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IEEE OPEN JOURNAL OF THE SOLID-STATE CIRCUITS SOCIETY Special Section on Biomedical Electronics

RECENT advances in biomedical electronics have opened the doors to pervasive/wearable technologies as well as bioinspired systems. Traditional disease treatment is shifting toward preemptive, personalized healthcare. For these biomedical electronics to work seamlessly, careful design of integrated circuits for sensing, signal processing, and powering is crucial. However, biomedical applications often are under unique and harsh environments, such as under extremely stringent power budgets and fluctuating supply voltages; on top of this, such applications require hermetic sealing with robust communications. Moreover, we also need to consider various aspects that other applications do not normally consider. As an example, the human body absorbs GHz range electromagnetic signals significantly, making typical RF communication and powering technologies such as Bluetooth or wireless power transfer (WPT) in GHz not an ideal choice in/around body area [1]. Also, with the rise of artificial intelligence and machine learning, personalized healthcare is becoming more popular, but for some applications, “personalized” means that training sets may get scarce, posing issues to achieving high sensitivity and specificity at once. This special section will present the latest developments in integrated circuits in biomedical electronics to overcome the aforementioned issues: powering, sensing, and processing.

Many biomedical devices, such as bionic arms and implantable/wearable sensors, have limited energy sources; hence they often exploit power transfer from an energy source to the device of interest. Such WPT can be done using a variety of methods, for example, exploiting the medical implant communication system (MICS) band, inductive coupling [2], or, more aggressively, using the human body itself as powering medium [1]. Whichever methods we may use, we need to ensure that a proper dc voltage is generated at the receiving end. This is done by exploiting suitable dc–dc converters, which must comply with stringent low-power requirements, as the energy efficiency of the powering system is one of the designer’s primary interests.

With this in mind, the first paper [A1] by Lee et al. discusses powering implanted medical devices (IMDs) through WPT paired with an automatically reconfigurable switched-capacitor (SC) dc–dc converter. As many implantable systems require a multiple-voltage domain, the proposed SC dc–dc converter simultaneously generates multiple voltages, with two regulated and two unregulated outputs; the unregulated voltage output will then be fed to the subsystems’ voltage regulators. Composed of an input-adaptive dc–dc conversion stage and a regulating stage, the converter automatically reconfigures the conversion ratio and connection order of the two SC dc–dc converters to adapt to the different input levels. The adaptive reconfiguration allows for high conversion efficiencies over a wide input voltage range, with fewer flying capacitors than the typical dc–dc converters. As the input level and load conditions fluctuate greatly in IMDs, maintaining high efficiencies over varying environments is extremely important. The converter is implemented in a 180-nm standard CMOS process and achieves 95.5% and 77.4% conversion efficiencies for unregulated and regulated voltages, respectively, over a wide input range of 1–4 V while providing four simultaneous outputs.

Once we have an adequate powering mechanism, now it is time to have a sensor interface to capture high-fidelity biosignals. The second paper [A2] by Ma et al. covers sensing with particular emphasis on electrochemical electrodes and readout. With its real-time response and high accuracy, electrochemical sensing and detection are widely used for health monitoring and medical diagnosis [2], [3], [4], [5]. Here, sensing quality will depend on both the electrodes and the readout circuits, where researchers have continuously improved both aspects for the past decades. The paper reviews the recent material development of passive electrodes and the evolution of state-of-the-art active electrodes. When it comes to readout circuits, both voltage- and current-based topologies are used; the paper compares the pros and cons of each type. The readout circuits for passive electrodes focus on high precision and high bandwidth. On the other hand, for active electrodes, more emphasis is on multichannel configuration and dynamic/adaptive nonideality compensation. The paper also discusses recent breakthroughs in device innovation for electrochemical sensings, such as the ion-selective field-effect transistor (ISFET) [6] and organic electrochemical transistors (OECTs) [7].

Another important field of research in biomedical electronics is processing/analysis. Unlike conventional DNA analysis, which requires time-consuming sample flushing, amperometric DNA analysis is performed with in situ samples; hence real-time analysis is possible [8]. One critical point for a successful DNA analysis is accurate temperature control. For example, DNA hybridization is highly dependent on temperature; a 10 °C increase in temperature drops the redox current by 10% [9]. At the same time, polymerase chain reaction (PCR) requires an accurate time-varying temperature control between 20 °C and 90 °C so that DNA multiplication is done properly. Such temperature regulation becomes particularly tricky when the multichannel, multimodal system has different temperatures across different regions. To address this, the third paper [A3] by Jafari et al. presents a distributed thermal regulation technique for multimodal amperometric DNA analysis. With the in-cell heating and temperature sensing integrated in a 130-nm standard CMOS, the authors integrated proportional–integral–derivative (PID) control into the system to regulate the local temperature within ±0.5 °C of any desired value between 20 °C and 90 °C.

APPENDIX: RELATED ARTICLES

[A1] U. Lee, W. Jung, S. Ha, and M. Je, "An auto-reconfigurable multi-output regulating switched-capacitor DC–DC converter for wireless power reception and distribution in multi-unit implantable devices," *IEEE Open J. Solid-State Circuits Soc.*, early access, Aug. 26, 2022, doi: 10.1109/OJSSCS.2022.3202145.

[A2] Y. Ma et al., "A review of electrochemical electrodes and readout interface designs for biosensors," *IEEE Open J. Solid-State Circuits Soc.*, early access, Nov. 14, 2022, doi: 10.1109/OJSSCS.2022.3221924.

[A3] H. M. Jafari, X. Liu, and R. Genov, "Synergistic distributed thermal regulation for on-CMOS high-throughput multi-modal amperometric DNA-array analysis," *IEEE Open J. Solid-State Circuits Soc.*, early access, Jan. 12, 2023, doi: 10.1109/OJSSCS.2023.3236305.

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[2] H.-M. Lee and M. Ghovanloo, "An adaptive reconfigurable active voltage doubler/rectifier for extended-range inductive power transmission," in *IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers*, Feb. 2012, pp. 286–287.

[3] R. Li et al., "A flexible and physically transient electrochemical sensor for real-time wireless nitric oxide monitoring," *Nat. Commun.*, vol. 11, pp. 1–11, Jun. 2020. [Online]. Available: https://doi.org/10.1038/s41467-020-17008-8

[4] S.-Y. Lu et al., "18.4 A wireless multimodality system-on-a-chip with time-based resolution scaling technique for chronic wound monitoring," in *IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers*, vol. 64, Feb. 2021, pp. 282–284.

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[6] D. M. Garner et al., "A multichannel DNA SoC for rapid point-of-care gene detection," in *IEEE Int. Solid-State Circuits Conf. (ISSCC) Dig. Tech. Papers*, Feb. 2010, pp. 492–493.

[7] X. Tian et al., "Pushing OECTS toward wearable: Development of a miniaturized analytical control unit for wireless device characterization," *Anal. Chem.*, vol. 94, no. 16, pp. 6156–6162, 2022.

[8] P. M. Levine, P. Gong, R. Levicky, and K. L. Shepard, "Active CMOS sensor array for electrochemical biomolecular detection," *IEEE J. Solid-State Circuits*, vol. 43, no. 8, pp. 1859–1871, Aug. 2008.

[9] A. Sassolas, B. D. Leca-Bouvier, and L. J. Blum, "DNA biosensors and microarrays," *Chem. Rev.*, vol. 108, no. 1, pp. 109–139, 2008.

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