Preface

Radio Frequency Identification (RFID) is a wireless data capturing technique for automatic identification, tracking, security surveillance, logistic, and supply chain management. In the modern era RFID is one of the top ten technologies that have tremendously impacted society. RFID offers flexibility in operation and higher data capacity compared to that for optical barcodes. Therefore, RFID has gained momentum to be used in all possible applications. The most visible application of RFID is Electronic Article Surveillance (EAS) in superstores. Expensive items are tagged so that the unpaid items give warning signals at the entry and exit points of stores. EAS is a 1-bit tag, can only respond to *yes or no* situations. More expensive and high capacity tags carry much more useful information that an optical barcode can offer. Therefore, RFIDs offer not only flexibility and capacity but also item level tagging, tracking, and surveillance. However, the bottleneck of mass deployment of RFIDs for low cost item tagging is the cost of the tag. The cost of the conventional RFIDs has been decreasing day by day. However, there is a limit due to the silicon chip attached to the tag. These chips are application specific integrated circuits (ASICs) and the price of the chip can be tens of cents. To alleviate this cost problem, researchers are envisaging alternatives such as chipless tags. Thin film transistors (TFTs) on organic substrates and fully printable tags are the two commercially viable solutions that can compete with optical barcodes in mass implementations. If the cost of the tags can be reduced to less than a cent, the tags will find many potential applications. This book has addressed the most recent development of chipless and conventional tags—their systems and applications.

In 1995 when the author of this preface was a full-time PhD student at the University of Queensland (UQ), Brisbane, Australia, a few researchers were working on quasi-optical power combiners (QOPCs) in microwave and antenna research laboratories. In the 90s, QOPC was a hot topic. The development of an RFID or a radio frequency transponder was a topic of research. The RFID resembled the principle of harmonic mixing in space similar to that for QOPC. TO this author's memory, the researchers were referring to the seminal paper "Progress in Active Integrated Antennas and Their Applications" by Yongxi Qian and Tatsuo Itoh (1998). For the author, that was the first introduction to the technical details of a physical layer development of a transponder—a bow-tie antenna connected with a sub-harmonically pumped quasi-optical mixer (Stephan & Itoh, 1984). The UQ group designed effectively a passive RFID tag with a few lumped components. During the '90s, there was very little known about the RFID tags to common people. Toll roads, intelligent transportation systems, car immobilizers, and personalized door bells were in the inception phase and just had been introduced in other parts of the world. As for an example, European insurance companies enforced car immobilizers to protect cars from theft in the early 90s. After the author's PhD thesis in 1998, he moved to Nanyang Technological University in Singapore. There, he and his colleagues applied for a nationally strategic large research grant to the National Science and Technology Board (NSTB) of Singapore. The project was the development of a

micro-electromechanical-system identification tag (MEMSIT) in the mm-wave frequency band. The objective of the project is to develop a MEMSIT for smart cards. Professor Choi Look Law was the lead chief investigator and Dr. Karmakar was the chief investigator of RF Design. That was his formal introduction to research with the RFID. In the project they designed many interesting circuits and gears for the characterization of the designed circuits. The developed circuits were 24 GHz MEMS slot antennas, microstrip antenna arrays for RFID readers, filters, and their measuring jigs. Later on after the completion of the project, when Karmakar moved to Monash University, Melbourne, Australia in 2004, his CSIRO colleague Dr. Gerhard Swiegers invited him to apply for the Australian Research Council Discovery Grant on Chipless RFID. Dr. Sweigers had been developing a one-bit tag using printable pn-junction diode on a polymer substrate. He wanted to design a fully printable tag on a thin polymer substrate. Dr. Karmakar did comprehensive literature review on the topic and found that not much work was done on the chipless RFID tags at that time. A few developments on chipless RFIDs were: chemical nanostructures, radio frequency Surface Acoustic Wave (RF-SAW), and RFID tattoos. Except RF-SAW, the proposed and available chipless tags offered very short reading distance in the range of a few millimetres. The author found a gap in research on fully printable chipless tag using passive microwave circuits and antennas. The inception of chipless idea at Monash University germinated with a multi-resonator circuit and two antennas—one for transmission and one for reception. The proposed multi-resonator circuit is a planar wheel filter developed in 2001 (Karmakar & Padhi). The antennas are broadband fractal antennas to cover the multi-bit frequency signatures. Later on, a former PhD student of the author's defined this method as the *Re-transmission* based tag. The concepts of chipless tags have gained momentum from 2006 with the successful ARC Discovery grant *DP0665523*: *Chipless RFID for Barcode Replacement*. For the last five years three successful PhD completions with high distinction and more than one hundred referred journal and conference proceedings papers, book chapters, one edited book on *Smart Antennas For Radio Frequency Identification Systems* (2010) with Wiley InterScience, two Australian Provision Patents, two international patent applications and many regional ones on chipless RFIDs generated from the research work. The author's research group is highly cited on chipless RFIDs. This book is his first initiative to combine most recent works from prominent researchers in the field.

A few works on chipless tags are well cited: (i) Jalaly and Robertson (2005), (ii) McVay, Hoorfar, & Engheta (2006), (iii) Zhang, Tenhunen, Zheng (2006), (iv) Mukherjee (2007), and (v) Preradovic *et al.* (2007). Both frequency and time domain chipless tags were addressed in these papers. In the recent years many research teams from France, Japan, Germany, Korea, Spain, Thailand, and USA have been investigating chipless RFID tags and reader systems.

According to the respected research institute IDTechEx, chipless RFID tags will occupy more that 60% market share of RFID markets within a few years time if the tags can be made less than a cent (IDTechEx, 2009). The market of RFID technology surpassed $5bn in 2009 and is projected to be more than $25bn in 2018. The accelerated pace of RFID tags, middleware and reader development will address many technological challenges as well as provide many new solutions in printing techniques, algorithm and reader architectures. Anti-collision will also play an important role in mass deployments of chipless RFID technology in multi-faceted applications. Chipless RFID will change the culture of the way we do transactions in our businesses and livings. Like chipped RFIDs, chipless RFIDs have the capability to provide flexibility in operations with its salient features of non-line-of-sight (NLOS) and all-weather reading capability without much human intervention. It has the potential to replace trillions of optical barcodes printed each year. Therefore, many research activities on chipless RFID tags have been conducted not only in academia but also in industries. In this regard, printed electronics technologies shall play the vital role. Again according to the market analyses by IDTechEx, a few hundred industries are

engaged in printed electronics for identifications, tagging and telecommunications markets. As quoted by IDTechEx, "This organic and printed electronics is growing to become a $300 billion market and, in 2007 alone, many factories came on stream to make "post silicon" transistors, displays and solar cells using thin films and, increasingly, printing. Most of the action is taking place in East Asia, Europe and North America.....*There is also the prospect of replacing 5-10 trillion barcodes yearly with printed RFID that is more versatile, reliable and has a lower cost of ownership*" (Harrop, Reuter, & Das, 2009).

Every new technology goes through a cycle of developmental phases. From the inception of the technology and its conceptual development, many doubts, confusions and technical challenges hinder the progress of the development. Once these barriers are overcome, investors and funding bodies come forward to support the research and development activities. New applications and investment on returns motivate the end users to embrace the technology for growth and expansion of their businesses. Once the development reaches to the maturity, huge commercial implementation happens to all possible sectors. The deep penetration of the technology in mass market changes the business and transactions cultures. A few examples of such matured technologies are optical barcodes, emails, internets and mobilephones. The evolution of RFID has no exception. Starting from the Identification, Friend or Foe (IFF) in the World War II, the seminal paper by Stockman (1948) on RFID, and strong patronization of RFID technology by Walmart, US Department of Defence and similar consortia from the rest parts of the world, the RFID technology has grown to a mammoth technology. However, as the RFID finds applications in every wake of our lives and businesses, the challenges to cater the need for these applications are also enormous. The main challenge of mass deployment of RFID is the cost of the tag and reliable reading processes. Significant momentum has been gained on to develop various technologies to address the issues of the cost and reliable reading process of the RFID tag. The book presents the recent technical developments in chipless and conventional tags, their components and reading methods.

Significance of Chipless RFID Tags: Removal of application specific integrated circuits (ASIC) microchips from the conventional RFID tags can only provide viable commercial solution to mass deployment of RFID for low cost item tagging (Karmakar, 2010). The author's industry partner FE Technologies Pty Ltd., based in Geelong, Victoria, Australia has been marketing their Smart Library® (FeTech Group, 2010) RFID system in Australia and overseas. In February 2009 FE Technologies demonstrated their automated library database management system in front of a group of librarians from Monash University. Smart Library® comprises an automatic check out kiosk, a smart trolley and a magic wand as a handheld reader for inventory checking and misplaced items. Monash University's library possesses more than 3 million books to cater about 10,000 staff and 50,000 students in Australia and overseas campuses in Malaysia and South Africa. With a book tag costing 50¢ each; Monash University immediately needs to invest about $2m to implement their RFID system. While the existing optical barcodes for books cost less than 10¢ per unit and the existing library database management system based on the optical barcode works very well within the existing infrastructure and operational culture, there is a question always remains about the return on investment of more than $2m to implement the RFID system for the library database system for Monash University's libraries. This is a big question mark and an uphill battle to persuade the management to finance the implementation of RFID for the library. This is only one example. The huge potential of the RFID in such many other applications is hindered by the high price of the chipped tags. The viable solution is the low cost printable chipless RFID tag which will cost less than 1¢ and can complete with the optical barcode. The chipless RFID tags developed by the author's research group at Monash University are simple in concept. It is a fully printable passive microwave electronic circuit, which can be printed with conductive inks using an inkjet printer or other printing tools. Some conductive inks are invisible. Therefore, RFID tags can be made invisible. This technology

will open up a fully new spectrum of applications starting from Australian polymer banknotes, library books, apparels, shoes, and tagging of low cost and perishable items such as apples and bananas. Now imagine the market volume if low cost printed tags can be delivered and reliably read. To make the tag chipless and simple in operation, the bulk of the operation will be bestowed on the reader electronics. Certainly the reader should be built more powerful that the conventional chipped tag readers to process the returned echoes of the tags and encode the unique identification and location of the tag. The smart signal processing and detection algorithm and smart antennas in the reader will play a major role to improve the reading of the tags.

RFID is an emerging technology that has been going through various developmental phases in terms of technological developments and businesses (applications), the potential as well as the challenges are huge. As for the example of the implementation of the RFID in Monash University's Library above, the bottleneck is the cost of the tag and its mass deployment. The answer to the problem lies in the development of new materials and printing technologies which can appropriately address the problem and bring forth a sustainable solution in terms of economy and technological advancements. A full chapter is dedicated to the development of printing techniques, polymer substrate, and flexible design of chipless tags on the polymer using various printing techniques.

Where the tags become dumb, the reader should be smart. The smartness will come from the smart signal capturing capabilities from the dumb tags and the post-processing of the returned echoes which are the signals from the uniquely identifiable tags. Significant advancement has been made in the new design of RFID systems and detection techniques of RFID tags, discrimination of tagged items and protocols developed for wireless sensors network applied to RFID systems. The book includes a full section on these topics.

As an enabling technology, RFID encompasses multiple disciplines. Similar to radar technology, RFID is a multi-disciplinary technology which encompasses a variety of disciplines: (i) RF and microwave engineering, (ii) RF and digital integrated circuits, (iii) antenna design, and (iv) signal processing software and computer engineering. The latter encodes and decodes analog signals into meaningful codes for identification. According to Lai et al (2005), "The fact that RFID reading operation requires the combined interdisciplinary knowledge of RF circuits, antennas, propagation, scattering, system, middleware, server software, and business process engineering is so overwhelming that it is hard to find one single system integrator knowledgeable about them all. …. In view of the aforesaid situation, this present invention (RFID system) seeks to create and introduce novel technologies, namely redundant networked multimedia technology, auto-ranging technology, auto-planning technology, smart active antenna technology, plus novel RFID tag technology, to consolidate the knowledge of all these different disciplines into a comprehensive product family." The book has incorporated these multi-disciplinary contents in three different sections: (i) RFID antennas and Amplifiers, (ii) Chipless RFID Tags, and (iii) RFID System and Detection of RFID Tags.

Due to the flexibility and numerous advantages of RFID systems compared to barcodes and other identification systems available so far, RFIDs are now becoming a major player in retail sectors and government organisations. Patronization of the RFID technology by organisations such as Wal-Mart, K-Mart, the USA Department of Defense, Coles in Australia and similar consortia in Europe and Asia has accelerated the progress of RFID technology significantly in the new millennium. As a result, significant momentum in the research and development of RFID technology has developed within a short period of time. The RFID market has surpassed the billion dollar mark recently (Das & Harrop, 2006), and this growth is exponential, with diverse emerging applications in sectors including medicine and

health care, agriculture, livestock, logistics, postal deliveries, security and surveillance and retail chains. The book includes application in tracing systems on the integrity of pharmaceutical products, near field authentication, monitoring system for sleep apnoea diagnosis in wireless body sensor network (WBSN) using active RFID and MIMO technology, chipless RFID based temperature and partial discharge (PD) detection sensors and finally, wireless sensors network and their applications in RFIDs.

Today, RFID is being researched and investigated by both industry and academic scientists and engineers around the world. Recently, a consortium of the Canadian RFID industry has put a proposal to the Universities Commission on the education of fresh graduates with knowledge about RFID (GTA, 2007). The Massachusetts Institute of Technology (MIT) has founded the AUTO-ID centre to standardize RFID, thus enabling faster introduction of RFID into the mainstream of retail chain identification and asset management (McFarlane & Sheffi, 2003; Karkkainen, & Ala-Risku, 2003). The synergies of implementing and promoting RFID technology in all sectors of business and day to day life have overcome the boundaries of country, organisation, and discipline.

As a wireless system, RFID has undergone close scrutiny for reliability and security (EPCglobal, Inc., 2006). With the advent of new anti-collision and security protocols, efficient antennas and RF and microwave systems, these problems are being delineated and solved. Smart antennas have been playing a significant role in capacity and signal quality enhancement for wireless mobile communications, mobile ad-hoc networks and mobile satellite communications systems. Smart antennas are used in RFID readers where multiple antennas and associated signal processing units are easy to implement (Lai et al, 2005). Even multiple antennas are proposed in RFID tags to improve reading rate and accuracy (Ingram, 2003).

Besides the contributions from outside, the author's research group at Monash University have contributed significantly in the physical layer development of RFID reader architectures for chipped and chipless RFID tag systems, RFID smart antennas, wireless sensor network protocols for RFID, and anti-collision algorithm. The research group has been supported by the Australian Research Council's Discovery Project Grants *DP665523: Chipless RFID for Barcode Replacement* and *DP110105606: Electronically Controlled Phased Array Antenna for Universal UHF RFID Applications*; the Australian Research Council's Linkage Project Grants *LP0989652: Printable, Multi-Bit RFID for Banknotes*; *LP0776796: Radio Frequency Wireless Monitoring in Sleep Apnoea (particularly for paediatric patients)*; LP0669812*: Investigation into improved wireless communication for rural and regional Australia*; *LP0991435: Back-scatter based RFID system capable of reading multiple chipless tags for regional and suburban libraries*; and *LP0989355: Smart Information Management of Partial Discharge in Switchyards using Smart Antennas*; and finally, Victorian Department of Innovation, Industry & Regional Development (DIIRD) Grant: *Remote Sensing Alpine Vehicles Using Radio Frequency Identification (RFID) Technology* within the Department of Electrical and Computer Systems Engineering, Monash University from 2006 to date. The dedication of former postgraduate students Drs. Sushim Mukul Roy, Stevan Preradovic and Isaac Balbin and current research staff and PhD students under the author's supervision has brought the chipless RFID tag and reader system as the viable commercial products for Australian polymer banknotes, library database management systems, access cards, remote sensing of faulty power apparatuses in switchyards and the wireless monitoring of sleep apnoea patients. The RFID and smart sensor related research projects supported by Australian Research Council's Discovery and Linkage Projects and Victoria Government are worth approximately three million dollars. More than twenty researchers have been working in various aspects of these projects. The book contains six chapters on our research findings in the above research topics.

The dramatic growth of the RFID industry has created a huge market opportunity. Patronization from Wal-Mart alone has triggered their more than two thousand suppliers to implement RFID system for their products and services. The motto is to track the goods, items, and services from their manufacturing point until the boxes are crushed once the goods are sold. Thus industries can track every event in their logistics and supply chain management and make sound plan for efficient operations and business transactions. The RFID system providers are searching all possible technologies that can be implemented in the existing RFID system (Gen2 becomes a worldwide standard) that can be made cheap, can be implemented to provide high accuracy in multiple tags reading with minimum errors and extremely low false alarm rate, location finding of tags for inventory control and asset tracking. Employing smart information management system in the reader presents an elegant way to improve the performance of the RFID system. The book has covered many technical aspects of these requirements.

Deploying smart antennas in the reader architecture and network, smart antennas may bring outstanding improvement in throughput, high speed reading and position detection of tagged items. These facilities can be obtained with an efficient beamforming scheme and diversity techniques. Positioning of tagged items has many applications in industry thanks to the direction finding ability of the smart antennas. The RFID technology is moving in higher and higher frequencies to incorporate more data-bits. Frequency bands in upper microwave and mm-wave such as 5.8, 24, and 60 GHz are less occupied by conventional telecommunications technologies. Therefore, new developments in RFID (Ingram, 2003), and especially in chipless RFID are happening in these frequency bands. In the author's lab he and his colleagues are developing ultra-wide band (UWB) microwave and mm-wave chipless RFID tags, reader architectures and smart antennas. The book includes two chapters dedicated to a low side lobe microwave smart antenna design for RFID readers at 5.8 GHz and UWB chipless tags on thin polymer substrates from the author's research group. Besides these, UWB chipless RFID developments in Grenoble–INP of France and Georgia Institute of Technology of USA are also presented in the book.

Smart antennas can also be used in handheld RFID readers making the reading more efficient and long range. The beamforming and interference suppression abilities of the smart antenna make the reader capable to increase throughput. In a networked environment of the RFID readers where each reader represent a node, the smart antenna in a node with packet routing protocols, the direction finding and suppression of interference abilities from the neighboring nodes provides the optimum routing relaying between nodes. A chapter dedicated to smart sensor network protocols for RFID system is included in the book.

A MIMO wireless communication channel can be built by installing antenna arrays that provide uncorrelated signal outputs at both readers and tags. The MIMO system provides many number of channels with the number of antenna elements in both transmit and receive chains. The MIMO system enhances the channel capacity hence the throughput of the RFID reader. Even Multiple antennas are proposed in the RFID tags by pushing the operating frequency at 5.8 GHz frequency band to incorporate multiple antennas in a credit card size tag (Griffin & Durgin 2010). The benefit is the high speed tag reading and significant throughput improvement. MIMO also enhances the anti-collision capability and capturing effect of the tag when the reader reads multiple tags in close proximity. Antenna selection and channel estimation play an important part for throughput improvement of RFID system. A couple of chapters are dedicated to address the implementation issues of MIMO antennas in RFID system. The book includes a couple of chapters on anti-collision protocols for RFIDs.

The book aims to provide the reader with comprehensive information with the recent development of chipless and conventional RFID systems both in the physical layer development and the software algorithm and protocols. To serve the goal of the book, it features fourteen chapters authored by the

leading experts in both academia and industries. They offer in depth descriptions of terminologies and concepts relevant to the RFID components and systems—antennas related to the RFID, physical layer development including the printing techniques of chipless RFID tags, the system development and various detection techniques for both chipless and conventional tags, the security issues of chipped and chipless tags, development of chipless RFID tags, and reader system to address authentications.

The author has about fifteen books on RFIDs in his personal library collections. He continuously collects and reads books on RFIDs. These books are readily available from online book shops such as Amazon.com. Every scientific book publishers have a series of book on RFIDs and their applications in governance, pharmaceuticals, logistics, supply chain managements, retail, and original part manufacturing. These books mainly report specific applications, introduce fundamental issues, and gather information on RFIDs, specific technical details that are commonly available from other resources. This book aims to come out of the convention approach of reporting the technology. The book presents the most recent technological development from renowned researchers and scientists from academia and industries. Therefore, a comprehensive coverage of definitions of important terms of RFID systems and how the RFID technology is evolving into a new phase of development can be found in the book. The book covers the state-of-the-art development on RFID in recent years. Seven scientists from five large to medium size industries including Microsoft Research Center, USA, Securency Intl. Pty. Ltd, Australia, Unique Microwave Design, Australia, Tata Consultancy Services, India, and fifty academic researchers from Australia, Chain, France, Italy, Mexico, Taiwan, Ukraine, UK, and USA, have contributed chapters in the book. Therefore, the book not only delivers the emerging development in a total package of chipless and conventional RFIDs, but also provides diversities in topics. The rich contents of the book will benefit the RFID technologist, planners, policy makers, educators, researchers, and students. Many universities and tertiary educational institutions teach RFID in certificate, diploma, undergraduate, and graduate levels. This book can be served as a textbook or a companion book and a very useful reference for students and researchers in all levels.

The book can be best used as a complete reference guide if an expert wants to design a complete RFID system using either a chipless or a conventional radio frequency identification system. The beneficiaries of the book are the specialists of specific disciplines such as antennas and RF designs for both tags and readers, chipless RFID tag designs, system aspects on detection, discrimination, sensor network protocols, security issues, and design of security protocols and systems. The readers of the book can maximize their knowledge on a systematic middleware and enterprise software planning, anti-collision protocol designs for multiple tag and reader scenarios such as warehouses, manufacturing plants, supply chain managements, and pharmaceuticals. If some experts and executives want to implement RFID in a particular system in their organizations, they are encouraged to read the last few chapters on design and implementation of RFIDs and RFID based sensors in various emerging applications. Each section is rich with new information and research results to cater for the needs of specialists in system as well as specific components of the RFID.

In the book, utmost care has been paid to keep the sequential flow of information related to the various aspects as mentioned above on the RFID system and its emerging development. The hope is that the book will serve as a good reference of RFID and will pave the ways for further motivation and research in the field.

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