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EDITORIAL

IEEE ACCESS SPECIAL SECTION EDITORIAL: ENERGY HARVESTING TECHNOLOGIES FOR WEARABLE AND IMPLANTABLE DEVICES

Implantable and wearable electronic devices can improve the quality of life as well as the life expectancy of many chronically ill patients, provided that certain biological signs can be accurately monitored. Thanks to advancements in packaging and nanofabrication, it is now possible to embed various microelectronic and micromechanical sensors such as gyroscopes, accelerometers, and image sensors into a small area on a flexible substrate and at a relatively low cost. Furthermore, these devices have been integrated with wireless communication technologies to enable the transmission of both signals and energy. However, to ensure that these devices can truly improve a patient's quality of life, new preventative, diagnostic, and therapeutic devices that can provide hassle-free, long-term, continuous monitoring will need to be developed, which must rely on novel energy harvesting solutions that are non-obstructive to its wearer. So far, research in the field has focused on materials, new processing techniques, and one-off devices. However, existing progress is not sufficient for future electronic devices to be useful in any new application, and a great demand exists toward scaling up the research toward circuits and systems. Few interesting developments in this direction indicate that special attention should be given toward the design, simulation, and modeling of energy harvesting techniques while keeping system integration and power management in consideration.

This Special Section includes contributions from leading experts from both academia and industry. We believe that novel approaches toward devices, circuits, and systems will allow readers to identify the requirements, challenges, and future directions related to the field of energy harvesting for future wearable and implantable devices. In particular, this Special Section aims to report the latest advancements and future trends of key techniques and frameworks enabling optimal harvesting, storage, and use of energy from the environment or the human body while considering the technical constraints and the uncertainties involved. Hence, this Special Section will be useful for a broad audience of people working in different domains.

A total of 56 articles were submitted to the Special Section and 20 were accepted for publication. We will briefly describe each of these articles and discuss how they are linked to the general theme of the Special Section.

In the article "Prediction of harvestable energy for self-powered wearable healthcare devices: Filling a gap," by Wahba *et al.*, the authors discuss various machine learning algorithms that can be used to predict the amount of harvestable energy from sources such as solar, mechanical, and electromagnetic radiation. This becomes crucially important as wearable devices are expected to effectively manage their own energy resources.

Moreover, the article by Abdul-Aziz *et al.*, "High performance supercapacitor based on laser induced graphene for wearable devices," describes using a CO_2 laser for fabricating supercapacitor electrodes. The authors demonstrated excellent device stability and high capacitance in comparison to previously fabricated graphene supercapacitors.

The article by Jinwei *et al.*, "Simulation of crystalline silicon photovoltaic cells for wearable applications," describes the authors' approach in comparing the current-voltage results from seven different commercial and free simulations tools for predicting the performance of solar cells for wearable applications. According to their investigations, the non-commercial PC3D software program produces results that agree with previously published experimental data. These findings are useful for researchers interested in optimising the performance of solar energy harvesters.

In addition to cutting-edge disciplinary research, our Special Section includes pedagogical articles in the area of wearable and implantable devices. For example, in the article "Implantable and wearable neuroengineering education: A review of postgraduate programs," by Ghannam *et al.*, the authors describe the essential components of an educational program for neuroengineers aiming to develop next-generation wearable and implantable devices for neurological applications. A survey of postgraduate programs was presented, with institutions from North America and Europe leading the development of such programs.

Similarly, another pedagogical article was included in our Special Section by Fan *et al.*, "Teaching embedded systems for energy harvesting applications: A comparison of teaching methods adopted in UESTC and KTH," which describes student experiences in applying active learning techniques during the teaching of an embedded systems course for energy-harvesting applications.

Furthermore, in the article by Li *et al.*, "MSP-MFCC: Energy-efficient MFCC feature extraction method with mixed-signal processing architecture for wearable speech recognition applications," the authors discuss a novel, energy-saving mixed-signal processing architecture that is optimized for speech recognition on wearable applications.

The article by Tafekirt *et al.*, "A sensitive triple-band rectifier for energy harvesting applications," describes an innovative power rectifier that is capable of efficiently harvesting energy from three RF bands: GSM-900, GSM-1800, and WiFi-2450. The rectifier demonstrated high efficiency, low power consumption, and good power sensitivity.

As for the article by Wagih *et al.*, "Real-world performance of sub-1 GHz and 2.4 GHz textile antennas for RF-powered body area networks," the authors demonstrate a wearable, textile-based antenna for harvesting energy from realistic directional or omnidirectional transmitters.

In addition to harvesting RF power, Bing *et al.* demonstrate simultaneous wireless and information power transfer (SWIPT) using the hybridized power time splitting relay protocol in the article entitled "Transceiver design for SWIPT MIMO relay systems with hybridized power-time splitting-based relaying protocol."

Keeping with the concept of RF energy harvesting, the Special Section included contributions from Ding *et al.* on "Implantable wireless transmission rectenna system for biomedical wireless applications," where the performance of a novel circular antenna and rectifying circuit were experimentally demonstrated. The system was designed to operate at the 915 MHz ISM band.

Another RF power design that was experimentally demonstrated by Qian *et al.* proposed a compact and low-power wireless modulator to directly encode input RF signals onto its oscillation carrier wave. The article entitled "Wireless powered encoding and broadcasting of frequency modulated detection signals" discusses a novel circuit that can simultaneously detect, encode, and broadcast locally acquired MR signals using tiny amounts of wireless power.

In the article by Kawar *et al.*, "An input power-aware efficiency tracking technique with discontinuous charging for energy harvesting applications," the authors proposed a discontinuous charging technique that maximizes the power conversion efficiency according to the power sensed at the input.

Furthermore, the article by Qian *et al.*, "Wireless reconfigurable RF detector array for focal and multiregional signal enhancement," demonstrates how wirelessly amplified NMR detectors (WAND) can use wirelessly pumped power to amplify MRI signals.

In terms of energy conversion, the article entitled "A highly reliable SIMO converter using hybrid starter and overcharging protector for energy harvesting systems," by Jung *et al.* proposes a single inductor multi-output (SIMO) converter that delivers a stable system supply voltage for energy harvesting applications that require high reliability.

Moreover, two articles on electromagnetic energy harvesting were included in the Special Section. First, in the article by Liu *et al.*, "Design and research on a nonlinear 2DOF electromagnetic energy harvester with velocity amplification," a novel two degree of freedom vibration-based energy harvester was proposed. An experimental prototype to verify the simulation results was also demonstrated. Their design delivered 10.18 mW of power at a frequency of 8 Hz. Furthermore, the article by Digregorio *et al.*, entitled "Modeling and experimental characterization of an electromagnetic energy harvester for wearable and biomedical applications," demonstrates an electromagnetic energy harvester capable of scavenging energy from low-g acceleration as well as slow movements, which is ideal for wearable and implantable applications involving random or unpredictable movements.

In the article by Cen *et al.*, entitled "Design of capacitor array in 16-Bit ultra-high precision SAR ADC for the wearable electronics application," the authors demonstrate a 16-bit 6-channel high-voltage successive approximation register for wearable devices requiring high accuracy.

Similarly, in "High-precision adaptive slope compensation circuit for DC-DC converter in wearable devices," Fan *et al.* demonstrate a 96% precision adaptive slope compensation circuit for dc–dc converters in wearable devices, which was demonstrated using the virtuoso spectre circuit simulator.

Moreover, following soaring interest in flexible and polymer-based wearable devices, the review article by Ying *et al.*, entitled "Device based on polymer Schottky junctions and their applications: A review," summarizes the latest trends in polymer-based Schottky junctions for applications that include photodetectors, gas sensors, and energy harvesters.

Finally, the article "Inertial kinetic energy harvesters for wearables: The benefits of energy harvesting at the foot," by Beach and Casson, compares the amount of power that can be harvested from four different body locations, which are the wrist, hip, ankle, and foot. In comparison to these locations, the highest amount of power can be harvested from the foot. Moreover, it is the least sensitive location for changes in the frequency of walking rate. These promising results are an important step toward achieving fully autonomous and batteryless wearable devices.

In conclusion, we would like to thank all the authors who submitted their research articles to our Special Section. We highly appreciate the contributions of the reviewers for their constructive comments and suggestions. We also would like to acknowledge the guidance from IEEE ACCESS Editor-in-Chief and staff members. The Guest Editors hope that this Special Section will benefit the scientific community and contribute to the knowledge base.

HADI HEIDARI, *Lead Editor*
James Watt School of Engineering
University of Glasgow
Glasgow G12 8QQ, U.K.

MEHMET ÖZTÜRK, *Guest Editor*
Department of Electrical and Computer Engineering
North Carolina State University
Raleigh, NC 27695, USA

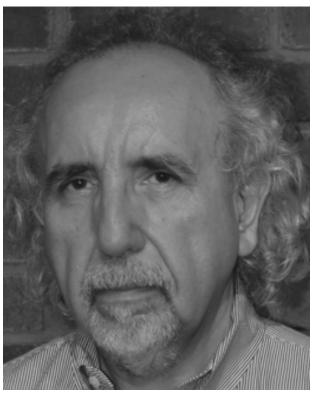
RAMI GHANNAM, *Guest Editor*
James Watt School of Engineering
University of Glasgow
Glasgow G12 8QQ, U.K.

MAN-KAY LAW, *Guest Editor*
Institute of Microelectronics
University of Macau
Taipa, Macau

HAMIDEH KHANBAREH, *Guest Editor*
Department of Mechanical Engineering
University of Bath
Bath BA2 7AY, U.K.

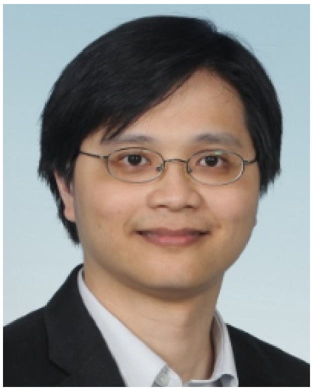
ABDUL HALIM MIAH, *Guest Editor*
Department of Electrical and Computer Engineering
University of Florida
Gainesville, FL 32611, USA

HADI HEIDARI (Senior Member, IEEE) received the Ph.D. degree in microelectronics from the University of Pavia, Italy. He is currently an Associate Professor (Senior Lecturer) with the School of Engineering, University of Glasgow, U.K., where he leads the Microelectronics Laboratory. He has authored more than 200 publications in top-tier journals and conferences. His research interests include developing microelectronics and sensors for neurotechnology devices. He is also a member of the IEEE Circuits and Systems Society Board of Governors (BoG) and the IEEE Sensors Council Administrative Committee (AdCom). He was a recipient of a number of awards, including the Best Paper Awards from ISCAS 2014, the PRIME 2014, the ISSCC 2016, the IEEE CASS Scholarship (NGCAS 2017), and the Rewards for Excellence Prize from the University of Glasgow in 2018. He was also the General Chair of the 27th IEEE ICECS 2020 in Glasgow. He has served on the organizing committee for several conferences, including the U.K.–China Emerging Technologies (UCET), PRIME in 2015 and 2019, the IEEE Sensors in 2016 and 2017, NGCAS 2017, and BioCAS 2018. He is also an organizer of several special sessions of the IEEE conferences. He is also an Associate Editor of the IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, IEEE Access, and *Microelectronics Journal* (Elsevier). He is also a Guest Editor of the IEEE Transactions on Biomedical Circuits and Systems.



MEHMET ÖZTÜRK (Fellow, IEEE) received the B.S. degree in electrical engineering from Boğaziçi University, İstanbul, Turkey, in 1980, the M.S. degree in electrical engineering from Michigan Technological University, Houghton, MI, USA, in 1983, and the Ph.D. degree in electrical and computer engineering from North Carolina State University, Raleigh, NC, USA, in 1988, under the supervision of Jimmie J. Wortman. After graduation, he joined Department of Electrical and Computer Engineering, where he is currently serving as a Professor of Electrical and Computer Engineering, where his research interest includes novel processes for advanced CMOS ICs with an emphasis on applications of Group IV epitaxy in channel and source/drain engineering. His current research interest includes flexible electronics for energy harvesting, particularly flexible thermoelectric devices for body energy harvesting.

RAMI GHANNAM (Senior Member, IEEE) received the B.Eng. degree in electronic engineering from King's College London, the D.I.C. and M.Sc. degrees from Imperial College London, and the Ph.D. degree from the University of Cambridge in 2007. He is currently an Assistant Professor of Electronic and Nanoscale Engineering with the University of Glasgow. He held previous industrial positions at Nortel Networks and IBM Research GmbH. His research interests include energy harvesters, interactive devices, and engineering education. He has published almost 100 articles in these areas, including five patents and one edited book. He is also a Senior Fellow of Glasgow's RET scheme and serves as the Scotland's Regional Chair for the IEEE Education Society. He also serves as the Chair for the IET Pedagogy in Engineering and Technology TN. He has been awarded with the Siemens Prize.



MAN-KAY LAW (Senior Member, IEEE) received the B.Sc. degree in computer engineering and the Ph.D. degree in electronic and computer engineering from The Hong Kong University of Science and Technology (HKUST), Hong Kong, in 2006 and 2011, respectively. In 2011, he joined HKUST as a Visiting Assistant Professor. He is currently an Associate Professor with the State Key Laboratory of Analog and Mixed-Signal VLSI, Institute of Microelectronics, University of Macau, Macau. He has authored and coauthored more than 100 technical publications and holds six U.S./Chinese patents. His research interests include the development of ultra-low-power CMOS sensing/readout circuits and energy harvesting techniques for wireless and biomedical applications. He is also a TPC Member of IEEE ISSCC. He was a co-recipient of the ASQED Best Paper Award in 2013, the A-SSCC Distinguished Design Award in 2015, the ASPDAC Best Design Award in 2016, and the Macao Science and Technology Invention Award by Macau Government–FDCT in 2020 (First Class) and in 2014 and 2018 (Second Class). He also serves as a Technical Committee Member for the IEEE CAS Committee on Sensory Systems as well as the Biomedical and Life Science Circuits and Systems. He is also a Distinguished Lecturer of IEEE CASS and IEEE SSCS.

HAMIDEH KHANBAREH received the B.Sc. degree in materials science and engineering from the University of Tehran in 2008, the M.Sc. degree *(cum laude)* in aerospace engineering from the Delft University of Technology, The Netherlands, in 2012, and the Ph.D. degree from the Novel Aerospace Materials group, Delft University of Technology in 2016, working on functionally graded ferroelectric polymer composites. During the Ph.D. degree, she worked as a Visiting Scientist with the Molecular Electronics Research Group, Max Planck Institute for Polymers (MPIP), Mainz, Germany. She was appointed as a Prize Fellow with the Materials and Structures Research Centre, Department of Mechanical Engineering, University of Bath, U.K. and was also appointed as an Assistant Professor with the Department of Mechanical Engineering in 2018, where she established her independent research group, Ferroelectric Materials for Applications in Medical Devices, Energy and Environment (FAME2) Research Group. She is currently an Assistant Professor with the Department of Mechanical Engineering, University of Bath. She is currently leading the FAME2 Research Group. She has authored over 30 publications in top-tier journals. Her research interests include the next generation of ferroelectric materials for sensing and energy harvesting by utilizing expertise in the manufacture, modeling, and characterization of these materials. Her research has been funded by major research councils and funding organizations, including the Engineering and Physical Sciences Research Council (EPSRC) and Innovate U.K. She is also a member of the IOM3 Smart Materials & Systems Committee (SMASC), the Institute of Physics (IOP), the Institute of Electrical and Electronics Engineers (IEEE) Ferroelectrics, the Royal Society of Chemistry (RSC), and the U.K. Society of Biomaterials (UKSB).

ABDUL HALIM MIAH received the Ph.D. degree in electronic engineering from Kwangwoon University, Seoul, South Korea, in 2016, and the Ph.D. degree in wideband vibration energy harvesting from low-frequency vibration as well as human-body-induced motion. He is currently working as a Postdoctoral Associate with the Interdisciplinary Microsystems Group (IMG), Electrical and Computer Engineering Department, University of Florida (UF), USA. Prior to joining the UF, he worked on energy harvesting for wearable smart devices applications as a Postdoctoral Research Associate with the Department of Mechanical Engineering, The University of Utah, USA. He has more than 50 publications in peer-reviewed journals and reputed international conferences and holds two patents. He has also been serving as a Reviewer for various prestigious peer-reviewed journals and international conferences, including IEEE ACCESS, IEEE TRANSACTIONS ON ELECTRON DEVICES, *Journal of Micromechanics and Microengineering*, *Applied Energy*, *Smart Materials and Structures*, *Nano Energy*, *International Journal of Energy Technology*, *Sensors*, and *Nanomaterials*. His current research interest includes miniature wireless charging systems for cluttered environments. His research interests include multi-source energy harvesting, self-powered wearables, micro-electromechanical systems, wireless power transfer, magnetic microsystems, and multi-functional materials and systems. He has served as a Lead Guest Editor for a Special Issue in *Shock and Vibration*.

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