prabhu, & Gadh, 2007). Auto-ID system has several branches such as optical barcode, biometric, smart card, RFID and other systems. Commonly, the barcode and RFID system are involved in tagging of the object or product. The optical barcode is comparatively cheaper and can be labelled on any of the products to be identified. Though the optical bar code system is cheaper, it has several disadvantages. It needs a line of sight in communication. It malfunctions due to dirt, damp, wear and tear. It has always risk of tempering. Moreover, it cannot be fully automated and needs manual operation for its function. On the other hand, the RFID depends on data transmission by means of radio frequency signals, and subsequently, the whole operation is line-of-sight (LOS) and weather independent. A full automatic system can be possible to be developed by using RFID. As a result, RFID is a potential and better candidate compared to the barcode for its object tagging and tracking abilities (McFarlane & Sheffi, 2003).

Since silicon chips are fabricated on a wafer-by-wafer basis, there is a fixed cost per wafer that is independent of the integrated-circuit (IC) design thus the cost of the RFID chip can be estimated based on the required silicon area for the RFID chip. Hence, with highly optimized low transistor count application-specific integrated circuits (ASICs), implemented assembly processes and extremely large quantities (over 1 billion) of RFID chips sold per annum, a minimum cost of 5 cents is a reasonable estimate for chipped RFID tags (Ahsan, Shah, & Kingston, 2010).

The major application of RFID technology including manufacturing processes, supply chain management, inventory control in warehouse, counterfeit prevention in bank notes and secured documentation are established. Scientists and researchers throughout the world have been trying to resolve some current issues involved in the RFID system such as costing, reliability, security, and standardizing before being implemented in the relevant sectors. Therefore, there is a lot of scope to do research in this field of RFID.

Item tracking and identification is one of the major challenges of RFID because this market represents 10 trillions of units sold each year. Competing with the optical barcode technology is a hard task for classical RFID tag having an antenna and a chip, whereas chipless RFID tag has a key role to reach this goal. Indeed, this emerging technology is under growing interest and many research projects are under development.

RFID systems can be classified in many ways. On the basis of its frequency of operation it is low frequency (125 KHz), high frequency (13.56MHz), ultra high frequency (860 to 930 MHz), microwave (2.45 GHz) and ultra wide band (UWB) that working between 3.1 to 10.7 GHz. In each working band of frequencies different detection techniques and topologies are adopted while designing the system. Moreover, the dimensions of the tag are also a function of the operating frequency (Butters & Consultant, 2006).

Similarly, on the basis of on board tag power supply it is classified as: active type tag realises of its transmission, reception and other functions on the battery on-board, semi-active type tag that also has battery on board only to keep the digital circuitry alive but needs the assistance of reader interrogation signal power to send and receive the information and passive type tag which comprises no battery on board and totally dependent on the interrogation signal power to perform all necessary operations. The chipless tags don't carry any silicon chip on-board so, it is inherently passive in nature. Since there is no inclusion of chip on board the chipless is the main competitor to replace the conventional barcode system.

Nowadays, a number of active and passive RFID systems in different frequencies are available in the market. Hence, a wide range of RFID tag and their corresponding reader are available in the commercial market. At present, chipless RFID technology opens a new research area in RFID due to its simplicity and low cost since a chipless tag doesn't hold any silicon chip and no classical RF modulation schemes are required for communication (Garfinkel, Juels, & Pappu, 2005). The UWB enables a wide frequency range for the researchers to design different chipless RFID systems and UWB RFID systems are now at the forefront of the research. However, the UWB RFID technology is not omnipresent and yet to be fully deployed commercially.

There are mainly two significant parts of the RFID system, tag and reader. Basic mechanism of the RFID, the reader or interrogator sends the RF interrogation signal and in response, the tag transmits the data stored in it. The architecture of an RFID reader absolutely depends on the type of tag used. However, the main components of RFID reader are antenna(s), analogue section that consist of transmitter and a receiver, and the digital section. Usually the analogue section is called the front-end of the reader. Figure 1.1 shows the basic block diagram of an RFID system.

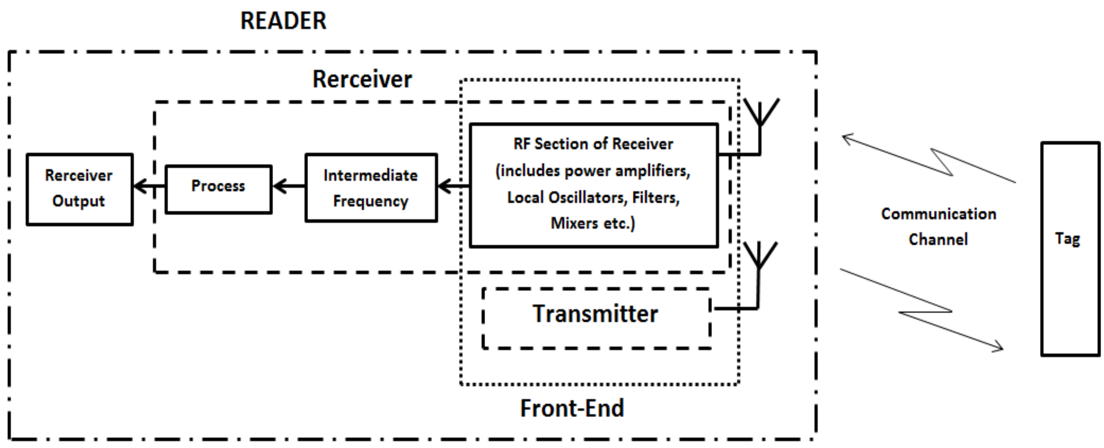

Figure 1.1: The basic block diagram of an RFID system

The front-end is connected with the transmitting and receiving antenna(s) as the gateway of the reader. Mainly, the construction of the reader front-end is based on the type of the tag and also the frequency of the operation. For the chipless type resonator tag, the reader transmitter consists of VCO (voltage controlled oscillator), band pass filter (BPF) and a power amplifier (PA). The VCO generates a linear chirp (swept) frequency interrogation signal. The reader, which is a coherent frequency-modulated continuous-wave device, interrogates a tag and decodes the tag's identification data from its both amplitude and phase information (Preradovic, Karmakar, & Zenere, 2010). The tag and reader are integrated part in an RFID research and there is no scope to consider them separately.

Chipless tag is inherently passive and attractive to the end users since they do not have an on-board power supply and therefore rely only on the power emitted from the reader. Passive tags may or may not contain an integrated circuit, memory block, or application specific integrated circuit.

Chipless tags are usually in the form of electronic article surveillance (EAS) or surface acoustic wave (SAW). It can be used in retail shops for auto inventory management and security purposes. Basically the chipless RFID tags are exploiting the physical effects of the tag's design. All chipless RFID tags differ fundamentally from tags which contain an IC, in terms of operational principles and power consumption. The tag itself generates data due to its physical architecture and design, and therefore, it represents a unique ID device.

Nowadays, the chipless RFID reader approaches are complex, bulky, expensive and commercially inadequate in the market. Their existences are still in the incubation stages inside the research lab. Though the chipless tag price is going lower, however the price of the reader is still very high and the dimension of reader is also bulky. As a result, these are the big issues at present to the RFID end users. An UWB RFID reader is an RF transceiver. Refers to Figure 1.1, the circuitry of the RFID reader is complex in design. This actually makes the system bulky, costly and complex. One of the solutions is to use the RF switch but, in this case implementation of the switch cannot be feasible because the reader keeps sending the CW signal while receiving the backscatter signal from the tag. Also because of the large bandwidth of the UWB system the generation of the constant analogue chip signal is very difficult and difficult to find in the existing market. This makes a conclusion that one reader can be made in such a way that there is no constant chirp but only the corresponding signals related to the tag.

1.2 PROBLEM STATEMENT

The authors in Jalaly et al., (2005) presented a tag that encodes 5 bits with 5 microstrip dipole resonators. The data was encoded by controlling the presence/absence of resonance (based on the resonator) at a known frequency. Using the same coding technique, Preradovic et al, (2009), has proposed a tag based on multiple spiral resonators and was able to encode 35 bits. This design is efficient in terms of coding capacity but needs a large size (7 cm 15 cm) since one bit is equal to one resonator. The phase can also be used to encode data and several techniques have been experimented. Mukherjee et al., (2011) uses a wideband antenna as a reflector connected to a complex load that can produce different phase profiles.

For each phase profile an identifier is associated. The authors in Balbin & Karmakar, (2009), used multiple patch antennas connected to a stub of variable length and encodes data by varying the phase of each antenna independently. However, at the present time, coding capacity is not significant (few bits) and it is still a big challenge to embed a large number of data into a tag of size similar to that of a credit card (5 cm 8 cm). Despite many proposals are made, due to the space dependency, the UWB passive RFID tag dimension is still relatively large to fully replace the conventional barcode.

In classical RFID, anti-collision management is a part of the protocol but in case of the chipless tag that cannot be implemented. However some techniques based on time or spatial separation of tags can be used. An antenna with narrow beam width can be designed for this purpose, but the main weaknesses of chipless technology concerns their non-rewritable capability and their data capacity limited to a few tens of bits. This last characteristic could be a limiting factor for many applications, and this is why work has to be done to increase the data capacity of chipless tags.

In the reader front-end topologies, there are two configurations omnipresent i.e. two antenna (bi-static) and single antenna (mono-static) configuration. In most of the lower frequencies (until UHF band) the mono-static antenna is established. In UWB still the bi-static configuration is not replaced by the mono-static only because of the separation of the transmitted and received signal. However, bi-static antenna based front-end configurations for the RFID reader, imposes few problems such as

Bi-static antenna system makes the system bulky. Use of two separate antennas for transmission and reception makes the system almost double costly. Implementation of the bi-static antenna system is sophisticated, so, the design becomes complex. Two antennas always make crosstalk/isolation problem.

There are a few drawbacks, which are significant, associated with chipless RFIDs. No protocol is followed with this type of RFID; therefore, collision is a major challenge. The required reader would need more sophisticated architecture and will be more expensive than existing commercial readers. The reader's transmitted power is limited by the Federal Communications Commission, FCC, Section 15.247 to an effective isotropic radiated power (EIRP) of 1 Watt. At practical operating distances, the chipless RFID has a clear advantage, requiring less radiated power.

Often, it has been seen from literature that in the RFID system, the main focus is on the tag and how it can be read. Many researchers tried to read the backscattered data from the passive UWB tag with highly sophisticated test instrumentations such as, VNA (vector network analysers), spectrum analysers etc. In different literatures, the authors tried to propose the UWB RFID readers that can successfully read the microstrip resonator type tag. Where, the generation of the chirp signal (and also in the tag space) limits the inclusion of more bits to the system. Inclusion of more bits needs more bandwidth which leads to the difficulties to design large bandwidth chirp signal. In our knowledge there are very little emphasis given on the development on the reader while developing a RFID system. Moreover, due to the large bandwidth of the system, to generate the constant amplitude chirp signal, the design of the VCO is very difficult to implement for the reader front end of UWB passive RFID tag.