Guest Editorial

OVER THE past few years, a significant growth of research involving the utilization of RF/microwave technologies in healthcare applications has been taking place, and this TRANSACTIONS' "Special Issue on Biomedical Applications of RF/Microwave Technologies" is a good proof. Encouraged by funding from government agencies and private sources, and recognizing the emerging opportunities offered by high-frequency electronics and novel sensing technologies for advancing healthcare, researchers from various engineering disciplines have directed their interests to applications involving biological science and clinical medicine.

The increase in RF/microwave-related activities targeting medical or biological problems is noticeable within the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) community and beyond. These activities are broad in their scopes and involve multiple disciplines. They range from therapeutic, diagnostic, remote monitoring, and imaging applications of microwave technologies in clinical settings, as well as those involving sensing and communication over or through body tissues, where physiological or biochemical information are transmitted wirelessly, to the biological effects of these applications, in which the interaction of microwaves with tissues and living systems should be understood and manipulated. In addition, RF/microwave now serves as one of the key enabling technologies in innovative healthcare delivery and telemedicine.

This TRANSACTIONS' Special Issue features papers from the U.S., U.K., Japan, Korea, Australia, Canada, Saudi Arabia, Italy, Malaysia, Belgium, Germany, China, and France, indicating global efforts utilizing RF/microwave innovation for healthcare. The presented papers fall into the following categories.

Three papers are on exposure systems for bioelectromagnetic research. The paper by Paffi *et al.* provides a systematic review and classification of *in vivo* microwave exposure systems. Some key issues have been identified and addressed concerning the importance of reliable dosimetric characterization of exposure systems for different types of *in vivo* studies. The paper by Romeo *et al.* presents a waveguide applicator for exposure of cell cultures at GSM, UMTS, and Wi-Fi frequencies. Numerical dosimetry is validated by scattering parameters and calorimetric measurements. The paper by Boriskin *et al.* is on using a special antenna for enhancing exposure efficiency and uniformity with application to bioelectromagnetic studies at 60 GHz. Two other papers also deal with the electromagnetic effects at the cellular level. In the paper by Kohler *et al.*, a dosimetric and microdosimetric study of an *in vitro* exposure setup based on a TEM exposure system is reported that allows the exposure of cells in a culture dish to nanosecond-pulsed electric fields (nsPEFs). High-intensity nsPEFs with durations of nanoseconds to hundreds of nanoseconds have found breakthrough biomedical applications, such as in cancer treatment and gene therapy. The paper by Grenier *et al.* reviews recent advances in microwave- and millimeter-wave-based dielectric spectroscopy performed at the cellular and molecular levels. This progressively emerging area permits non-invasive and real-time probing of cells in their biological culture environments. Techniques for characterizing small number of cells and single cells are also discussed. A paper by Apollonio *et al.* provides a literature review of the models for the interaction mechanisms in non-thermal bio-effects, together with an overview of those publications finding positive results. The authors conclude that the effects are widespread, but subtle, and only through a multiscale methodology it is possible to perform a comprehensive study of such effects.

Nine papers present radar-based systems for vital sign monitoring and object imaging. The review article by Li *et al.* highlights recent advances in healthcare applications of Doppler radar that remotely detects vital signs such as heartbeat and respiration of human subjects. The paper reviews different architectures, baseband signal processing, and system implementations, and discusses validations of this technology in clinical environments. The paper by Mercuri *et al.* presents a complete system for contactless health monitoring in a home environment, where radar, wireless communications, and data processing techniques are integrated together enabling fall detection and tagless localization. The prototype implementation has been designed to satisfy the ultra-wideband (UWB) spectrum masks. Another UWB radar is discussed in the paper by Chan *et al.*, which is based on a time-expanded correlation architecture and uses a circularly polarized antenna array having an axial ratio bandwidth from 3 to 10 GHz. The use of circular polarization improves the accuracy for vital signs monitoring. Schleicher *et al.* demonstrate in their paper an impulse-radio ultra-wideband (IR-UWB) hardware consisting of an impulse generator integrated circuit (IC) in the transmitter and a correlator IC with an integrating baseband circuit as correlation receiver, which can be used as a radar sensor for highly precise object tracking and breathing rate sensing. The IR-UWB paper by Li *et al.* presents a dual-frequency IR-UWB radar at center frequencies of 270 and 400 MHz, and a method based on an adaptive clutter cancellation algorithm for suppressing the respiration-like clutters, especially those reflected from walls or rubble adjacent to a trapped human target. A paper by Vinci *et al.* presents a remote respiration and heart beat monitoring radar based on a six-port interferometer operating a continuous wave signal at 24 GHz and a radiated power of less than 3 μW. Experimental investigation for 1-D imaging of human cardiac motion using a microwave Doppler radar is demonstrated in the paper by Wang *et al.* Standard microwave equipments are employed to generate and detect the radar signals.

The remaining two radar papers focus on cancer detection by imaging. The paper by Bassi *et al.* presents an integrated microwave imaging radar for breast cancer tumor screening. The radar operates at a broad frequency range from 2 to 16 GHz and

Digital Object Identifier 10.1109/TMTT.2013.2255936

consists of a custom integrated circuit implemented by the 65-nm CMOS technology and a pair of patch antennas. In the paper by Fear *et al.*, the authors report the first patient study of microwave breast imaging performed with a monostatic radar-based prototype system. The 3-D images are obtained for eight patients from 50 MHz to 15 GHz microwave sweeps with an UWB antenna. Several images exhibit results consistent with clinical histories motivating further detailed studies for human.

Imaging is also the subject of two other papers. Golnabi *et al.* implement a soft prior regularization technique for microwave tomographic imaging, which exploits spatial prior information from an alternative imaging modality such as magnetic resonance imaging (MRI). The system is designed to operate from 500 MHz to 3.0 GHz, and the method can tolerate the presence of false inclusion in prior information. The paper by Kurrant *et al.* demonstrates a microwave imaging technique in which the patient-specific prior information on tissue structures is provided using radar-based methods. Incorporating this approach with microwave tomography permits the microwave to be a standalone imaging modality for breast imaging. The interaction of electromagnetic waves with human body is explored in four papers. The paper by Xin *et al.* explores the B_1 shimming strategy for fetus MRI at 7 T with the constraint in specific absorption rate (SAR) for safety investigation. B_1 shimming is a technique to address the problem of inhomogeneous RF field distribution in MRI. Park *et al.* calculate errors of the electric fields induced in a human body under quasi-static approximation conditions. The paper by Thotahewa *et al.* reports the electromagnetic effects of implantable transmitting devices in head operating based on IR-UWB. Simulations illustrate the performance of an implanted UWB antenna tuned to operate at 4 GHz with a -10-dB bandwidth of approximately 1 GHz. SAR and temperature increase are analyzed to investigate the compliance of the transmitting device with international safety regulations. In the paper by Schwerdt *et al.*, computational and empirical methods are used to evaluate SAR within a human head phantom for an embedded passive wireless neurorecording microsystem reported previously by the authors. The device operates based on wireless backscattering of the third-order intermodulation products containing action potential signals from neurons, from an externally supplied 2.25–2.45-GHz carrier. An article by Ouda *et al.* presents a fully integrated 5.2-GHz 0.18-μm CMOS based RF power harvester with an on-chip antenna. The design is optimized for sensors implanted inside the eye to wirelessly monitor the intraocular pressure of glaucoma patients.

Three of the papers deal with integrated microwave systems and sensors for permittivity measurements. The paper by Laemmle *et al.* presents an integrated dielectric sensor with readout circuitry in 250-nm SiGe BiCMOS technology at 125 GHz, consisting of a 500-μm shorted half-wave coplanar waveguide transmission line. The paper by Hofmann *et al.* presents a Debye relaxation model for measuring the permittivity of aqueous glucose solution up to 40 GHz. Reflection-based as well as transmission-based sensors are introduced and utilized by a custom-made six-port reflectometer and homodyne vector network analyzer (VNA). The development of a fully integrated broadband reflectometer covering both 2- and 16-GHz bands is presented in the paper by Kim *et al.* The reflectrometer uses microelectromechanical systems (MEMS) and monolithic microwave integrated circuit (MMIC) technologies for complex permittivity measurements of biological materials. The integrated sensor papers also include the one by Wang *et al.*, which investigates the fundamental sensitivity of oscillator-based reactance sensors, which can be used in various types of biomedical sensing applications. Two papers focus on antennas for medical diagnosis and treatment. Hancock *et al.* present a multi-functional microwave antenna allowing efficient propagation of microwave energy at 14.5 GHz into tissue for performing *in situ* tissue characterization and ablation/coagulation (treatment) of cancerous tumors. The structure supports a separate channel to allow material transport inside the structure and biopsy needle without affecting the electromagnetic field propagation. In another paper by Hancock *et al.*, the design and initial pre-clinical evaluation of microwave traveling wave antenna structures to deliver microwave energy for producing controlled ablation around the inner wall of the esophagus for treatment of gastro-esophageal reflux disease is presented. Finally, an article by Soh *et al.* features a smart wearable textile array system with direction of arrival (DoA) estimation and beamforming developed for biomedical telemetry applications at 2.45 GHz. Characterization of this system in the proximity of a human arm phantom is performed.

Illustrated by the wide scopes, innovative ideas, and multidisciplinary nature of research topics in this TRANSACTIONS' Special Issue, microwave and RF technologies for biological and medical applications are emerging with their unique features and advantages. They enable novel and potentially practical solutions for globally dire healthcare issues. This TRANSACTIONS' Special Issue provides a small window to exam the scientific and engineering potentials offered by utilizing microwave and RF technologies in medical applications. We believe that they will have long-lasting and beyond measurable impacts on our society.

We wish to thank Dr. George Ponchak, the Editor-in-Chief of this TRANSACTIONS, for administrating the review processes and making the final decisions on these papers. We heartily thank the authors of these selected papers for their significant contribution. We also would like to sincerely thank the reviewers who made the publication of this TRANSACTIONS' Special Issue possible.

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Dr. Tofighi has been the chair of the IEEE MTT-10, Technical Committee (TC) on Biological Effects and Medical Applications of RF and Microwave since 2009. He has served IEEE Microwave Theory and Techniques Society (IEEE MTT-S) sponsored conferences, including the IEEE MTT-S International Microwave Symposium (IMS), Radio and Wireless Symposium (RWS), BioWireless Conference, and International Wireless Symposium (IWS) in various capacities. He has been the chair of IEEE MTT-S IMS Technical Program Committee (TPC) #27 (biological Effects and Medical Applications of RF and Microwave, 2008–2011) and the vice chair of TPC #38 (RF Devices for Wireless Health Care Applications and Biosensing, 2012–2013), of which he had also a role in its formation. He was also one of the guest editors of the IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES' Special Issue on "RF and Microwave Techniques in Wireless Implants and Biomedical Applications" (October 2009).

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Dr. Chiao has chaired and co-chaired 17 international conferences. He is the co-chair of the IEEE Microwave Theory and Techniques Society (IEEE MTT-S) Technical Committee 10 "Biological Effect and Medical Applications of RF and Microwave." He has been with the IEEE International Microwave Symposium RF MEMS Committee, Biological and Medical Technology Committee, and RF Devices for Wireless Health Care Applications and Biosensing Committee since 2003. His research earned the Wacky Innovation #9 Award of the Innovation 100 Awards in 2007 and the 2009 Well-Tech Award. He was the recipient of the 2011 Mentor Recognition of the Siemens Foundation, the 2011 Lockheed Martin Aeronautics Company Excellence in Engineering Teaching Award, the 2011 Tech Titans Technology Innovator Award, the 2011 Edith and Peter O'Donnell Award in Engineering of The Academy of Medicine, Engineering and Science of Texas, the 2012 Research Milestone Award in Hero of Healthcare, the 2012 IEEE Region 5 Outstanding Engineering Educator Award, and 2012–2014 IEEE MTT-S Distinguished Microwave Lecturer.