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Monday, Apr 27

10:30 - 12:00

1A: Tag Circuits

Low-power Energy Supply Circuit for Passive RFID Transponder **01**

Hong-Zhou Tan (Sun Yat-Sen University, P.R. China); Hu Jian-Guo (Sun Yat-Sen University, P.R. China)
This paper addresses low power design approaches for passive RFID transponder. It proposes a novel low power energy supply circuit, which includes amplitude limiter, rectifier circuit, analog power supply circuit, digital power supply circuit and high voltage power supply circuit. The simulation and measurement results show that proposed voltage rectifier, amplitude limiter and power supply circuit with low voltage checking can provide stable power supply voltage with a small input power and high conversion efficiency. It has been applied to a passive transponder chip design, which was fabricated successfully based on 0.35 μm CMOS process.

A Low-Power Dual-Clock Strategy for Digital Circuits of EPC Gen2 RFID tag **07**

Qiasi Luo (University of Science and Technology of China, P.R. China); Li Guo (University of Science and Technology of China, P.R. China); Qing Li (State Key Laboratory of ASIC & System, Fudan University, P.R. China); Gang Zhang (Fudan University, P.R. China); Junyu Wang (Fudan University, P.R. China)
Power consumption is critical to the performance of EPC Gen2 RFID tags. System clock frequency of tags should be as low as possible to reduce the power consumption and still conform to the protocol. This paper analyses the impact of different clock strategies on digital circuits of EPC Gen2 tag. An error shift approach is proposed to reduce the backscatter link frequency (BLF) errors. A dual-clock strategy with both 1.28 and 2.56 MHz clocks for the digital circuits is developed.

Compared with the 1.92 MHz unitary-clock strategy, the dual-clock strategy offers larger decoding margins and BLF margins, consumes 5.66% to 9.44% less power estimated in CMOS 0.18μm technologies, and fully conforms to the EPC Gen2 protocol as well.

Wenyi Che (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Yuqing Yang (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Conghui Xu (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Na Yan (State Key Lab of ASIC & System, Fudan University, P.R. China); Qiang Li (State Key Laboratory of ASIC & System, Auto-ID Laboratory, Fudan University, P.R. China); Hao Min (State Key Lab of ASIC & System, Fudan University, P.R. China)

An EPCglobal Gen2 compatible semi-passive (or be called battery-assisted passive) tag is proposed. The transmission link is studied to optimize the power distribution in a backscatter RFID system. For long read range consideration, design targets for low power tag are given. The tag chip is implemented in SMIC 0.18 μm standard CMOS technology. A high efficiency AC-DC charge pump serves as a rectifier. A low power wake-up circuit detects the input energy level and controls a button cell battery to supply the chip. The equivalent tag power is 230 nW by measurement.

Stefan Gruber (Infineon Technologies Austria AG, Austria); Hannes Reinisch (Graz University of Technology, Austria); Wolfgang Pribyl (Graz University of Technology, Austria); Gerald Holweg (Senior Manager, Austria)

The sensitivity parameter is one of the most important parameters characterizing UHF RFID tags. This paper presents methods for measuring this parameter. It focuses on the use of non-expensive laboratory equipment. Nevertheless, the proposed methods provide accurate results. Losses and behavior of the setup are calculated and described in detail. Single-ended and differential structures are distinguished and handled separately. Since the antenna plays an important role, its behavior is also considered. Still, the measurement setup is contact based.

1B: Measurement and Simulation Methods

Daniel Arnitz (Graz University of Technology, Austria); Ulrich Muehlmann (NXP Semiconductors, Austria); Thomas Gigl (Graz University of Technology, Austria); Klaus Witrisal (Graz University of Technology, Austria)

A chip manufacturing process requires extensive support of CAD-tools in order to predict the behavior of the embedded circuitry and to ensure the intended system functionality. Past experience shows that the overall performance of UHF RFID systems is mainly limited by multipath propagation and detuning. In this context, system-level simulations are vital to assess the overall performance and improve the embedded circuit. We present a simulator framework capable of handling chip-level tag models, fading MIMO radio channels, and interrogator building blocks on signal level. It is based on highly flexible behavioral tag-models instead of highly accurate but static ASIC models. In contrast to other UHF RFID simulators, it is explicitly designed to handle wideband signals, fading channels, nonlinearities, and detuning effects. The simulator is currently used to develop and evaluate the performance of ranging and realtime channel estimation systems. The presented results emphasize the feasibility of our framework in the evaluation of a range estimation approach between a standard UHF RFID transponder and an interrogator.

Holger Arthaber (Vienna University of Technology, Austria); Christian Schuberth (Vienna University of Technology, Austria)

This paper introduces a simple and inexpensive approach for emulating recorded radio frequency identification (RFID) link scenarios in the lab. This allows developing and testing of RFID systems, improving their performance... under perfectly reproducible conditions. Hence, it becomes possible to precisely compare the performance of different reader settings (data rate, modulation, arbitration mode...) or to compare different readers and/or tags. This includes statistical analysis of the performance as well. The proposed setup further enables statistical analysis of the results as the emulation of a certain link scenario can be played back arbitrary often. This work discusses the channel emulation for an 815/915 MHz RFID system: The recording of scenarios, the 'connectorization' of RFID-tags, and the channel emulator itself. Finally, exemplary test results of a commercial RFID reader connected to the emulator are presented.

Christoph Angerer (Vienna University of Technology, Austria); Robert Langwieser (Vienna University of Technology, Austria)

Today’s RFID systems are dependent on a wide range of different parameters that influence the overall performance. Such parameters can for example be the selected data rate, encoding scheme, modulation setting, transmit power or different

hardware configurations, like one or two antenna scenarios. Furthermore, it is often desired to optimise several performance goals, like read out range, read out quality, throughput, etc, which are often contradicting each other. In order to achieve a desired performance of an RFID system, it is essential to understand the influences of the single parameters of interest and their interconnection. Due to the multitude, wide range and interdependencies of influencing factors, this however is a complex task. Simulations offer insights in these relations but rely on the correct modeling of the influence of- and between the parameters. With our set-up prototyping system for RFID, we are able to flexibly and accurately explore the influence and interconnection of such parameters in a wide range on a basis of real time measurements.

Read Range Measurements of UHF RFID Transponders in Mobile Anechoic Chamber **48**

Wolfram Strauss (Fraunhofer Institute for Integrated Circuits, Germany)
This paper presents a novel and simple method to determine the read ranges of radio frequency identification (RFID) transponders. Range tests in a well defined and accurate stationary anechoic chamber (SC) are awkward and expensive. An extendible mobile anechoic chamber (MC) to produce a large number of repeatable range measurements with minimal effort is proposed. A mobile chamber suitable to reside in our laboratories was designed and built. MC measurements were crosschecked with SC measurements of label transponders. Reading ranges for a number of commercially available metal mount tags, so far not publicly available, were derived. Metal transponders are 3D objects leading to more constraints in applications than labels. Therefore range densities, i.e., reading range per area or volume of the tag, as novel key figures were introduced to make tags more comparable and to determine the optimal transponder for a given use case. The current results are suitable to serve as a relative measure to compare transponders.

1C: Healthcare (Special Session)

Chair: J. Schmidt (Infineon); Chair: Joerg Schmidt (Infineon, Germany)
Talks:
Reliable and secure identification, management and tracing of specimens, Joachim Gerstel, joint analytical systems (jas),
RFID in Healthcare - A Multidiscplinary Perspective, MD Suraj Kapa, Mayo Clinic, Rochester, MN
Tracking of medical implants - from a technical perspective, N.N., Magellan Technology
Panel:
joint analytical systems (jas), Schreiner LogiData, UPM Raflatac, tagstar systems, Mayo Clinic (Rochester, MN), KSW Microtec, RFID in Healthcare Consortium, Magellan Technology, FEIG electronic
Abstract: The RFID market is continuously in motion. New application possibilities and new requirements determine the growth of this technology. Especially the healthcare segment and the pharmaceutical chain have been pointed out as one of the significant growth factors for RFID applications in the past. Unfortunately many projects and applications have been lagging behind expectations. Recommendations from the FDA have lost of its momentum and California has postponed their activities targeting ePedigree. Nevertheless this technology could add value and create significant benefits for the healthcare market – even if these applications will not address the mass market. We will see a slower but continuous growth for RFID in this area. This session will emphasize on the newest trends and current developments regarding the healthcare and pharmaceutical market – technology issues are highlighted just as concrete running applications. The session will show the different opportunities in using different solutions for special applications.

13:00-15:00 (1:30 PM - 3:00 PM)

2A: Protocol Part I

ALOHA Algorithm considering the Slot Duration Difference in RFID system **56**

Liu Dan (Fudan University,China, P.R. China); Zhongxiang Wang (Fudan University,China, P.R. China); Hao Min (State Key Lab of ASIC & System, Fudan University, P.R. China); Junyu Wang (Fudan Universitzy, P.R. China)
when multiple RFID tag identification is becoming a commonplace, the anti-collision technology for multiple RFID tag environment has drawn mounting research interest in the RFID domain. Many published Aloha-based algorithms, assuming that all the slots have the same duration, tend to increase the number of successful slots by tag estimation and dynamic frame scheduling, and thus improve the system efficiency (the ratio of successful slots to all slots in each frame), which is limited by 1/e according to the theory of Probability. Whereas, in this paper, the effect of the empty slots and collided slots is analyzed and two novel methods based on the parameters of EPC Gen2 protocol, BIS and Collision Detection, are proposed, to improve the RFID system efficiency by reducing the cost of the none successful slots other than the successful slots. Moreover, a new approach to evaluate the system efficiency for multiple tag identification, taking consideration of the duration difference of the slots, is presented. According to the simulation and test results, the proposed methods, BIS and Collision Detection, can improve the system throughput by 120% and 30~40% respectively.

Reliable Identification of RFID Tags Using Multiple Independent Reader Sessions **64**

Rasmus Jacobsen (Aalborg University, Denmark); Karsten Nielsen (Aalborg University, Denmark); Petar Popovski

(Aalborg University, Denmark); Torben Larsen (Aalborg University, Denmark)
Radio Frequency Identification (RFID) systems are gaining momentum in various applications of logistics, inventory, etc. A generic problem in such systems is to ensure that the RFID readers can reliably read a set of RFID tags, such that the probability of missing tags stays below an acceptable value. A tag may be missing (left unread) due to errors in the communication link towards the reader e.g. due to obstacles in the radio path. The present paper proposes techniques that use multiple reader sessions, during which the system of readers obtains a running estimate of the probability to have at least one tag missing. Based on such an estimate, it is decided whether an additional reader session is required. Two methods are proposed, they rely on the statistical independence of the tag reading errors across different reader sessions, which is a plausible assumption when e.g. each reader session is executed on different readers. The first method uses statistical relationships that are valid when the reader sessions are independent. The second method is obtained by modifying an existing capture-recapture estimator. The results show that, when the reader sessions are independent, the proposed mechanisms provide a good approximation to the probability of missing tags, such that the number of reader sessions made, meets the target specification. If the assumption of independence is violated, the estimators are still useful, but they should be corrected by a margin of additional reader sessions to ensure that the target probability of missing tags is met.

Björn Nilsson (Halmstad University, Sweden); Lars Bengtsson (Chalmers University, Sweden); Bertil Svensson (Halmstad University, Sweden)
Active Radio Frequency Identification (A-RFID) is a technology where the tags (transponders) carry an on-board energy source for powering the radio, processor circuits, and sensors. Besides offering longer working distance between RFID-reader and tag than passive RFID, this also enables the tags to do sensor measurements, calculations and storage even when no RFID-reader is in the vicinity of the tags. In this paper we introduce a medium access data communication protocol which dynamically adjusts its back-off algorithm to best suit the actual active RFID application at hand. Based on a simulation study of the effect on tag energy cost, readout delay, and message throughput incurred by some typical back-off algorithms in a CSMA/CA (Carrier Sense Multiple Access / Collision Avoidance) A-RFID protocol, we conclude that by dynamic tuning of the initial contention window size and back-off interval coefficient, tag energy consumption and read-out delay can be significantly lowered. We also present specific guidelines on how parameters should be selected under various application constraints (viz. maximum readout delay; and the number of tags passing).

Matthew Trotter (Georgia Institute of Technology, USA); Gregory Durgin (Georgia Tech, USA); Joshua Griffin (Georgia Institute of Technology, USA)
A major limitation in backscatter radio applications such as passive sensing and RFID is the read range from the reader to tag, which is limited by the power available to the tag. RFID system cost can be decreased by increasing the read range, which reduces the number of readers needed. The Power Optimized Waveform (POW) is a new type of multiple-tone carrier that is designed to improve the read range and power efficiency of charge pump-based passive tags. This paper presents the POW concept; its effects on existing class 1 EPC, generation 2 RFID systems; and several example POWs.

2B: Sensors

Yann Têtu (CEA-Leti/Minatec, France); Iiro Jantunen (Helsinki University of Technology, Finland); Bertrand Gomez (CEA-Leti/Minatec, France); Stephanie Robinet (CEA-Leti/Minatec, France)
A 2.45GHz passive RFID tag including a digital pressure sensor and its use in a mobile-phone-centric architecture for sensor networks are described. The combination of a low-cost remote-powered sensor tag and an open architecture makes possible a variety of ambient intelligence applications. The tag gathers power from the ISM band at 2.45GHz and wireless pressure measurement is demonstrated at a distance of 42 cm with 0.5 W EIRP transmission power and 110 cm with 4 W. The sensor is able to carry out pressure measurement with a 12-bit-resolution and a 100Hz reading frequency.

Rahul Bhattacharyya (Massachusetts Institute of Technology, USA); Christian Floerkemeier (MIT, USA); Sanjay Sarma (MIT Auto-ID Center, USA)
Displacements can be used as indicators of structural health and are measured by commercially available sensors that need to be accurate and cost effective. In this paper, we examine a technique to utilize a UHF RFID tag antenna as a displacement sensor by mapping structural deformation to a change in RFID tag characteristics. We evaluate how changes in two different parameters, a) tag backscatter power and b) minimum reader transmit power required for RFID chip activation, can be mapped to structural deformation. The theoretical principles of sensor development are first discussed followed by a presentation of the results of experimentation. It is demonstrated that the sensor is sensitive to displacements for a dynamic range of 40 mm.

A Capacitive Touch Interface for Passive RFID Tags 103

Alanson Sample (University of Washington, USA); Daniel Yeager (University of Washington, USA); Joshua Smith (Intel Research Seattle, USA)

This paper presents a novel method for incorporating a capacitive touch interface into existing passive RFID tag architecture without additional parts or changes to the manufacturing process. Our approach is to make the tag's antenna a dual-function element in which the antenna simultaneously acts as both a low frequency capacitance sensor and also as an RF antenna. To show the feasibility of our approach, we have prototyped a passive UHF tag with embedded capacitive sensor using our WISP platform and report on its sensing measurements. Finally, we describe how it can be used for touch interfaces, as well as other user applications with the addition of a LED for user feedback.

SAW RFID Spread Spectrum OFC and TDM Technology 110

John Pavlina (University of Central Florida, USA); Donald Malocha (University of Central Florida, USA)

SAW based sensors can offer wireless, passive operation over numerous environments, and various device embodiments are used for retrieval of the sensed data. SAW has many unique advantages over possible competing technologies, including the following characteristics: passive, radiation hard?, operable over wide temperature ranges, small, rugged, inexpensive, and identifiable. In a multi-sensory environment, it is necessary both to identify the sensor and retrieve the sensed information. The OFC SAW technology approach has been funded by NASA for possible inclusion in ground, space flight, and space exploration sensor applications. The purpose of this paper is to present the concept of encoding SAW-based sensors for use in a multiple sensor environment. The emphasis will be on orthogonal frequency coded (OFC) devices with a form time division multiplexing (TDM) overlaid on them. It will be is shown that in addition to the benefits of OFC such as enhanced processing gain and lower interrogation power spectral density (PSD), the TDM allows for a decrease in overlapping energy and therefore a decrease in intersensory collisions which are shown to cause peak ambiguity. This approach should be applicable to many different SAW based sensors: temperature, pressure, liquid, gas, etc. Measured device results are presented and compared with coupling of modes (COM) model predictions to demonstrate performance. This paper will discuss the use of SAW OFC in a temperature sensor application. Devices are then used in computer-simulated transceiver design, and the results of a possible sensor system are discussed.

2C: Tag and Reader Testing (Special Session)

Chair: Daniel Deavours (Kansas University)

Talks:

Tag Measurement Principles, Pavel Nikitin, Intermec

Tag Measurement Approaches, Jukka Voutilainen, Voyantic

Reader Performance Measurements, Jin Mitsugi, Auto-ID Labs Japan

Panel: Invited speakers

Abstract: Tag and reader testing represents an important topic in the early phase of many RFID projects. Test methodologies have evolved significantly in recent years. This session will analyze the current state of the art in RFID tag and reader testing and discuss future trends.

15:30-17:00 (3:30 PM - 5:00 PM)

3A: Protocol Part II

Effect of Gen 2 Protocol Parameters on RFID Tag Performance 117

Pavel Nikitin (Intermec Technologies, USA); Kodukula Rao (Intermec Technologies, USA)

In this paper, we analyze the effect of Gen2 protocol parameters on RFID tag performance (tag sensitivity and backscatter efficiency). We describe our measurement methodology and perform characterization of several tags with different latest Gen2 ICs available on the market (Monza, UCODE, and Higgs families). We present experimental data and draw conclusions on how some of the protocol parameters (such as pulsewidth) affect the tag performance in forward and reverse links.

Evaluation of ISO 18000-6C Artifacts 123

Nikhil Ayer (University of Texas at Arlington, USA); Daniel Engels (University of Texas at Arlington, USA)

In this paper, we have evaluated the ISO 18000-6 Type-C protocol also known as EPC Class-1 Generation-2 RFID protocol parameters, on the performance of the RFID system. Tari, operating frequency, pulse width and modulation index are evaluated in the protocol at the constant transmitted power. The experiments were designed to eliminate the effects of the tag's antenna design. All the experiments are conducted in the anechoic chamber. The study shows that the slowest tari with half duty cycle, and the higher modulation index receives maximum power from the tag and hence longer reading distance. The fastest tari with the half duty cycle and higher modulation index has the fastest read rate. The Tag respond with the Tari as small as 5usec which provides a 5% read rate increase compared to the fastest Tari requested in the protocol.

3B: Localization & Active Tags

A Novel Localization Scheme for Passive RFID Tags; Communication Range Recognition (CRR) 163

Tomotaka Wada (Kansai University, Japan); Norie Uchitomi (Kansai University, Japan); Yuki Ota (Kansai University, Japan); Toshihiro Hori (Kansai University, Japan); Kouichi Mutsuura (Shinshu University, Japan); Hiromi Okada (Kansai University, Japan)

This paper focuses on the localization technology of passive RFID (Radio Frequency IDentification) tags. By this technology, we will be able to detect some target, to get information on it, and to find the position and the distance of it. This paper proposes a novel scheme named Communication Range Recognition (CRR) in order to localize RFID tags effectively. This scheme finds the edges of the communication range of the RFID reader antenna when its position is moving by the robot appropriately. We evaluate the performance of the estimated position error through numerous experiments. We show that our proposed scheme can reduce the moving distance of the RFID reader without degrading the accuracy of localization in comparison with the conventional schemes.

Verification Methodology for Battery Lifetime Requirements of Higher Class UHF RFID Tags 170

Christoph Trummer (Graz University of Technology, Austria); Christoph Kirchsteiger (Graz, University of Technology, Austria); Alex Janek (Graz, University of Technology, Austria); Christian Steger (Graz University of Technology, Austria); Reinhold Weiss (Graz University of Technology, Austria); Markus Pistauer (CISC Semiconductor Design+Consulting GmbH, Austria); Damian Dalton (Neosera Systems Ltd., Ireland)

Today's higher class tags usually are powered by batteries. The battery's capacity and the application's power demand influence the operational lifetime of the tag. Therefore, the designated application and lifetime requirement have to be kept in mind when designing a higher class tag. Moreover, the lifetime requirement needs to be verified in order to ensure the application will be successful. However, verification of the lifetime requirement is usually a very complex task. A verification environment for the application and its lifetime requirement needs to be created manually. After simulation with a battery model the results can be compared to the requirements document. Due to the complex and time-consuming nature of verification this often results in later time-to-market and increasing costs. In this work we present a novel, highly automated methodology to verify battery lifetime requirements. From the requirements document of the higher class UHF RFID tag a verification environment is created automatically. After power estimation is performed a battery model can be connected to the automatically generated lifetime verification environment. Finally, simulation is performed to verify whether the higher class UHF RFID tag fulfills the lifetime requirement of the application. The main benefit of our methodology is a decrease in the verification effort due to the high degree of automation in the creation of the verification environment. Moreover, simulation time is decreased which enables faster exploration of various batteries. This results in faster time-to-market and a reduction of costs.

3C: Open Source RFID Software (Special Session)

Chair: C. Floerkemeier (MIT/Fosstrak)

Talks:

Rifidi, Prasith Govin, Primari

LLRP Toolkit, Daniel Bowman, Impinj

Fosstrak, Christian Floerkemeier, MIT/Fosstrak

Panel:

Abstract: Open Source RFID Software is becoming increasingly popular. Tools such as Rifidi's IDE, the LLRP Toolkit or Fosstrak's software suite facilitate RFID application development significantly. These software tools begin to emerge as core components around which custom RFID solutions are built. This session will discuss current trends in RFID open source software projects. Representatives from prominent open source initiatives such as Rifidi, LLRP Toolkit and Fosstrak will present recent developments in the field and a discussion panel will analyze future opportunities.

Tuesday, Apr 28

11:00 - 12:30

4A: Privacy and Security Part I

Untraceable RFID Authentication Protocols: Revision of EC-RAC 178

Yongki Lee (University of California at Los Angeles, USA); Lejla Batina (Katholieke Universiteit Leuven, Belgium); Ingrid Verbauwhede (University of California at Los Angeles, USA)

Radio Frequency IDentification (RFID) systems are steadily becoming paramount due to their vast applications such as supply chains, inventory, tolling, baggage management, access control etc. While they have potentials to improve our lives, they also present a privacy risk. Privacy is often overlooked in many applications, but due to pervasiveness of RFIDs the issue has to be taken into account. However, additional security always comes at price and the scarceness of resources on a tag makes

conventional privacy-preserving protocols infeasible. In this paper we propose several authentication protocols that are all made of the same building blocks. More precisely, we first revise the EC-RAC (Elliptic Curve Based Randomized Access Control) protocol and we expand it into several authentication protocols. All the proposed protocols satisfy the basic requirements, which are the system scalability, un-traceability and security against cloning attacks and replay attacks, but each protocol has different security properties. The security proofs are implied by means of cryptographic reductions i.e. they are based on the security of the Schnorr protocol and the hardness of the decisional Diffie-Hellman problem.

4B: Reader Design

In this contribution an antenna is described that allows simultaneous transmission and reception in the same frequency band. Circular polarization is employed for a most reliable communication with radio frequency identification (RFID) transponders that typically have linearly polarized antennas. To achieve high separation between transmitted and received signals, a square patch antenna originally transmitting horizontally and vertically polarized radiation is combined with a 3 dB-hybrid circuit. With this hybrid circuit the antenna can simultaneously radiate a right-hand circularly polarized wave and receive a left-hand circularly polarized wave. Furthermore, the transmit signal that is unintentionally leaking into the receive path can be compensated by tuning the hybrid circuit with two variable capacitance diodes. At 866 MHz a maximum Tx/Rx-separation of 65 dB was achieved in a static scenario. In a time variant indoor scenario with a metal object moving on a conveyor belt a Tx/Rx-separation of more than 52 dB was achieved by continuously tuning the hybrid circuit with a minimum-search algorithm.

Demonstration of Improved Passive UHF RFID Coverage using Optically-Fed Distributed Multi-Antenna System **217**

Sithamparanathan Sabesan (University of Cambridge, United Kingdom); Michael Crisp (University of Cambridge, United Kingdom); Richard Penty (Cambridge University, United Kingdom); Ian White (University of Cambridge, United Kingdom)

Optically-fed distributed antenna system (DAS) technology is combined with passive ultra high frequency (UHF) radio frequency identification (RFID). It is shown that RFID signals can be carried on directly modulated radio over fiber links without impacting their performance. It is also shown that a multi-antenna DAS can greatly reduce the number of nulls experienced by RFID in a complex radio environment, increasing the likelihood of successful tag detection. Consequently, optimization of the DAS reduces nulls further. We demonstrate RFID tag reading using a three antenna DAS system over a 19m range where 100% of the test points can be successfully read. The detected signal strength from the tag is also observed to increase by an average of approximately 10dB compared with a conventional non-DAS RFID system. This improvement is achieved at +31dBm isotropically radiated power (EIRP) power from all three antenna units (AUs).

4C: Embedding and De-embedding Electromagnetic Structures for RFID Systems (Special Session)

Chair: Darmindra Arumugam (University of Pittsburgh & Carnegie Mellon University, USA)

Talks:

Practical Passive UHF RFID Systems: Design and Characterization Challenges within Computational Electromagnetism, Darmindra D. Arumugam, CMU

Design of UHF RFID Systems with the aid of Computational Electromagnetics, C.J. Reddy, EMSS USA - FEKO

Panel: Darmindra D. Arumugam, CMU; C.J. Reddy, EMSS USA – FEKO; Pavel Nikitin, Intermec; Leonid Mats, Tego

Abstract: It is widely known that designing passive RFID systems using CEM methods are somewhat precise, but differ in accuracies as compared to real-world results based on the algorithms, methods, and meshing guidelines used, as well as devices utilized for measurement and characterization of systems. By embedding electromagnetic structures such as measurement and/or characterization devices/systems into the CEM environments, we are able to visualize electromagnetic modeling results that are much more accurate than previously known, thus allowing an original design to perform exceedingly similar in the CEM environment as it would in the real world. This special session would incorporate modeling of designs for devices and/or connection systems which are typically used during the measurement and characterization stages that would allow for the de-embedding of these structures from the realworld measurements. We will also concentrate on the application, utility, and physics of electromagnetic structures used for the purpose of de-embedding.

16:00-15:30 (2:00 PM - 3:30 PM)

5A: Privacy and Security Part II

Serialized TID numbers – A headache or a blessing for RFID crackers? **225**

Mikko Lehtonen (ETH Zurich, Switzerland); Antti Ruhanen (Confidex Oy, Finland); Florian Michahelles (ETH Zurich, Switzerland); Elgar Fleisch (ETH Zurich & University of St. Gallen (HSG), Switzerland)

Though Transponder ID (TID) numbers of Radio Frequency Identification (RFID) tags were originally introduced to identify the chip model, serialized TID numbers are currently advertised as security features of UHF chips. Serialized TID numbers do not provide any cryptographic protection, but they do introduce a hurdle against adversaries who want to clone RFID tags today. Furthermore, serialized TID numbers are very relevant for end-users who want to protect their UHF from cloning today since cryptographic chips are not yet commercially available in that frequency range. In this paper, we analyze the suitability of TID numbers for security applications by evaluating the effort to bypass the TID check by exploiting various vulnerabilities, and we compare this effort to the needed level of protection in an example of anti-counterfeiting in the tobacco industry. The analysis suggests the hurdle that TID checks provide is not high enough for industrial scale security applications and it will get lower and might even diminish due to commodification of the RFID technology. However, end-users of security applications can still benefit from the increased tag cloning resistance that serialized TID numbers provide before migrating to more secure solutions.

5B: Antenna & Propagation Part I

University, USA); Timothy Kurzweg (Drexel University, USA); Adam Fontecchio (Drexel University, USA); Kapil Dandekar (Drexel University, USA)
In this paper, we present optically transparent flexible conductive polymer antennas for radio frequency identification systems. The designs for these antennas are presented along with simulated and measured results of antenna radiating properties. These conductive polymer antennas are compared to antennas with the same design fabricated out of copper. Finally, we include an analysis of the optical transparency of the conductive polymer antennas.

Analysis and Design of Wideband Passive UHF RFID Tags Using a Circuit Model **275**

Daniel Deavours (University of Kansas, USA)
The great majority of commercial UHF RFID tags are based on dipole antennas using a modification of a T-match as a matching circuit. The literature contains examples of wideband matching, but provides little insight as to how wideband behavior is achieved. Here, we present a simple circuit-based theory to describe the antenna, matching circuit, and IC behavior; we present an approach for developing an impeding matching strategy to maximize bandwidth; and we present a concrete example and analysis using a method of moments (MoM) numerical solver. The results show very good agreement with theory.

5C: Chipless RFID (Special Session)

Invited Talks & Discussion Panel: Chair: Rich Fletcher (Tagsense, USA)
Talks:
Short Review of Chipless RFID, Rich Fletcher, Tagsense Inc.
Design of Global SAW Tag RFID Devices, Clinton S Hartmann, RF-SAW
Nanobers: Printed Microwave Tags made from Carbon Nanotubes, Morton Green, Inkode
Panel: Invited speakers
Abstract: The ability to perform wireless identification and sensing with passive material structures has enabled a variety of applications where the use of traditional chip-based RFID is not possible. In addition to offering extreme low-cost, chipless RFID is capable of operating in extreme environments and provides a rich variety of physical phenomena that has proven useful for security and sensing applications as well as identification. With new growth in the general RFID market, there has been renewed interest in chipless technologies to complement chip-based RFID. In this session, we review key features of chipless RFID technologies and discuss niche markets and emerging applications.

4:00 PM - 5:30 PM

6A: Applications & Networking

A Passive SAW Based RFID System for Use on Ordnance **283**

Paul Hartmann (RF SAW Inc., USA)
Automatic RFID tracking of ordnance in transport or storage has been difficult or impossible due to the dangers that arise from possible accidental actuation of electro-explosive devices due to RF electromagnetic fields. Limits on the maximum RF power densities that meet Hazards of Electromagnetic Radiation to Ordnance (HERO) emission standards preclude many passive RFID systems from operating safely in the vicinity of ordnance due to the high level of RF radiation needed to power the electronics onboard the RFID tag. This paper describes a Surface Acoustic Wave (SAW) based RFID system that allows safe operation of an RFID system with no standoff or separation distance between the reader antenna and the item of ordnance. Surface Acoustic Wave RFID systems are a “chipless” technology that utilize the piezoelectric properties of certain monolithic crystal materials to provide a truly passive RFID technology which can be operated at RF power levels well below those established for safety near ordnance.

Inference of Product Quality by using RFID-enabled Traceability Information -A Study on the US Pharmaceutical Supply Chain- **290**

Tatsuya Inaba (Keio University, Japan)
We present a stochastic model to infer a product quality index by using product traceability information. We propose a model by using Bayesian Network and apply it to the US pharmaceutical supply chain where regulations to mandate exchanging of traceability information for individual prescription drugs are being studied. In supply chains where traceability information of only a few products is available, consumers simply take the quality of products with traceability information is higher than those without traceability information. But when traceability information of many products become available, consumers need to understand the difference and choose the products that have a sufficient quality for them. Our model can be used in this situation. We show that our model successfully differentiate product quality indices by using a numerical study with a hypothetical scenario.

Load Shedding Based Resource Management Techniques for RFID Data **298**

Nova Ahmed (Georgia Institute of Technology, USA)
RFID based systems are enjoying widespread adoption in a variety of application scenarios. Item tracking in a supply chain environment is one such application. Despite the widespread adoption there are a number of challenges that need to be handled in an RFID deployment. From an application perspective, there are two challenges: (a) the data rates for large deployments are growing by leaps and bounds; (b) the demands placed on the system for query processing in real time are also on the rise. Meeting these challenges in large-scale deployments is non trivial. The hardware base for RFID based systems compound these challenges due to the fact that RFID readers are error-prone and reliable reading of RFID tags is hampered by a number of physical limitations such as environmental conditions, and contents of the items carrying the tags. Naturally, the reliability of these systems become even more questionable when both the data rates increase and the need for real time processing of queries increases. We propose load shedding mechanisms that use the spatial and temporal properties of RFID deployments to combat the challenges due to increased demands for tag and query processing in real time. These mechanisms are piggy-backed on top of a middleware Reliable Framework for Radio Frequency IDentification (RF^2ID) that uses redundancy to improve the reliability of RFID deployment. The basic idea in RF^2ID is to use the spatial notion of a path taken by items flowing from source to destination. By cumulatively aggregating the tags collected by entities called Virtual Readers (VR) that are placed along the path, the total reliability of the system is enhanced. The VRs cooperatively shed the load under heavy load conditions. The built-in redundancy in the RF^{2}ID system allows the VRs to shed load with reasonable system performance thus enhancing the overall reliability of the deployment. Two different load shedding strategies are proposed in the literature: space based approach and time based approach. These strategies have been implemented in the RF^2ID middleware and performance results show the efficacy of these mechanisms for dealing with increased data rates.

A Real Options Approach for Strategic RFID Investment Decision **306**

Xiaodan Wu (Hebei University of Technology, P.R. China); Chao-Hsien Chu (Penn State University, USA); Dianmin Yue (Hebei University of Technology, P.R. China); Junbo Bai (Hebei University of Technology, P.R. China); Yunfeng Wang (Hebei University of Technology, P.R. China)
One major roadblock for RFID adoption is to justify its return on investment. Most researchers used cost/benefit analysis, discount cash flow, or net present value method to support the decision; however, these methods does not consider uncertainties and lack flexibility when valuate the investment in RFID. In this paper, we examine the uncertainties and risks associated with RFID investment and propose the use of real options approach to consider them. We demonstrate how can a real options method be used and suggest a process for making strategic RFID investment decision. The results were evidenced and supplemented with a sensitivity analysis.

6B: Antenna & Propagation Part II

Multipath Fading Measurements for Multi-Antenna Backscatter RFID at 5.8 GHz **314**

Joshua Griffin (Georgia Institute of Technology, USA); Gregory Durgin (Georgia Tech, USA)
UHF and microwave backscatter RF tag systems, including radio frequency identification (RFID) and sensor systems, experience multipath fading that can be more severe than that found in a conventional transmitter-to-receiver channel. Previous work has shown that multipath fading can be reduced on the modulated backscatter signal received from the RF tag in a non-line-of-sight (NLOS) channel if more than one RF tag antenna is used to modulate backscatter. This paper presents the first multipath fading measurements for backscatter tags using multiple antennas at 5790 MHz -- the center of the 5725-5850 MHz unlicensed industrial, scientific, and medical (ISM) frequency band that may offer reliable operation for future, miniature RF tags. NLOS measurement results are presented as cumulative density functions (CDF) and fade margins for use in backscatter link budget analysis and a detailed description of the custom backscatter testbed used to take the measurements is provided. The measurements show that gains are available for multiple antenna RF tags and results match well with gains predicted using analytic fading distributions derived previously.

Performance Analysis of Stacked RFID Tags **322**

Terry Ye (Hong Kong R/D Center for Logistics and Supply Chain Management, Hong Kong)
Most RFID tag performance analysis is based on the assumption that the tag is stand-alone when interacting with the readers. However, in the real world, RFID tags are often stacked together when deployed, i.e., RFID-labeled carton boxes stacked on the pallet. When multiple RFID tag antennas are placed close to each other, each antenna behaves like a shielding and reflecting object to others and the radiation pattern and other EM properties will be detuned. The stacking impact often leads to performance degradation and in many cases, read and write failure. In this paper, we first derive an RCS model to generalize a loaded antenna as a shielding and reflecting object. We then introduce a normalized mutual impedance matrix of multiple antennas to formulate the coupling effects among stacked antennas. To quantify and visualize the stacking impact in a real world scenario, we also construct a 3-D EM model in Agilent® AMDS consisting of 27 (3 × 3 × 3) stacked carton boxes, each with Alien® tags attached on the surface. Our theoretical calculation agrees with AMDS simulation and shows that both tag radiation pattern and other EM properties will be greatly altered by neighboring tags. Compared with tags in stand-alone scenarios, the degradation at different positions and directions could be very significant (more than 6dB).

Change of Read Range for UHF Passive RFID Tags in Close Proximity 330

Yu Tanaka (Tokyo University of Science, Japan); Yohtaro Umeda (Tokyo University of Science, Japan); Osamu Takyu (Tokyo University of Science, Japan)

In this paper, we discuss change of read range between a passive UHF RFID tag and reader when a tag is close to another tag. The read range is determined by the strength of forward link and reverse link, which are represented by received power at a tag and reader, respectively. Approaching of tags causes electromagnetic interference between antennas of tags and results in change in impedance matching condition between an antenna and IC of a tag. This change in impedance matching condition decreases in read range. Therefore, we measure the change in received power of a tag and reader experimentally so as to identify which link limits read range and to restrict the existence range of IC impedance. In addition, a technique for extending read range when tags are close is proposed.

On the Measurement of the Delta Radar Cross Section for UHF Tags 338

Saad Skali (Grenoble-inp/esisar, France); Christophe Chantepy (Grenoble-inp/esisar, France); Smail Tedjini (Grenoble-inp, France)

This paper presents a methodology for the practical measurement of the variation of the Radar Cross Section (ΔRCS) for the RFID UHF tags. This is a very critical parameter, and will govern the tag performance. It also influences both the reading distance as well as the sensitivity of UHF tag. The experimental procedure is based on the measurement of baseband I and Q signals. Measurements are carried out in an anechoic chamber under bistatic antennas configuration. I and Q signals are measured twice: with and without the tag into the anechoic chamber. This allows the measurement of the difference of re-radiated power issued from the tag only, and thus the ΔRCS is obtained. The paper includes the analysis procedure and the experimental setup. The later is based upon an anechoic environment, a vector signal generator and a vector signal analyzer. The delta RCS is obtained as a function of the reader power. The paper describes the proposed procedure as well as its application to some tags of type ISO/IEC 18000-6C (EPC Class 1Gen2) tag.

6C: Near-Field Electromagnetic Ranging (Special Session)

Chair: Hans Schantz (The Q-Track Corporation, USA)

Talks:

A Technical Primer on Near-Field Electromagnetic Ranging, Hans Schantz, Q-Track

Near-Field Electromagnetic Ranging Versus Ultra-Wideband, Kai Siwiak, TimeDerivative

Radiation Worker Dosimetry Training System, John Unden, Q-Track

Panel: Invited speakers (Schantz, Siwiak, Unden)

Abstract: Near-Field Electromagnetic Ranging is an emerging indoor wireless location technology using narrowband (CW tone) signals operating at low frequencies (~1MHz) and long wavelengths (~300m). By exploiting the excellent propagation behavior of low frequency signals' near-field phase characteristics, these systems typically achieve 30cm-1m (1-3ft) accuracy at ranges of 30-60m (100-200ft) even in cluttered industrial environments. The pilot commercial deployment of near-field electromagnetic ranging is in the nuclear industry (see http://www.q-track.com/VideoALARMS.htm), but other applications include military training, miner tracking, and supply chain management.