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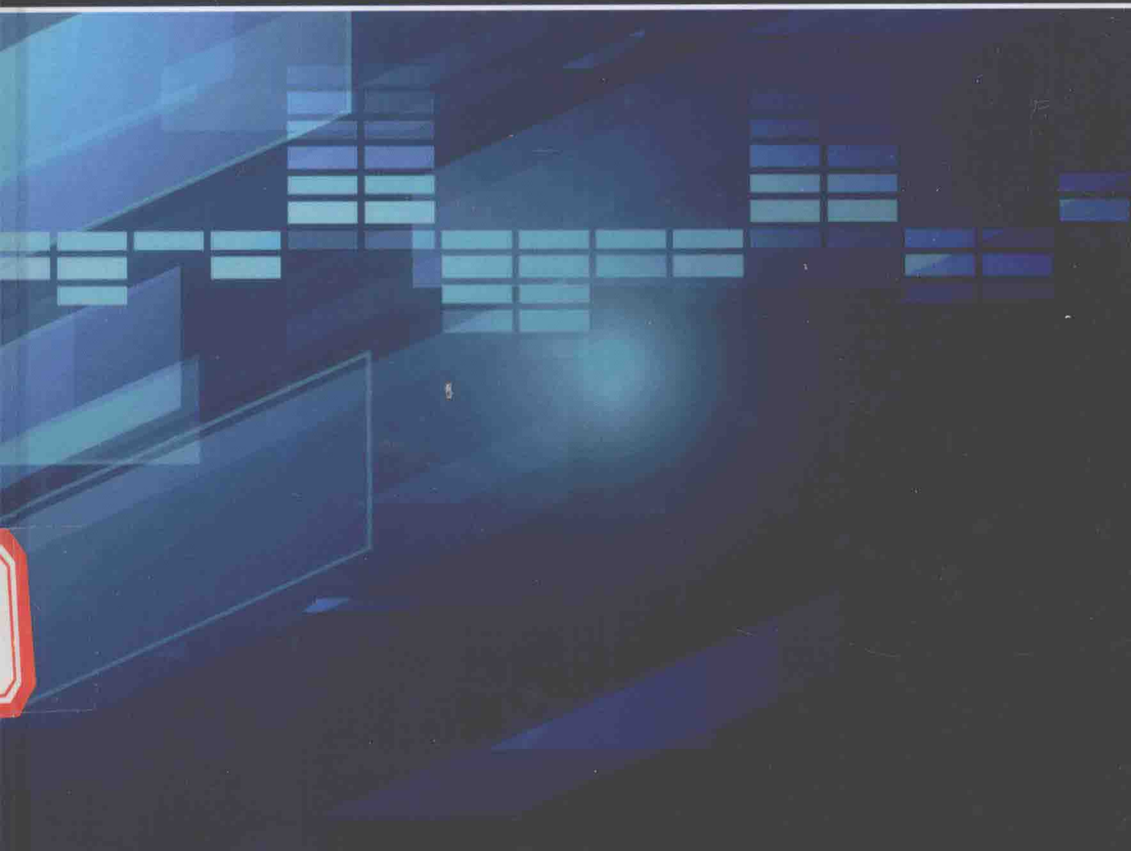

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PREFACE

Introduction to Radio Frequency Identification (RFID): RFID is a wireless modulation and demodulation technique for automatic identification of objects, tracking goods, smart logistics, and access control. RFID is a contactless, usually short-distance transmission and reception technique for unique ID data transfer from a tagged object to an interrogator (reader). The generic configuration of an RFID system comprises (i) an ID data-carrying tag, (ii) a reader, (iii) a middleware, and (iv) an enterprise application. The reader interrogates the tag with the RF signal, and the tag in return responds with an ID signal. Middleware controls the reader and processes the signal and finally feeds into enterprise application software in the IT layer for further processing. The RFID technology has the potential of replacing barcodes due to its large information-carrying capacity, flexibility in operation, and versatility of application [1]. Due to its unique identification, tracing, and tracking capabilities, RFID also gives value-added services incorporating various sensors for real-time monitoring of assets and public installations in many fields. However, the penetration of RFID technology is hindered due to its high price tag, and many ambitious projects have stalled due to the cost of the chips in the tags. Chipless RFID tags mitigate the cost issues and have the potential to penetrate mass markets for low-cost item tagging [2]. Due to its cost advantages and unique features, chipless RFID will dominate 60% of the total RFID market with a market value of $4 billion by 2019 [3]. Since the removal of the microchip causes a chipless tag to have no intelligence-processing capability, the signal processing is done only in the reader. Consequently, a fully new set of requirements and challenges need to be incorporated and addressed, respectively, in a chipless RFID tag reader. This book addresses the new reader architecture and signal processing techniques for reading various chipless RFID tags.

Recent Development of Chipless RFID Tags: IDTechEx (2009) [3] predicts that 60% of the total tag market will be occupied by the chipless tag if the tag can be made at a cost of less than a cent. However, removal of an application-specific integrated circuit (ASIC) from the tag is not a trivial task as it performs many RF signal and information-processing tasks. Intensive investigation and investment are required for the design of low cost but robust passive microwave circuits and antennas using low-conductivity ink on low-cost and lossy substrates. Some types of chipless RFID tags are made of microwave resonant structures using conductive ink. Obtaining high-fidelity (high-quality factor) responses from microwave passive circuits made of low-conductivity ink on low-cost and lossy materials is very difficult [4]. Great design flexibility is required to meet the benchmark of reliable and high-fidelity performance from these low-grade laminates and poor conductivity ink. This exercise has opened up a new discipline in microwave printing electronics in low-grade laminates [5].

The low-cost chipless tag will place new demands on the reader as new fields of applications open up. IDTechEx [3] predicts that, while optical barcodes are printed in only a few billions a year, close to one trillion (>700 billion) chipless RFIDs will be printed each year. The chipless RFID has unique features and much wider ranges of applications compared to optical barcodes. However, very little progress has been achieved in the development of the chipless RFID tag reader and its control software, because conventional methods of reading RFID tags are not implementable in chipless RFID tags. As for an example, handshaking protocol cannot be implemented in chipless RFID tags. Dedicated chipless RFID tag readers and middleware [6] need to be developed to read these tags reliably.

The development of chipless RFID has reached its second generation with more data capacity, reliability, and compliance to some existing standards. For example, RF-SAW tags have new standards, can be made smaller with higher data capacity, and currently are being sold in millions [7]. Approximately 30 companies have been developing TFTC tags. TFTC tags target the HF (13.65 MHz) frequency band (60% of existing RFID market) and have read–write capability [7]. However, neither RF-SAW nor TFTC is printable and could not reach sub-cent-level prices. In generation-1 of conductive ink-based fully printable chipless RFID tag development, few chipless RFID tags, which are in the inception stage, have been 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 are in prototype stage, and no further development to commercial grade has been reported to date. A comprehensive review of chipless RFID can be found in the author's most recent books [12].

Following 20 years of RF and microwave research experiences, the author has pioneered multi-bit chipless RFID research [13, 14]. For the last 10 years at Monash University, the author's research activities include numerous chipless tag and reader developments as follows.

At Monash University, the author's research group has developed a number of printable, multi-bit chipless tags featuring high data capacity. These tags can be categorized into two types: *retransmission based* and *backscattered based*. The *retransmission-based* tag, originally presented by Preradovic et al. [13], uses two orthogonally polarized wideband monopole antennas and a series of spiral resonators. The RFID reader sends a UWB signal to the tag, and the receiving antenna of the tag receives it, and then it passes through the microstrip transmission line. The gap-coupled spiral resonator-based stopband filters create attenuations and phase jumps in designated frequency bands, and this magnitude and phase-encoded signal is retransmitted back to the reader by the tag's transmitting antenna. The attenuation in the received signal due to the resonator encodes the data bits. In two Australian Research Council (ARC) Grants (DP0665523: *Chipless RFID for Barcode Replacement*, 2006–2008, and LP0989652: *Printable Multi-Bit Radio Frequency Identification for Banknotes*, 2009–2011), the author developed up to 128 data bits of chipless RFID with four slot-loaded monopole antennas and wideband feed networks [15]. This chipless tag is fully printable on polymer substrate.

Backscatter-Based Chipless Tag: Balbin et al. [13] have presented a multiantenna backscattered chipless tag. Here, only the resonator structure is present on the tag, and as no transmitter–receiver tag antenna exists, it is more compact than retransmission-type tags. The interrogation signal from a reader is backscattered by the tag. By analyzing this backscattered signal's attenuation at particular frequencies, the tag ID is decoded.

Monash University Chipless RFID Systems: Under various research grant schemes, the CI has developed various chipless RFID tag reader architectures and associated signal processing schemes. To date, four different varieties of chipless RFID tag readers have been developed for the 2.45, 4–8, and 22–26.5 GHz frequency bands. Feasibility studies of advanced level detection [13] and error correction algorithm have been developed.

As stated [2, 12–14], the author's group has developed four different varieties of chipless RFID tag readers in various frequency bands at 2.45, 4–8, and 22–26.5 GHz frequency bands. The readers comprised an RF transceiver section, a digital control section, and a middleware (control and processing). The reader transmitter comprises a swept frequency voltage-controlled oscillator (VCO) [6, 16]. The VCO is controlled by a tuning voltage that is generated by a digital-to-analog converter (DAC). Each frequency over the ultra-wideband (UWB) from 4 to 8 GHz is generated with a single tuning voltage from the DAC. In addition, the VCO has a finite settling time to generate a CW signal against its tuning voltage. Combining all these operational requirements and linearity of the devices, the UWB signal generation is a slow process (taking a few seconds to read a tag). To alleviate this problem and improve the reading speed, some corrective measures can be taken. They are (i) high-speed ADC and (ii) low settling time VCO. These two devices will be extremely expensive if available in the market. The reader cost will be very high to cater for the requirement specifications of the chipless RFID reader. In this regard, signal processing for advanced detection techniques alleviates the reading process in greater details. Also, the sensitivity of the reader architecture using dual antenna in bistatic radar configuration and I/Q modulation techniques can be greatly enhanced. Highly sensitive receiver design is imperative in detecting very weak backscattering signal from the chipless tag. With the presence of interferers and movement and the variable trajectory of the moving tags, this situation is worsened. In this regard, a highly sensitive UWB reader receiver needs to be designed. Designing such a receiver is not a trivial task where the power transmission is limited by UWB regulations. I\Q modulation in the receiver will improve the sensitivity to a greater magnitude.

Additional to this high-sensitivity receiver design, high-end digital board with a powerful algorithm will alleviate the reading process. The digital board serves as the centerpiece of the reader where data would be processed, and numerous control signals to the RF section of the reader would be generated. The digital board has a Joint Test Action Group (JTAG) port where a host PC can be connected to monitor, control, and reprogram the reader if necessary. In addition, it is also the host to the power supply circuit, which is used to generate the necessary supply voltages for most components of the reader. The digital board consists of (i) an FPGA board with ADC, (ii) a power supply circuit, and (iii) a DAC. High sampling rate A/D and D/A converters and an FPGA controller will augment the powerful capturing and processing of backscattering signals. The digital electronics and interface with a PC will accommodate custom-made powerful algorithm such as singular value decomposition for improved detection [17] and time–frequency analysis [18] for localization [19] and anticollision [20] of chipless RFID tags. All this control algorithm and signal processing software will be innovations in the field. The book has addressed these advanced level analog and digital designs of the chipless RFID reader.

In conventional chipped RFID system, established protocols are readily available for tag detection and collision avoidance. Reading hundreds of proximity tags with the flick of an eye is commonplace. However, reading multiple chipless RFID tags in close proximity is not demonstrated as yet. RFID middleware is an IT layer to process the captured data from a tag by a reader. Middleware applies filtering, formatting, or logic to tag data captured by a reader so that the data can be processed by a software application. For chipped RFID, there are established protocols for these tasks. However, in chipless RFID, tasks such as handshaking are not possible. Therefore, a completely new set of IT layers needs to be developed. Raw data obtained from a chipless tag need to be processed and denoised, and new techniques need to be developed. They are as follows: (i) signal space representation of chipless RFID signatures [21], (ii) detection of frequency signature-based chipless RFID using UWB impulse radio interrogation [22], (iii) a singularity expansion method for data extraction from chipless RFID [23], and finally (iv) noise reduction and filtering techniques [23, 24]. These methods will improve the efficacy and throughput of various types of reading processes. For example, in (i), tag signatures are visualized as signal points in a signal space (Euclidian space). (i) performs better than a threshold-based approach to detection. In (ii), the received signal from a chipless tag is processed in time domain, and information-carrying antenna mode RCS is processed to identify tags. In (iii), transient response from the tag is processed in poles and residues, and tag ID is detected. In (iv), wavelet transforms and prolate spheroidal wave functions are used for noise filtering. All these detection and filtering techniques are investigated in the context of the chipless RFID system, and the best approach to tag detection is integrated in the IT application layer.

The book aims to provide the reader with comprehensive information with the recent development of chipless RFID signal processing, software development algorithm, and protocols. To serve the goal of the book, the book features ten chapters in two sections. They offer in-depth descriptions of terminologies and concepts relevant to chipless RFID detection algorithm and anticollision protocols related to the chipless RFID reader system. The chapters of the book are organized into two distinct topics: (i) *Section 1:* Detection and Denoising and (ii) *Section 2:* Multiple Access and Localization. In chapter 1 chipless RFID fundamentals with a comprehensive overview are given. The physical layer development of reader architecture for conventional RFID systems is an established discipline. However, a physical layer implementation of the chipless RFID reader is a fully new domain of research. This author group has already published a book in this area [25]. This book focuses on the back-end postprocessing and detection algorithms for chipless RFID reader. Various detection algorithms for chipless RFID tags such as signal space representation, time-domain analysis, singularity expansion method for data extraction, and finally denoising and filtering techniques for frequency signature-based chipless RFID tags are presented in Chapters 2–5. Collision and error correction protocols, multi-tag identification through time–frequency analysis, FMCW-radar-based collision detection and multi-access for chipless RFID tags, and localization and tracking of tag are presented in Chapters 6–9. Finally, a state-of-the-art chipless RFID tag reader that incorporates all the physical and IT layer developments stated previously are presented in Chapter 10. The chapter has demonstrated how the reader can mitigate interferences and collisions keeping the data integrity in reading multiple tags in challenging environments such as retails, libraries, and warehouses.

In the book, utmost care has been paid to keep the sequential flow of information related to the chipless RFID reader architecture and signal processing. Hope that the book will serve as a good reference of chipless RFID systems and will pave the ways for further motivation and research in the field.

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