Guest Editorial: Special Issue on IEEE RFID 2019 Conference

WITH the proliferation of the Internet of Things, there is an increased demand to enhance every day physical objects with sensors and communication abilities so that they can have digital counterparts ("digital twins") in a connected world. While many solutions based on protocols such as ZigBee, Bluetooth, ANT, LoRa, LPWAN, NB-IoT, HaLow, etc. do exist, RFID technology presents a compelling alternative. Radio Frequency Identification (RFID) is a generic term for a variety of active and passive RF technologies. RFID transponders have varying degrees of sophistication and their design is often a tradeoff between functionality and cost. At one end of the spectrum, there are active RFID tags that offer on-board battery and memory, sensor integration, active RF transmitters and hence communication range up to kilometers albeit at increased costs. At the other end, passive and semi-passive RFID tags rely on a simple load modulation to backscatter ID and data back to the reader over several meters distance. Passive RFID tags, in particular, lend themselves well for applications needing large-scale, low-cost, automatic identification and are a good option for imparting digital identity to a host of physical assets. Industry alliances such as the NFC forum (for HF RFID) and the RAIN RFID alliance (for UHF RFID) have been formed to motivate and promote these efforts.

In the passive RFID domain, the last two decades have seen a coordinated effort in areas such as open standards development for networked RFID, low-cost, mass-manufacturing techniques for transponder hardware and energy efficient chip design. The technology progressed immensely over that time. The latest RAIN RFID ICs have a die area of only about 0.1 mm^2 and RF sensitivity of -22 dBm, which is about 12 dB better than two decades ago, translating into 4x tag read range.

An estimated 20 billion passive RFID tags (LF, HF, and UHF) have been sold in 2019 to a wide range of industries and businesses including consumer goods tracking, apparel tagging, defense, security, access, healthcare, construction, and airlines and aerospace. One of the areas of strong interest to RFID is the retail sector. For example, Decathlon (the largest sporting goods retailer in the world) uses RFID to track and manage its inventory throughout the entire supply chain, from factories to the distribution centers and hundreds of stores worldwide. As another example, Japan, one of the countries facing labor force crisis due to a serious shrinkage of population, aims to automate all of its convenience stores with RFID by 2025. There are plenty of challenges to be solved too - for example, how to reliably use RFID for loss prevention, where traditionally electronic article surveillance (EAS) security systems based on other technologies have been used.

As the demand for low-cost, edge devices to bridge the physical-digital divide grows, so has the scope of RFID research. Besides object identification, researchers have examined the possibility of using RFID tags for low-power wireless sensing, localization and activity inference. The research is often cross disciplinary and merges RFID domain knowledge with advancements in fields such as material science, energy harvesting and machine learning. In the last 5 years alone there have been about 1600 issued U.S. patents and 3500 IEEE Journal and Conference publications (with the term "RFID" in their title), which serve to underline the rapid growth of the field.

In 2017, IEEE launched a new IEEE JOURNAL OF RADIO FREQUENCY IDENTIFICATION (JRFID). Each year, the journal features a special issue that presents a collection of extended papers from that year's IEEE RFID conference. Papers in this special issue are extended versions of paper and poster presentations that were featured in IEEE RFID 2019, a highly competitive premier technical conference on RFID that took place in Phoenix, AZ, USA on April 2–4, 2019. The seven papers presented in this issue are written by researchers from five countries: Germany, New Zealand, Austria, China and the USA. The topics of this paper include antenna design for near and far field applications, tag localization, a lightweight and secure protocol for proof of tag grouping, low cost system design for tag data acquisition, low-cost RFID based sensing and embroidered RFID tags for apparel tagging.

Parthiban *et al.* present the design of a dual near and far field UHF RFID reader antenna designed for retail check-out counters. They perform a comparison of their work with the state of the art along metrics like antenna gain, beamwidth and impedance matching. They quantify the effect of different types of materials, such as water, wax and metal, when placed at different locations on the antenna. This is indicative of products being scanned at a check-out counter and presents a practical aspect of the work. Finally, they present their design, simulations and testing clearly making it easy for the work to be replicated.

Hasler *et al.* present a novel technique to identify the distances between clusters of RFID tags using time difference of arrival and peak RSSI from the scanned tags. They are able to achieve positioning accuracy of up to 30 cm in best case scenarios using off-the-shelf RFID reader equipment. This opens up many possibilities in retail such as the ability to detect misfiled items on the shop floor. The authors present their

Digital Object Identifier 10.1109/JRFID.2020.2973562

algorithm and results clearly making it easy for researchers to replicate their work. Furthermore, they make their experimental data openly available to the community for further research.

Cherneva and Trahan present a lightweight and secure grouping proof for clusters of scanned RFID tags. Their technique does not rely on an external trusted timestamp and reduces the amount of communication and computation necessary for authentication, which is essential for resource constrained devices like passive RFID tags. As such, it presents a good compromise between security, privacy and utility. A good comparison with the state of the art is conducted and the proof is well documented and analyzed.

Liu *et al.* present design guidelines for fabricating UHF RFID antennas using conductive threads. Their contribution involves a discussion of the properties of conductive fibers, a circuit model for antennas using conductive threads and a comparison between simulated results based on their work and experimental verification for 0, 2, 3 and 5 turn meander line antennas. They attempt to explain the discrepancies between the simulated and measured results and propose a design guideline as a result. Their work forms a good framework for researchers interested in embroidering such antennas in smart fabrics.

Thomas presents the design of a UHF RFID tag platform that can be assembled using off the shelf commercially available low-cost components. The platform is designed to be easily implementable by non-experts so that they can rapidly prototype alternative RFID protocols, interface with sensors, conduct power transfer experiments etc. All the components and circuit designs are archived on open source repositories. The application of this platform as a data acquisition and communication tool as part of the undergraduate teaching curriculum was also discussed.

Tan *et al.* present the design of an NFC sensing platform, that is capable of supporting RFID and I^2C communication protocols on one chip. The I^2C master is directly integrated on the chip without the need for a microcontroller that reduces the cost and complexity of the device. An LDO architecture for power supply rejection is also presented that helps improve sensor resolution by a factor of 6.4 relative to a noisy supply voltage. The authors provide a detailed comparison of their work with the state of the art and provide sufficient description of their design for their work to be replicated.

Beuster *et al.* present the design of a low-cost UHF RFID tag positioning and measurement system that can be assembled using low-cost electronics and items sourced at the hardware store. They automate the process of tag placement in a 3D environment and use that to map the RSSI and phase response of the tag in the environment – allowing one to visualize fading patterns and the effect of metallic reflectors. They also demonstrate how a low-cost software radio can be used to analyze the tag response.

These papers represent a small sampling of the diversity of many active research topics in the field of RFID: antennas and propagation, sensors, localization, IC and reader design, system analysis, protocol improvements, etc. Undoubtedly, the field of RFID will continue to grow, encompass multidisciplinary fields of study and pose new challenges to researchers in industry and academia.

RAHUL BHATTACHARYYA
Massachusetts Institute of Technology
Cambridge, MA 02139 USA

PAVEL NIKITIN
Impinj, Inc.,
Seattle, WA 98109 USA

Rahul Bhattacharyya received the Ph.D. degree in systems engineering from the Massachusetts Institute of Technology, Cambridge, MA, USA, in 2012. He is currently the Associate Director of the Auto-ID Labs, MIT, where his research encompasses the development and integration of technologies that form the framework for the Internet of Things (IoT). He has authored over 35 technical peer reviewed publications. He was a recipient of the 2015 IEEE RFID-TA Conference Best Paper Award. He is a Guest Editor of the IEEE JOURNAL OF RADIO FREQUENCY IDENTIFICATION. He was Guest Editor for a special issue on IoT for the IEEE TRANSACTIONS ON AUTOMOTIVE SCIENCE AND ENGINEERING. He is currently serving as the Technical Program Co-Chair of the 2020 IEEE RFID Conference. He has also served as the TPC Chair of IEEE RFID 2018–2019 and the Fourth International Conference on IoT in 2014 at MIT.

Pavel Nikitin received the Ph.D. degree in electrical engineering from Carnegie Mellon University, Pittsburgh, PA, USA, in 2002. He worked at Honeywell, Intermec, University of Washington, IBM, and Ansys. He is currently a Senior Staff Antenna Designer with Impinj, Inc., Seattle, WA, USA, where he is involved into research and development of RFID products. He is also an Affiliate Associate Professor with the Electrical Engineering Department, University of Washington. He has authored over 50 IEEE technical publications and has over 60 U.S. and European patents. He was a recipient of the 2017 and 2010 IEEE RFID Conference Best Paper Awards and the 2005 Antenna Measurement Techniques Association Symposium Best Paper Award.