Guest Editorial: Selected Papers From the 2020 IEEE International Solid-State Circuits Conference

THE IEEE International Solid-State Circuits Conference (ISSCC) is the flagship conference of the IEEE Solid-State Circuits Society and the foremost global forum for presenting advances in solid-state circuits and systems-on-a-chip. From 2010–2019, the IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS has highlighted selected papers from ISSCC on topics related to biological and healthcare applications. This special section features eight selected papers from ISSCC 2020, held in San Francisco, California, USA from February 16 to February 20, 2020.

This set of papers offers a sample of the rapidly expanding developments in solid-state circuits for health monitoring, therapeutics, diagnostics, and medical research applications. The selection of these papers, whose final decision was based on a thorough peer review process, was coordinated with the IEEE JOURNAL OF SOLID-STATE CIRCUITS (JSSC) to avoid overlap with its ISSCC 2020 special issue, which includes biomedical papers as well. We acknowledge the ISSCC 2020 General Chair, Prof. Jan van der Spiegel, and the Editor-in-Chief of the IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, Prof. Guoxing Wang, for their support.

The paper by Marefat *et al*. from Case Western Reserve University describes a low-power readout IC (ROIC) for high-fidelity recording of the photoplethysmogram (PPG) signal. The system comprises a highly reconfigurable, continuous-time, 2^{nd}-order, incremental delta-sigma modulator (I–$\Delta\Sigma$M) as a light-to-digital converter (LDC), a 2-ch 10b light-emitting diode (LED) driver, and an integrated digital signal processing (DSP) unit. The LDC operation in intermittent conversion phases coupled with digital assistance by the DSP unit allow signal-aware, on-the-fly cancellation of the dc and ambient light-induced components of the photodiode current for more efficient use of the full-scale input range for recording of the small-amplitude, ac, PPG signal. Fabricated in TSMC 0.18 μm 1P/6M CMOS, the PPG ROIC exhibits a high dynamic range of 108.2 dB and dissipates on average 15.7 μW from 1.5 V in the LDC and 264 μW from 2.5 V in one LED (and its driver), while operating at a pulse repetition frequency of 250 Hz and 3.2% duty cycling. The overall functionality of the system is also demonstrated by high-fidelity recording of the PPG signal from a human subject fingertip in the presence of both natural light and indoor light sources of 60 Hz.

The paper by Erfani *et al*. from the same group at Case Western Reserve University is a companion paper to the one above. This paper presents a reconfigurable, dual-output, regulating rectifier featuring pulse width modulation (PWM) and dual-mode pulse frequency modulation (PFM) control schemes for single-stage ac-to-dc conversion, which can provide two independently regulated supply voltages (each in 1.5–3 V) from an input ac voltage. The dual-mode PFM controllers feature event-driven regulation as well as frequency division. The former incorporates stable, fast, digital feedback loops to adaptively adjust the driving frequency of four power transistors based on the desired output power level to perform voltage regulation and deliver fast, transient, load currents. The latter sets the driving frequency of the power transistors to a user-defined fraction of the input frequency. The PWM controllers incorporate stable, analog, feedback loops to accurately adjust the conduction duration of the power transistors for voltage regulation and can be combined with PFM frequency division for an extended operation dynamic range. Fabricated in 0.18 μm 1P/6M CMOS, the regulating rectifier features power conversion efficiency (PCE) of $>$83.8% at 2 MHz and 5 MHz, with the first output channel delivering $\sim$1 mW from V_{DD} of 1.5 V and the second output channel delivering variable power from V_{DDH} of 2.5 V to a load in the range of 0.1 to 1 kΩ. Peak PCE values of 90.75% (2 MHz, 100 Ω) and 90.7% (5 MHz, 200 Ω) are also measured. The regulating rectifier is suitable for the emerging modality of capacitive wireless power transfer to biomedical implants.

The paper by Jia *et al*. from North Carolina State University, Worcester Polytechnic Institute, Bionic Sciences Inc., and Michigan State University describes a wireless, batteryless, trimodal neural interface system-on-chip (SoC) capable of 16-ch neural recording, 8-ch electrical stimulation, and 16-ch optical stimulation, all integrated on a 5 $\times$ 3 mm^2 chip fabricated in 0.35 μm standard CMOS process. The trimodal SoC is designed to be inductively powered and communicated. The downlink data telemetry utilizes on-off-keying pulse-position modulation (OOK-PPM) of the power carrier to deliver configuration and control commands at 50 kbps. The analog front-end (AFE) provides adjustable mid-band gain of 55–70 dB, low/high cut-off frequencies of 1–100 Hz/10 kHz, and input-referred noise of 3.46 μV_{rms} within 1 Hz–50 kHz bandwidth. The AFE outputs of every two channels are digitized by a 50 kS/s 10-bit SAR ADC and multiplexed together to form a 6.78 Mbps data stream to be sent out by OOK-modulating a 434 MHz RF carrier through a power amplifier (PA) and 6 cm monopole antenna,

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which form the uplink data telemetry. Optical stimulation has a switched capacitor-based stimulation (SCS) architecture, which can sequentially charge four storage capacitor banks up to 4 V and discharge them in selected µLEDs at instantaneous current levels of up to 24.8 mA on-demand. Electrical stimulation is supported by four independently driven stimulating sites at 5-bit controllable current levels in ±25–775 μA range, while active/passive charge balancing circuits ensure safety.

The paper by Song *et al*. from imec presents a millimeter-scale, crystal-less, wireless transceiver for volume-constrained insertable pills. Operating in the 402–405 MHz medical implant communication service (MICS) band, the phase-tracking, receiver-based, over-the-air carrier recovery has ±160 ppm coverage. A fully integrated, adaptive, antenna impedance-matching solution is proposed to calibrate the antenna impedance variation inside the body. A tunable matching network with single inductor performs impedance matching for both transmitter (TX) and receiver (RX) and TX/RX mode switching. To dynamically calibrate the antenna impedance variation over different locations and diet conditions, a loop-back power detector using self-mixing is adopted, which expands the power contour up to 4.8 VSWR. The transceiver is implemented in 40 nm CMOS technology, occupying 2 mm^2 of die area. The transceiver chip and a miniature antenna are integrated in a 3.5 × 15 mm^2 prototype wireless module. It has a receiver sensitivity of –90 dBm at 200 kbps data rate and delivers up to –25 dBm EIRP in wireless measurements with a liquid phantom.

The paper by Park *et al*. from the National University of Singapore presents a retinal prosthesis that employs a 56.3 nW/channel neuromorphic image processor distributed across all pixels that extracts the outline of an imaged object by means of a spike-based asynchronous digital operation. This reduces the current dispersion and stimulus power. At every 5 × 5 pixels, a localized temperature-regulation circuit is added to ensure that the temperature increase of the neighboring retinal cells is limited to less than 1°C, and limits the overall power consumption of the SoC at a safe level. The 1,225-ch SoC fabricated in 0.18 μm CMOS occupies 15 mm^2, consumes 2.7 mW, and is demonstrated in image reconstruction.

The paper by Yu *et al*. from Rice University describes a wireless/programmable neural stimulator that utilizes the magnetoelectric (ME) effects for power and data transfer. The authors demonstrate safe delivery of power levels in the order of mW by taking advantage of low resonant frequencies in 250 kHz band to mm-sized implants at a depth of 30 mm in the tissue. The magnetoelectric neural implant consists of a 1.5 mm^2 chip, implemented in 180 nm CMOS, and includes a ME film, a storage capacitor, and off-chip electrodes on a flexible polyimide substrate. The chip consumes 23.7 μW for data recovery and control of biphasic current-controlled stimulation up to 1.5 mA and 200 Hz.

The paper by Tang *et al*. from the National University of Singapore presents a wearable, active, concentric electrode for concurrent EEG monitoring and body-coupled communication (BCC) data transmission. A 3-layer concentric electrode eliminates the wires. A common-mode-averaging unit is proposed to cancel not only the continuous common-mode interference (CMI), but also the instantaneous CMI of up to 51 V_{pp}. The localized potential matching technique removes the ground electrode. An open-loop programmable gain amplifier with a pseudo-resistor-based RC-divider block is employed to save silicon area. This work for the first time achieves concurrent EEG recording and BCC-based data transmission. The proposed chip achieves 100 dB CMRR and 110 dB PSRR, occupies 0.044 mm^2, and consumes 7.4 μW with an input-referred noise density of 26 nV/$\sqrt{\text{Hz}}$.

Finally, the paper by Li *et al*. from the same group at the National University of Singapore presents body-coupled power transmission and ambient energy-harvesting ICs. The ICs utilize human body coupling to deliver power to the entire body, and at the same time, harvest energy from ambient EM waves coupling through the body. The IC improves the recovered power level by adapting to the varying skin-electrode interface parasitic impedance at both the TX and RX sides. To maximize the power output from the TX, dynamic impedance matching is performed amidst environment-induced variations. At the RX, detuned impedance booster and bulk adaptation rectifier are proposed to improve the power recovery and further extend the power coverage. The ICs fabricated in 40 nm 1P/8M CMOS recover up to 100 μW from body-coupled power transmission and 2.5 μW from ambient body-coupled energy harvesting. The ICs achieve full-body power delivery, with the power harvested via the ambient body-coupling mechanism being independent of placements on the body. Both approaches show power sustainability for wearable electronics all around the human body.

ALISON BURDETT, *Guest Editor and Associate Editor*
Sensium Healthcare
115 Olympic Ave, Milton Park
Oxfordshire, OX14 4SA, UK

PEDRAM MOHSENI, *Guest Editor and Associate Editor*
Department of Electrical, Computer, and
Systems Engineering
Case Western Reserve University
Cleveland, OH 44106, USA

MAYSAM GHOVANLOO, *Guest Editor and Associate Editor*
Bionic Sciences Inc.
Atlanta, GA 30316, USA

ROMAN GENOV, *Guest Editor and Associate Editor*
Department of Electrical and Computer
Engineering
University of Toronto
Toronto, ON M5S 3G4, Canada

Alison Burdett (Senior Member, IEEE) received the B.Eng. degree in electrical and electronic engineering and the Ph.D. degree in electronic engineering from Imperial College London in 1989 and 1992, respectively. She currently splits her time between two roles, as CSO with Sensium Healthcare where she is responsible for delivering biomedical and advanced technology research programs related to very-low-power wireless monitoring, and as VP with Clinical Engineering, DnaNudge Ltd. Prior to joining Sensium, Alison was CTO of Toumaz Group (now Frontier Smart Technologies), and spent time in academia (as Senior Lecturer with Analogue IC Design, Imperial College London). She is a Chartered Engineer, a Fellow with the Institute of Engineering and Technology (FIET). She is a Member of the U.K. EPSRC Strategic Advisory Network, a Visiting Researcher with the Institute of Biomedical Engineering, Imperial College, and a Member of the Wellcome Trust Science and Innovation Program Advisory Group. She is an Associate Editor for IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS and was Technical Program Chair of the 2018 IEEE International Solid-State Circuits Conference.

Pedram Mohseni (Senior Member, IEEE) received the B.S. degree from the Sharif University of Technology, Tehran, Iran, in 1996, and the M.S. and Ph.D. degrees from the University of Michigan, Ann Arbor, MI, USA, in 1999 and 2005, respectively, all in electrical engineering. In 2005, he joined Case Western Reserve University, Cleveland, OH, USA, where he is currently the Goodrich Professor of Engineering Innovation and the Inaugural Chair of the Electrical, Computer, and Systems Engineering (ECSE) Department. He also holds a secondary appointment with the Biomedical Engineering Department. He has authored or coauthored two book chapters and more than 125 refereed technical and scientific articles. He holds eight issued and pending patents. His research interests include analog/mixed-signal/RF integrated circuits and microsystems for neural engineering, wireless sensing/actuating systems for brain-machine interfaces, interface circuits for micro-/nano-scale sensors/actuators, and point-of-care diagnostic platforms for personalized health. He was a Member of the Technical Program Committee (TPC) of the IEEE Radio Frequency Integrated Circuits Symposium from 2012 to 2015 and the IEEE Custom Integrated Circuits Conference from 2012 to 2019, and has been a Member of the TPC of the International Solid-State Circuits Conference since 2017. He has been a Member of the IEEE Solid-State Circuits, Circuits and Systems, and Engineering in Medicine and Biology Societies. He was a Member of the Administrative Committee of the IEEE Sensors Council from 2014 to 2017. He was the recipient of several awards, including the National Science Foundation CAREER Award, the Case School of Engineering Research Award, the First-Place Prize of the Medical Device Entrepreneur's Forum at the 58th Annual Conference of the American Society of Artificial Internal Organs, and the ECSE Mihajlo "Mike" Mesarovic Award for Extraordinary Impact. He was the TPC Co-Chair of the IEEE BioCAS conference in 2017 and the General Co-Chair of the conference in 2018. He has been an Associate Editor and a Guest Editor for several IEEE journals since 2008.

Maysam Ghovanloo (Fellow, IEEE) received the B.S. degree in electrical engineering from the University of Tehran, Tehran, Iran, and the M.S. degree in biomedical engineering from the Amir kabir University of Technology, Tehran, in 1997. He also received the M.S. and Ph.D. degrees in electrical engineering from the University of Michigan, Ann Arbor, in 2003 and 2004. From 2004 to 2007, he was an Assistant Professor with the Department of ECE, the North Carolina State University, Raleigh, NC. From 2007 to 2019, he was a Professor with the Georgia Institute of Technology School of Electrical and Computer Engineering, where he founded the GT-Bionics Lab. He is currently the founding CTO of Bionic Sciences Inc. and a Senior Designer with Silicon Creations LLC. He has ten issued patents and has coauthored more than 200 peer-reviewed book chapters, conference, and journal publications on implantable microelectronic devices, integrated circuits and microsystems for medical applications, and modern assistive and rehabilitation technologies. He is an Associate Editor for the IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS. He was a CAS Society Distinguished Lecturer in 2015–2016. He was the General Chair of the IEEE BIOMEDICAL CIRCUITS AND SYSTEMS (BioCAS) conference in 2015, and Technical Program Co-Chair in 2014, 2016, 2018, and 2019. He served as an Associate Editor for IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS, PART II from 2008–2011, as well as a Guest Editor for the IEEE JOURNAL OF SOLID-STATE CIRCUITS and IEEE TRANSACTIONS ON NEURAL SYSTEMS AND REHABILITATION ENGINEERING. He was the recipient of the National Science Foundation CAREER Award, the Tommy Nobis Barrier Breaker Award for Innovation, and Distinguished Young Scholar Award from the Association of Professors and Scholars of Iranian Heritage.

Roman Genov (Senior Member, IEEE) received the B.S. degree in electrical engineering from the Rochester Institute of Technology, NY in 1996 and the M.S.E. and Ph.D. degrees in electrical and computer engineering from Johns Hopkins University, Baltimore, MD, in 1998 and 2003, respectively. He is currently a Professor with the Department of Electrical and Computer Engineering, the University of Toronto, Canada, where he is a Member of Electronics Group and Biomedical Engineering Group and the Director of Intelligent Sensory Microsystems Laboratory. His research interests include primarily in analog integrated circuits and systems for energy-constrained biological, medical, and consumer sensory applications. He is a Co-Recipient of the Jack Kilby Award for Outstanding Student Paper at IEEE International Solid-State Circuits Conference, Best Paper Award of IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, Best Paper Award of IEEE Biomedical Circuits and Systems Conference, Best Student Paper Award of IEEE International Symposium on Circuits and Systems, Best Paper Award of IEEE Circuits and Systems Society Sensory Systems Technical Committee, Brian L. Barge Award for Excellence in Microsystems Integration, MEMSCAP Microsystems Design Award, DALSA Corporation Award for Excellence in Microsystems Innovation, and Canadian Institutes of Health Research Next Generation Award. He was a Technical Program Co-Chair at IEEE Biomedical Circuits and Systems Conference and a Member of IEEE International Solid-State Circuits Conference International Program Committee. He was also an Associate Editor for IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS-II: Express Briefs and IEEE SIGNAL PROCESSING LETTERS, as well as a Guest Editor for IEEE JOURNAL OF SOLID-STATE CIRCUITS. He is currently an Associate Editor for IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS and a Member of IEEE European Solid-State Circuits Conference Technical Program Committee.