

CHAPTER 1

INTRODUCTION

1.1 CHIPLESS RFID

Radio frequency identification (RFID) is a wireless data communication technology widely used in various aspects in identification and tracking. In this era of communication, information, and technology, RFID is undergoing tremendous research and developments. It has the potential of replacing barcodes due to its information capacity, flexibility, reliability, and versatilities in application [1]. The unique identification, tracking, and tracing capabilities of RFID systems have the potential to be used in various fields like real-time asset monitoring, tracking of item and animals, and in sensor environments. However, the mass application of RFID is hindered due to its high price tag, and many ambitious projects had been killed due to the cost of chipped tags. The low-cost alternative of chipped RFID system is the printable chipless RFID that has the potential to penetrate mass markets for low-cost item tagging [2]. The chipless tag doesn't have any chips, and hence, the most burdens for signal and data processing go to the reader side. This introduces a set of new challenges and requirements for the chipless RFID reader that need to be addressed. This book comprises the new

advanced signal processing and tag detection methods that are being used in chipless RFID for identification and tracking of tags.

RFID is an evolving wireless technology for automatic identifications, access controls, asset tracking, security and surveillance, database management, inventory control, and logistics. A generic RFID system has two main components: a tag and a reader [3]. As shown in Figure 1.1, the reader sends an interrogating radio frequency (RF) signal to the tag. The interrogation signal comprises clock signal, data, and energy. In return, the tag responds with a unique identification code (data) to the reader. The reader processes the returned signal from the tag into a meaningful identification code. Some tags coupled with sensors can also provide data on surrounding environment such as temperature, pressure, moisture contents, acceleration, and location. The tags are classified into active, semi-active and passive tags based on their onboard power supplies. An active tag contains an onboard battery to energize the processing chip and to amplify signals. A semi-active tag also contains a battery, but the battery is used only to energize the chip, hence yields better longevity compared to an active tag. A passive tag does not have a battery. It scavenges power for its processing chip from the interrogating signal emitted by a reader; hence, it lasts forever. However, the processing power and reading distance are limited by the transmitted power (energy) of the reader. The middleware does the back-end processing, command, and control and interfacing with enterprise application as shown in Figure 1.1.

As mentioned previously, the main hindrance in mass deployment of RFID tags for low-cost item tagging is the cost of the tag. The cost of the tag mainly comes from the application-specific integrated circuit

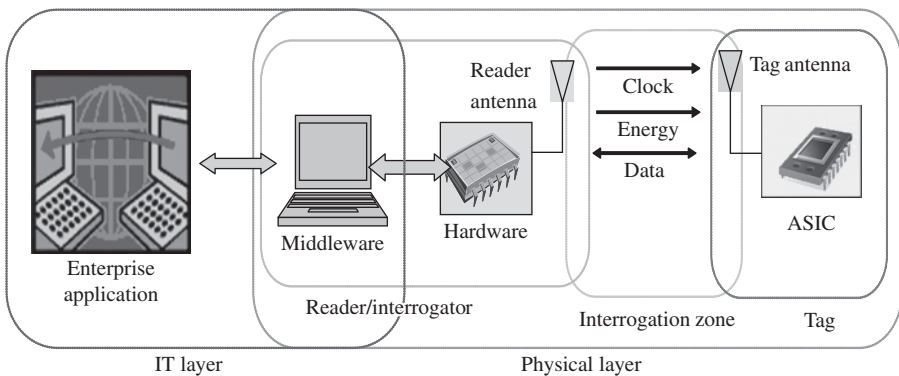


Figure 1.1 Architecture of conventional radio frequency identification system.

(ASIC) or the microchip of the tag. The removal of chip from the tag will lower the cost of tag to a great extent. This can be an excellent alternative for traditional barcodes, which suffer from several issues such as the following: (a) each barcode is individually read, (b) needs human intervention, (c) has less data handling capability, (d) soiled barcodes cannot be read, and (e) barcodes need line-of-sight operation. Despite these limitations, the low-cost benefit of the optical barcode makes it very attractive as it is printed almost without any extra cost. Therefore, there is a pressing need to remove the ASIC from the RFID tag to make it competitive in mass deployment. After removing the ASIC from the RFID tag, the tag can be printed on paper or polymer, and the cost will be less than a cent for each tag [4]. The IDTechEx research report [2] advocates that 60% of the total tag market will be occupied by the chipless tag if the tag can be made less than a cent. As most of the tasks for RFID tag are performed in the ASIC, it's not a trivial task to remove it from the tag. It needs tremendous investigation and investment in designing low-cost but robust passive microwave circuits and antennas using conductive ink on low-cost substrates. Additionally to these, obtaining high-fidelity response from low-cost lossy materials is very difficult [4]. In the interrogation and decoding aspects of the RFID system is the development of the RFID reader, which is capable to read the chipless RFID tag. Conventional methods of reading RFID tags are not implementable in reading chipless RFID tags. Therefore, dedicated chipless RFID tag readers need to be implemented [5]. This is the first book in this discipline that presents detailed aspects, challenges, and solutions for advanced signal processing for chipless RFID readers for detection, tracking, and anticollision.

The market of chipless RFID is emerging slowly, and the demand is increasing day by day. As forecasted by IDTechEx, the market volume of chipless RFID was less than \$5 million in 2009. However, this market will grow to approximately \$4 billion in 2019 [6, 7]. In contrast to 4–5 billion optical barcodes that are printed yearly, approximately 700 billion chipless tags will be sold in 2019. Therefore, a significant interest is growing in researchers for the development and implementation of low-cost chipless RFID systems. This book is presenting the advanced signal processing methods that are being used in chipless RFID system for detection, identification, and tracking, and collision avoidance.

The development of chipless RFID systems has already come a long way. Compared to early days, it has already in its second-generation development phase with more data capacity, reliability, and compliances

of some existing standards. RF-SAW tags got new standards, can be made smaller with higher data capacity, and currently are being sold in millions. Approximately 30 companies have been developing TFTC. TFTC targets HF (13.65MHz) band (60% of existing RFID market) and has the read–write capability [7].

In generation I, only a few chipless RFID tags, which were in the inception stage, were reported in the open literature. They include a capacitive gap coupled dipole array [8], a reactively loaded transmission line [9], a ladder network [10], and finally a piano and a Hilbert curve fractal resonators [11]. These tags were in prototype stage, and no further development in commercial grade was reported so far.

It is obvious that chipless RFID is a potential option for replacing barcodes and hence realizing the fact big industry players such as IBM, Xerox, Toshiba, Microsoft, HP, and new players such as Kavio and Inksure have been investing tremendously in the development of low-cost chipped and chipless RFID. Figure 1.2 shows the motivational factors in developing chipless RFID tags and reader systems. The data shown in the figure is approximated from two sources [6, 7]. Currently, the conventional chipped tags cost more than 10¢ if purchased in large

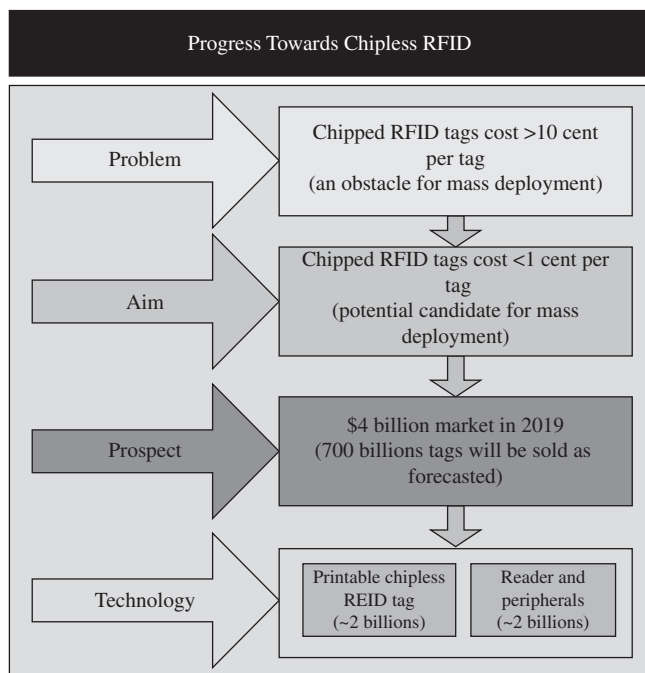


Figure 1.2 Prospect of chipless RFID technology.

quantities. This high tag price hinders mass deployment of RFID in low-cost item-level tagging. The goal is to develop sub-cent chipless tags that will augment the low-cost item-level tagging. The technological advancements in both the chipless tags and their readers and peripherals will create approximately \$4 bn market in 2019 [6, 7].

According to the prediction of www.MarketsandMarkets.com (accessed on June 9, 2012) [6], the revenue generated in global chipless RFID market is expected to reach \$3925 million in 2016 from \$1087 million in 2011, at an estimated combined annual growth rate of 29.3% from 2011 to 2016. The targeted market sectors for the chipless RFID include retail, supply chain management, access cards, airline luggage tagging, aged care and general healthcare, public transit, and library database management system. The author's group has been developing chipless RFID tag technologies targeting many of these sectors since 2004.

To the best of the author's knowledge, there is only one book so far by the same author group regarding the chipless RFID reader development [12]. The published book mainly focuses on the hardware development and implementation for chipless RFID tag reader. However, the background signal processing and identification have not been discussed in detail. This book focuses on the signal postprocessing for tag identification, tracking, noise mitigation, and multi-tag identification aspects. The author group and their chipless RFID research team has been working on the chipless RFID tag readers since 2004 [13]. Significant strides have been achieved to tag not only the polymer banknotes but also many low-cost items such as books, postage stamps, secured documents, bus tickets, and hanging cloth tags. The technology relies on encoding spectral signatures and decoding the amplitude and phase of the spectral signature [14]. The other methods are phase encoding of backscattered spectral signals [15] and time-domain delay lines [16]. So far, as many as more than twenty varieties of chipless RFID tags and five generations of readers are designed by this team. The proof of concept technology is being transferred to the banknote polymer and paper for low-cost item tagging. These tags have potential to coexist or replace trillions of optical barcodes printed each year. To this end, it is imperative to invest on low-cost conductive ink, high-resolution printing process, and characterization of laminates on which the tag will be printed. The design of a spectral signature-based tag needs to push in higher frequency bands to accommodate and increase the number of bits in the chipless tag to compete with the optical barcode. In this space, the reader design needs

to accommodate large reading distance and high-speed reading, multiple tag reading in close proximity, error correction coding, and anticollision protocols. Also, wide acceptance of RFID technology by consumers and businesses requires robust privacy and security protection [16, 17]. The book aims to address all these issues mentioned earlier to make the chipless RFID system a viable commercial product for mass deployment.

Figure 1.3 shows the salient features of a chipless RFID tag, and Figure 1.4 shows the burdens of a chipless RFID tag reader to meet the market demands. It is a highly challenging and interesting task to design a dedicated chipless RFID tag reader with all the requirements fulfilled as well as cost-effective. Figure 1.4 shows the chipless RFID system, which needs to address a whole spectrum of technical and regulatory requirements such as the number of data bits to be read and processed, operating frequencies, radiated (transmitted) power levels, and hence reading distance, mode of readings (time, frequency, or hybrid domain), compatibility with existing technological framework, simultaneous multiple tag reading, and resulting anticollision and security issues. All of these considerations will impact the development and commercialization of the new technology. IDTechEx [7] reports on the chipless RFID tag development by commercial entities and highlights the synergies to address all these issues to make the chipless RFID a commercially viable and competitive technology. The objective of the book is to address many significant issues and provide technical solutions of chipless RFID readers.

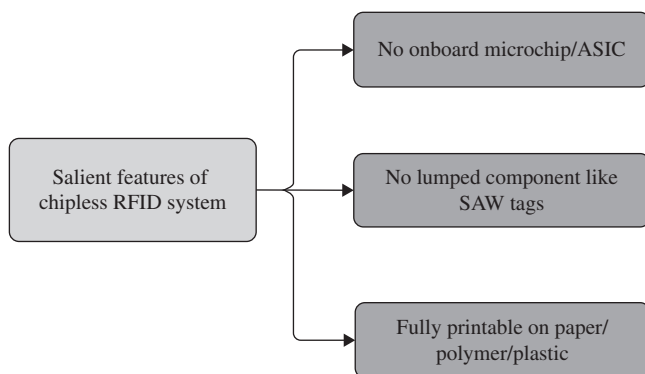


Figure 1.3 Salient features of chipless RFID tag (© 2010 Editor © Karmakar, N. C. Published 2010 by John Wiley & Sons, Ltd.).

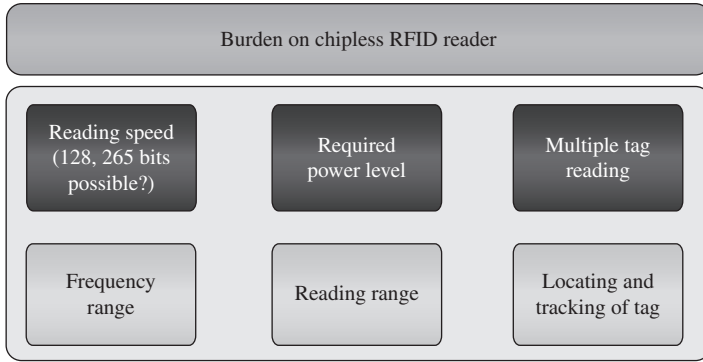


Figure 1.4 Design considerations for chipless RFID tag reader.

1.2 CHIPLESS RFID TAG READER

As advocated by IDTechEx [7], the chipless RFID tag readers and data processing software will cost similar to their chipped counterparts. The market segment of hardware and related middleware is more than the cost of tags used. Therefore, there are huge commercial potentials to invest in readers and related software development. However, there are no such resources on chipless RFID reader systems in the open literature as yet. This is the first initiative by the author to introduce the potential field in a combined and comprehensive body of literature. The book covers the following topics in the field in five sections:

1. Introduction to chipless RFID
2. Chipless RFID tag detection techniques
3. Noise mitigation for improving detection accuracy
4. Multi-tag identification and collision avoidance
5. Tag localization and tracking

Figure 1.5 shows the organization of the chapters in this book. The topics covered in each chapter are highlighted below:

Section 1: Detection and Denoising

Some fundamental system-level issues of the chipless RFID tag reader systems and their detection methods are presented in Chapters 2–5. In an efficient system, raw data obtained from the RF transceiver of the

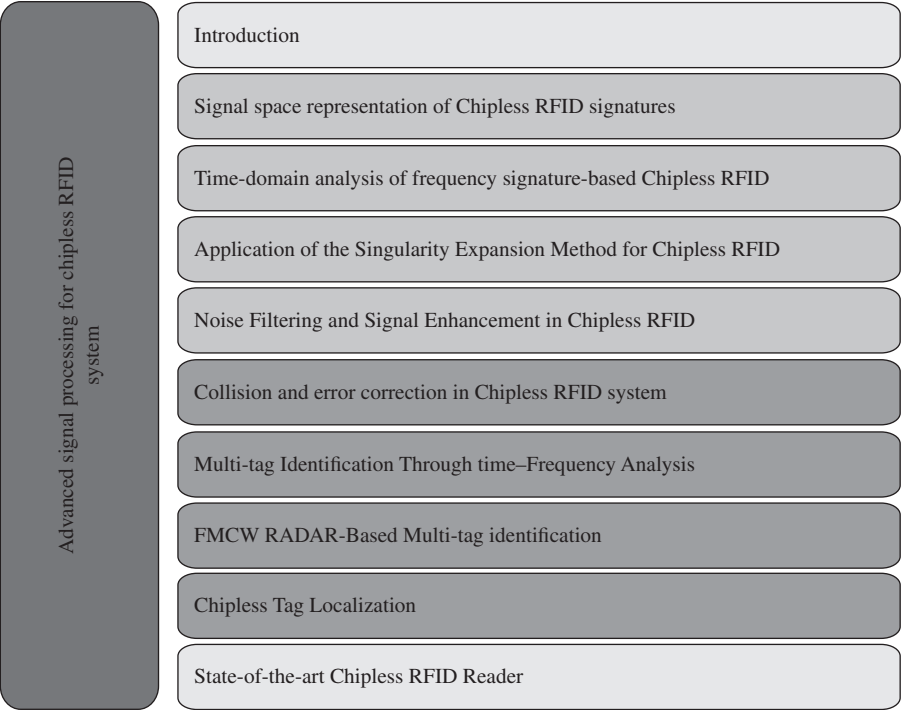


Figure 1.5 Organization of sections and chapters of chipless RFID systems.

chipless reader needs to be processed and denoised. In this aspect, a few new techniques are reported in this section. They are (i) signal space representation of chipless RFID signatures, (ii) detection of frequency signature-based chipless RFID using UWB impulse radio interrogation, (iii) singularity expansion method (SEM) for data extraction from chipless RFID, and finally (iv) noise reduction and filtering techniques used for the chipless RFID. These methods improve the efficacy and throughput of various types of reading processes. The following are the detailed descriptions of the chapters.

Chapter 2: Signal Space Representation of Chipless RFID Signatures

In this chapter, the decoding of information contained in a chipless RFID tag signature is realized using signal space representation technique. This method is commonly used in conventional digital communication systems. Therefore, this is a new approach to chipless RFID

detection. A different perspective on the detection of chipless RFID is presented where a mathematical model based on signal space representation is used. Here, the chipless RFID tag's signatures are visualized as signal points in a signal space (Euclidian space), which enables the detection of data bits contained in these signatures through conventional methods used in digital communications. It is shown that the proposed method has better performance compared to a threshold-based approach to detection.

Chapter 3: Time-Domain Analysis of Frequency Signature-Based Chipless RFID

This chapter presents the use of UWB impulse radio interrogation to remotely estimate the frequency signature of chipless RFID tags that are operating using the backscatter principle. Two types of frequency signature-based chipless RFID tags are investigated: (i) a multiresonator-loaded chipless RFID tag [14] and (ii) a multipatch-based chipless RFID tag [15]. Here, the received signal from a frequency signature-based chipless RFID tag is captured in the time domain. The spectral contents of the tag's returned echo signal are analyzed to identify the key components that make up the information-carrying signal. It is shown that the information-carrying portion of the signal is contained in the *antenna mode* of the backscattered signal, and the *structural mode* of the backscatter holds no information about the resonant features of the tag [18, 19]. The performance of the method is investigated under different tag positions. The theory of operation is validated using simulation, semianalytical methods, and experimental results.

Chapter 4: Singularity Expansion Method for Data Extraction for Chipless RFID

This chapter details the use of the SEM for extracting information from the chipless RFID tag. The theory of the SEM is reviewed, and its application to chipless RFID is explained. The SEM technique is used to characterize the response of an object that is subjected to a burst of high-energy electromagnetic (EM) radiation. Here, the transient response of an object that is excited by an impulse of EM energy is characterized using a set of poles and residues. Several works reported in literature that are based on the application of SEM for chipless RFID research are discussed.

Chapter 5: Denoising and Filtering Techniques for Chipless RFID

Backscatter received from chipless RFID tags are very weak and are affected by many detriments that make detection very challenging. These detriments include the additive thermal noise introduced by reader electronics, interfering echoes caused by clutter in the environment, and transient responses of receive and transmit antennas. The detection of weak signals from chipless RFID tags amidst these factors requires techniques to enhance the ratio of signal level to the interference and noise level. This chapter details some of the techniques reported in literature for detecting signals from chipless RFID that are contaminated by noise. Specifically, the use of wavelet transforms and prolate spheroidal wave functions for noise filtering is discussed.

Section 2: Multiple Access and Localization in Chipless RFID

The main motto of developing chipless RFID technology is to reduce the cost of the tag in sub-cent level and to facilitate mass deployment of the RFID technology for low-cost item-level tagging. Therefore, multiple access with collision avoidance techniques for proximity tags and subsequent signal integrity is a significant research. Unfortunately, the protocols dedicated for these purposes in the conventional chipped tag cannot be applied in chipless RFID tag scenarios. The reason behind this is that the chipless RFID tags do not contain an ASIC microchip capable of signal processing. Since the chipless tag is a fully printable microwave passive design and void of any intelligence, the processing for multiple access and signal integrity is done only in the chipless RFID tag reader. So far, little has been achieved in this field. In this book, three chapters are dedicated to address the issue and fill up the gap in the open literature. A comprehensive background and possible methods of multiple access and system integrity are presented. Chapters 6, 7, and 8 present linear block coding, time–frequency analysis, and finally frequency-modulated continuous wave (FMCW) radar for various chipless RFID tags. The detailed summaries of the chapters are presented below:

Chapter 6: Collision and Error Correction Protocols in Chipless RFID

Collision is an inherent problem in wireless communications. This chapter reviews the collision problem in both chipped and chipless RFID systems and summarizes the prevailing anticollision algorithms

to address the problem. Due to the uniqueness of chipless RFID system, the available collision avoidance methods are not applicable to the chipless RFID reader. Therefore, a collision avoidance method based on linear block coding for frequency-domain chipless RFID tags is discussed and some preliminary simulation results as the proof of concept are presented in the chapter.

Chapter 7: Multi-Tag Identification through Time–Frequency Analysis

Time–frequency analysis is an excellent tool for analyzing time-varying signals. It is widely used in radar signal processing. This chapter describes the potential application of time–frequency analysis, especially fractional Fourier transform (FrFT) in the chipless RFID system [20]. Instead of analyzing the collided response signal in the frequency domain, it is converted to time–frequency plane. FrFT compresses individual response signals to different regions in fractional plane. Afterward, windowing is used to separate them. The tag ID is determined from the spectrum of the separated signal. The validation of the algorithm has been carried out through simulation for different tag combinations.

Chapter 8: FMCW-Radar-Based Multi-Tag Identification

This chapter describes the application of FMCW-radar technique for localization, collision detection, and multiple access in the chipless RFID system. For localization, multiple antennas are placed around the tag to calculate the round-trip time-of-flight (RTOF) of response signal. Based on RTOF, trilateration localization technique is employed to localize the tag in two-dimensional plane. The signals from multiple tags are downconverted to intermediate frequency (IF) signal, and the spectrum is analyzed for collision detection and number of collided tag estimation. Afterward, each beat frequency signal corresponding to a tag is filtered out and analyzed for resonance information.

Chapter 9: Chipless Tag Localization

This chapter presents a localization method for chipless RFID tag. A short-duration ultra-wideband impulse radio (UWB-IR) signal interrogates the tags, and multiple receivers in the interrogation zone capture the backscattered signal from the tags. The received signals from the chipless tags are analyzed for the structural mode radar cross section

(RCS) to determine the relative ranges. Using the range information, Linear Least Square (LLS) method is employed for accurate localization of tagged items. The accuracy of localization method is analyzed by moving the chipless tag within a fixed interrogation zone. The analysis and results create a strong foundation for chipless RFID tags to be used in tracking and localization [21].

1.3 CONCLUSION

RFID is an emerging technology for automatic identification, tracking, and tracing of goods, animals, and personnel. In recent decades, the exponential growth of RFID market signifies its potentials in numerous applications. The advantageous features and operational flexibility of RFID have attracted many innovative application areas. Therefore, there is a need for tremendous development and open literature on RFID to report new results. However, the bottleneck of mass deployment of RFID technology is the cost of the tag and reading techniques and processes of the chipless tag. This is the first book in the field that covers comprehensively many significant aspects of chipless RFID reader architecture and signal processing.

This book project is an initiative to publish most recent results of research and development on the chipless RFID tag reader system. It aims to serve the needs for a broad spectrum of readers. The book has proposed a few novel detection techniques dedicated to radar array-based chipless RFID tags [14, 15]. Firstly, the signal space representation-based chipless RFID tag detection is used for the frequency signature-based chipless tags. Secondly, a UWB impulse radio detection technique is used to interrogate a frequency signature-based chipless tag. Thirdly, a SEM is used to separate poles and residues of the tag responses, and finally, various filtering techniques such as wavelet transformation and prolate spheroidal wave function are used for noise filtering. All these detection, denoising, and filtering techniques improve the efficacy of the reader.

The book has also proposed a few state-of-the-art multi-access and signal integrity protocols to improve the efficacy of the system in multiple tag reading scenarios. Comprehensive studies of anticollision protocols for the chipless RFID systems and various revolutionary techniques to improve the signal integrity have also been presented. It has also identified future challenges in the sphere. It also discusses the location finding of chipless tag and hence tracing and tracking of tagged items.

Finally, an industry approach to the integration of various systems of the chipless RFID reader technology—integration of physical layers, middleware, and enterprise software—is the main feature of the book. Overall, the book has become a one-stop shop for a broad spectrum of readers who have interests in the emerging chipless RFID and sensor technologies.

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