UNIVERSITI PUTRA MALAYSIA

MULTILEVEL MULTIRESONATOR CHIPLESS RADIO FREQUENCY IDENTIFICATION TAGS WITH HIGH ENCODING CAPACITY

OMAR JABBAR IBRAHIM

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By

OMAR JABBAR IBRAHIM

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

November 2016

DEDICATION

My beloved parents,

My Family

For their endless encouragement, patience, and support

And for being a great source of motivation and inspiration

And all my friends

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the Degree of Doctor of Philosophy

MULTILEVEL MULTIRESONATOR CHIPLESS RADIO FREQUENCY IDENTIFICATION TAGS WITH HIGH ENCODING CAPACITY

By

OMAR JABBAR IBRAHIM

November 2016

Chairman : Associate Professor Alyani Binti Ismail, PhD
Faculty : Engineering

Automatic Identification procedures (Auto-ID) have become very popular in recent years. They are used to provide information about people, animals, goods, and products in transit or in storage. Barcodes and RFID (Radio Frequency Identification) are the two widely used identification systems. Chipless RFID owing to its low cost has opened a new era for the identification world. There are not a lot of chipless RFID tags available in the market. However, due to the low cost, these tags started to conquer a part of the market. Several constraints such as coding capacity, miniaturization, cost per tag, printable designs, etc. need to be considered while developing chipless tags.

This thesis reviews the existing chipless tags and also presents the design, fabrication, and measurement of two different types of multiresonator based chipless RFID that operates within the UWB (Ultra-Wide Band) region (3.1-10.6GHz). It is an attempt to improve the performance of multiresonator based chipless RFID in terms of coding capacity. The tags have a CPW (Coplanar Waveguide) structure. The uniplanar property of the proposed tags makes these tags fully printable which simplifies the production process. Thus, the proposed tags are suitable for short ranged tagging of paper and plastic based items, such as paper documents and banknotes.First, an 8-bits B2L (Base-Two Levels) chipless tag that comprises two half-disc UWB monopole antennas and a B2L multiresonatoris presented. The multiresonator has a CPW structure with two types of resonators (Res-1 and Res-2) to create stop bands in the UWB spectrum. One type (Res-1) is placed on the center conductor, while the other (Res-2) is placed on the two sides of the ground plane. The use of the ground plane resonators enables the CPW to overcome the disadvantage of low bit density so that it increased the number of tag IDs by 1024 times than the reported tags. Distance measurements of the phase of the tag's insertion loss show a successful detection at a distance of (50 cm). Second, two designs of B3L (Base-Three Levels) chipless multiresonators circuits (MR-a and MR-b) to develop a B3L chipless RFID tag are designed. These tags are spectral signature-based chipless tags in which a resonant structure is used to encode data into three coding levels (0, 1, and 2) instead of the conventional two coding levels (0 and 1). Simulation results showed that MR-a

(embedded with Res-1 and Res-2 resonators) has a better performance than the MR-b (embedded with Res-3). Therefore, the MR-a and UWB antennas have been fabricated and integrated with each other to form the B3L chipless tag. Distance measurements showed a successful detection for the three levels was at a distance of 20 cm. The use of B3L chipless tag makes it possible to increase the number of tags' IDs by 17 times than the reported tags. This tag occupies half the bandwidth occupied by other reported tags, therefore, only part of the UWB spectrum (3.1-7GHz) can be used for coding and the upper region of the UWB spectrum can be avoided since it contains spurious resonances that may cause detection error.

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

PELBAGAI PERINGKAT PELBAGAI PENYALUN TAG RFID TANPA CIP DENGAN KEMAMPUAN PENGEKODAN TINGGI

Oleh

OMAR JABBAR IBRAHIM

November 2016

Pengerusi : Profesor Madya Alyani Binti Ismail, PhD
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Prosedur Pengesanan Automatik (Auto-ID) telah menjadi sangat popular pada tahun-tahun kebelakangan ini. Ia digunakan untuk memberi maklumat tentang orang, haiwan, barangan, dan produk dalam transit atau dalam simpanan. Kod bar dan RFID (Pengesanan Frekuensi Radio) merupakan dua sistem pengesanan yang digunakan secara meluas. RFID tanpa cip telah membuka suatu era baru untuk dunia pengesanan disebabkan oleh kosnya yang rendah. Tidak terdapat banyak tag RFID tanpa cip di pasaran. Walau bagaimanapun, disebabkan oleh kos rendah, tag-tag ini mula menakluki sebahagian daripada pasaran. Beberapa halangan seperti kemampuan pengekodan, pengecilan saiz, kos setiap tag, corak yang boleh dicetak dan lain-lain perlu dipertimbangkan semasa membangunkan tag-tag tanpa cip ini.

Tesis ini mengulas tag-tag tanpa cip yang sedia ada dan membentangkan reka bentuk, fabrikasi, dan pengukuran dua jenis RFID tanpa cip berasaskan multipenyalun yang beroperasi dalam lingkungan rantau UWB (Jalur Lebar Ultra) (3.1-10.6GHz). Ini adalah satu percubaan untuk meningkatkan prestasi RFID tanpa cip berasaskan multipenyalun dari segi kemampuan pengekodan. Tag tersebut mempunyai struktur CPW (Panduan Gelombang Sesatah). Ciri sesatah pada tag yang dicadangkan membolehkan tag ini di cetak sepenuhnya. Oleh itu, tag yang dicadangkan adalah sesuai untuk penandaan jarak dekat bagi kertas dan barangan berasaskan plastik, seperti dokumen kertas dan wang kertas.Pertama, tag 8-bit B2L (Tahap Asas Dua) tanpa cip yang terdiri daripada dua cakera setengah UWB dengan antena monopolar dan sebuah multipenyalun B2L dipersembahkan. Multipenyalun tersebut mempunyai struktur CPW dengan dua jenis penyalun (Res-1 dan Res-2) untuk mewujudkan jalur henti dalam spektrum UWB itu. Res-1 diletakkan pada pusat konduktor, manakala Res-2 diletakkan di kedua-dua belah satah bumi. Penggunaan penyalun satah bumi membolehkan CPW tersebut mengatasi kelemahan kepadatan bit rendah dengan menggandakan bilangan bit bagi setiap unit keluasan. Ukuran jarak bagi fasa kehilangan penyisipan tag tersebut menunjukkan pengesanan yang berjaya pada jarak 50 sm. Kedua, dua reka bentuk litar multipenyalun (MR-a dan MR-b) B3L (Tahap Asas Tiga) tanpa cip untuk membangunkan tag RFID B3L tanpa cip telah direka. Tag-

tag ini merupakan tag spektrum tanpa cip berasaskan tandatangan di mana struktur salunan digunakan untuk mengekod data kepada tiga tahap pengekodan (0, 1, dan 2) dan bukannya dua tahap pengekodan yang konvensional (0 dan 1). Keputusan simulasi menunjukkan bahawa MR-a (yang tertanam dalam penyalun Res-1 dan Res-2) memberi prestasi yang lebih baik daripada MR-b (yang tertanam dalam Res-3). Oleh itu, MR-a dan antena UWB telah direka dan bersepadu antara satu sama lain untuk membentuk tag B3L tanpa cip. Ukuran jarak menunjukkan pengesanan yang berjaya untuk tiga tahap tersebut pada jarak 20 sm. Penggunaan tag B3L tanpa cip membolehkan bilangan tag ID yang disediakan oleh setiap frekuensi salunan ditingkatkan. Oleh itu, hanya sebahagian daripada spektrum UWB (3.1-7GHz) boleh digunakan untuk pengekodan dan rantau pada bahagian atas spektrum UWB dapat dielakkan kerana ia mengandungi salunan palsu yang boleh menyebabkan ralat pengesanan.

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I certify that a Thesis Examination Committee has met on 11 November 2016 to conduct the final examination of Omar Jabbar Ibrahim on his thesis entitled "Multilevel Multiresonator Chipless Radio Frequency Identification Tags with High Encoding Capacity" 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.

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Declaration by graduate student

I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

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LIST OF ABBREVIATIONS

B2L	Base-two levels
B3L	Base-three Levels
CPW	Coplanar Wave guide
CST	Computer Simulation Technology
EAS	Electronic Surveillance Article
EM	Electromagnetic
GHz	Gigahertz
IC	Integrated Chip
ID	Identification
IDT	Interdigital Transducer
IFF	Identify Friend and Foe
ISI	Inter Sample Interference
ISM	Industrial Scientific and Medical
MHz	Megahertz
MRes.	Multi Resonator
MS	Microstrip
Ns	Nano second
OCR	Optical Character Recognition
OOK	ON-OFF Keying
PPM	Pulse-Position Modulation
QPSK	Quadrature Phase Shift Keying
RCS	Radar Cross Section
Res.	Resonator
RF	Radio Frequency

RFID	Radio Frequency Identification
SAW	Surface Acoustic Wave
SLMPA	Stub-Loaded- Microstrip -Patch-Antenna
SMA	Sub Miniature version A
SRR	Split Ring Resonator
TDR	Time-Domain Reflectometry
UWB	Ultra-Wideband
VNA	Vector Network Analyzer

CHAPTER 1

INTRODUCTION

1.1 Background

Automatic identification system refers to the process of identifying and tagging objects which mainly involves technologies such as barcodes, Optical Character Recognition (OCR), biometric procedures, voice identification, fingerprint, smart cards, Radio frequency identification (RFID) systems etc.(White, Gardiner et al. 2007). Among these, barcodes and RFID are the most widely used identification techniques. RFID is a technology firstly introduced during the 2nd World War to Identify Friend and Foe (IFF) aircrafts. Further, Stockman introduced the term RFID in his paper "Communication by means of Reflected Power" (Stockman 1948). However, the first real tag was the Electronic Surveillance Article (EAS) device that is the ancestor of modern tags, developed in 1960s (Finkenzeller 2003). Radio frequency identification is a wireless identification and data capturing technique that uses electromagnetic energy to communicate. RFID system consists of three main parts: a reader (interrogator) that transmits an interrogation signal, a tag (transceiver) that encodes and retransmits the incident signal, and a data processing system that processes information received by the reader. RFID systems have various applications where automatic identification of objects, people, or locations are needed. Asset Management, warehouse, supply chain management; authentication, counterfeit protection, security, mining human activities, automatic toll collection etc. are some of the applications (Finkenzeller 2003; Symonds 2009).

1.2 Problem statement

Although RFID has numerous applications, the tagging of paper/plastic based items such as postage stamps, tickets, envelopes banknotes, and documents is still a problem since the cost of the RFID tag is relatively high. Basically, RFID tags consist of an antenna and integrated chip (IC). The main cost of the RFID tag is the cost of the chip. Therefore, when considering mass market, RFID could not replace the conventional optical barcode in the mass market despite the disadvantages of barcode such as the short reading range and the need of line of sight. For that reason, much research has been performed to design chipless RFID tags (Jalaly and Robertson 2005; Balbin and Karmakar 2009; Blischak and Manteghi 2011; Vena, Perret et al. 2011; Vena, Perret et al. 2011; Kalansuriya, Karmakar et al. 2012; Vena, Perret et al. 2013; Tavakoli, Hajghassem et al. 2014; Zomorrodi and Karmakar 2014)(Jalaly and Robertson 2005; Balbin and Karmakar 2009; Blischak and Manteghi 2011; Vena, Perret et al. 2011; Vena, Perret et al. 2011; Kalansuriya, Karmakar et al. 2012; Vena, Perret et al. 2013; Tavakoli, Hajghassem et al. 2014; Zomorrodi and Karmakar 2014). Chipless RFID tags offer a promising solution for this. Chipless tags, as their name implies do not contain any silicon chip. It can operate under the vicinity of a reader through electromagnetic waves. The chipless tags can offer a comparable price as in the case of barcodes (Vena, Perret et al. 2013). There are chipless tags that can be printed on paper and plastic using conductive ink and thus proves to be a viable and economical solution. Thus, the main objectives are to develop low cost chipless RFIDs which have a price comparable to that of barcodes and also to develop tags where classical RFID tags cannot be employed. As an example, the surface acoustic wave (SAW) chipless RFID has been used as a temperature sensor in a steel plant having a harsh production environment (Fachberger, Binder et al. 2009). The sensor was designed to monitor temperatures in the range of 400°C, where the conventional semiconductor based RFID tags cannot be used. A special packaging and assembly was used for the SAW tags in order to utilize it for such a harsh environment. The titanium/aluminium based metallization was used for the SAW delay lines. Instead of soldering, laser welding was used. The reflected pulses from the SAW tags were used for the identification and sensing purposes. However, SAW tags cannot be categorized under low cost tags (they are even more expensive than passive RFID tags). Still they come under the category of chipless as they do not contain any chip. However, most of the reported tags are still prototypes, and the only tag type available in the market is surface acoustic wave (SAW) tag (Harma, Plessky et al. 2006). This tag type can be categorized as temporal tags. Another type of chipless RFID tag is frequential chipless tags, in which a resonant structure is used to encode data into the spectrum. These tags work in the ultra-wide band region (UWB) (3.1–10.6 GHz). One example of this tag type is multiresonator-based tag (Jalaly and Robertson 2005; Nijas, Dinesh et al. 2012; Weng, Cheung et al. 2013; Sumi, Dinesh et al. 2014), in which a reader sends a wide band interrogation signal; this signal is received by the tag through an UWB antenna Rx, and then the signal is propagated toward the multiresonator structure that encodes data bits into the spectrum. The signal is then retransmitted through a co-polarized transmitter antenna Tx. The presence or absence of a resonance frequency can be interpreted as 0 or 1 [base-2 levels (B2L) coding].

From the literature, multiresonator chipless tags have either microstrip (MS) (Preradovic, Balbin et al. 2009; Girbau, Lorenzo et al. 2012; Preradovic and Karmakar 2012; Zainud-Deen, Abo El-Hassan et al. 2013) or coplanar wave guide stricture (CPW) (Bhuiyan, Azad et al. 2013; Weng, Cheung et al. 2013). In the field of chipless RFID tag design, CPW structure has several advantages in comparison to MS structure. First, CPW resonators have higher attenuation at their resonance frequencies. Second, the single-layer layout of the CPW makes it preferable over the two-layered MS structure. However, in terms of compact layout, MS structure has the advantage of cascading the resonators on both sides of the microstrip transmission line. This property makes the number of resonators per unit length for MS structures twice that for CPW structure. Generally, the number of resonance frequency in the UWB spectrum is limited because of practical detection considerations, thereby limiting the number of tag IDs produced by B2L tags. Moreover, each resonance frequency has a spurious resonance that appears at approximately twice the first frequency (Weng, Cheung et al. 2013). These spurious resonances may cause detection error at the higher region of the UWB spectrum; the erroneous part may be avoided, but in the cost of reduction in number of tag IDs.

In this work, a new chipless RFID multiresonator is developed. This multiresonator has a CPW structure with two types of resonators to create stop bands in the UWB spectrum. One type is placed on the centre conductor, while the other is placed on the two sides of the ground plane. The use of the ground plane resonators enables the

CPW to overcome the disadvantage of low bit density by doubling the number of bits per unit length. Moreover, a base-3 level (B3L) chipless RFID tag is developed, in which three coding levels (0, 1, and 2) instead of the conventional two coding levels (0 and 1) are used. This technique compensates reduction in number of tag IDs when using only part of the UWB spectrum which contains no spuriouses.

1.3 Research aim and objectives

The main aim of this work is to develop new chipless RFID tags with high encoding capacity embedded with a centre conductor and a novel ground plane resonators. Towards the achievement of this aim, four objectives must be accomplished:

1- To develop two resonant structures that create stop bands in the UWB spectrum. One type is placed on the centre conductor of a CPW transmission line, while the other is placed on the two sides of the ground plane.
2- To design a B2L chipless multiresonator circuit and investigate the mutual effect among the resonant structures.
3- To design a novel B3L coding technique and design multiple B3L chipless multiresonator circuits.
4- To validate the operation of the two types of multiresonator circuits (integrated with two UWB half-disc monopole antennas) through distance measurements.

1.4 Scope of research

This thesis reports on the design and development of new multiresonator-based chipless RFID tags to enhance the encoding capacity. The flow of this work is illustrated in Figure 1.1. The arrows represent the direction followed in this thesis to achieve the objectives; the subjects with the dashed-lines are referring to other research areas that are out of the scope of this work.

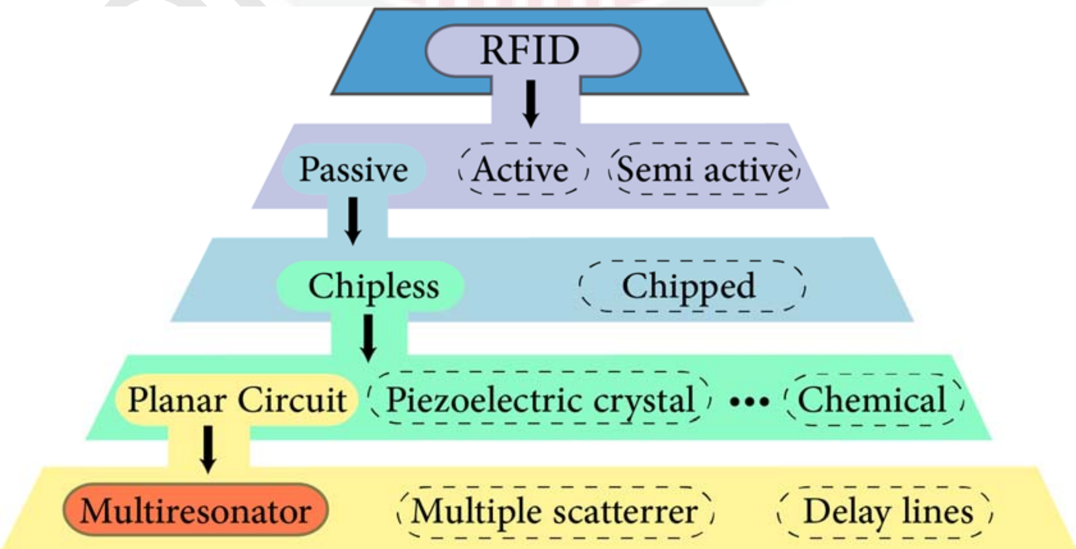

Figure 1.1 : Scope of research.

1.5 Organization of the thesis

The thesis is structured into five chapters; which are summarized as follows

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

Chapter 2 gives a thorough review of the existing chipless tags. Tags have been categorized as temporal tags and frequential tags and each tag are explained thoroughly. An attempt has been made to cover different existing encoding technique. Finally, a summary ends the chapter.

Chapter 3 presents the methodology of the research that consists of three stages. The first stage is the resonators stage, which contains the design steps of the resonators used in the final chipless radio frequency identification tag. The second is the multiresonator stages in which two types of multiresonators have been proposed. The last stage represents the integration between the tags antenna and multiresonators to perform distance measurements.

Chapter 4 presents the simulation and measurement results for the proposed chipless RFID multiresonators and tags.

In chapter 5 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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LIST OF PUBLICATIONS

O. J. Ibrahim, Alyani Ismail, Nor Kamariah and H. Adam, "Chipless Radio Frequency Identification Tag with High Encoding Capacity Based on Three Coding Levels," ARPN Journal of Engineering and Applied Sciences, vol. 10, no. 21, November 2015.

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