Introduction to Special Issue on Implantable Electronics

With great advances in electronics and electrode technologies, it has become possible to realize implantable biomedical microsystems that interface with internal body parts to monitor and manipulate their activities. One of the major success stories in the field of implantable systems is the cardiac pacemaker, which has been implanted in countless patients. Today, miniaturized wireless implantable systems are changing the face of biomedical research and clinical practices through the development of intelligent pacemaker, cochlear implant, neural prosthesis, bladder pressure monitor/control devices, and even precise drug delivery units. These systems are making broad scientific and transformational impact. They are saving or enhancing the lives of millions through clinical diagnosis and therapeutics for complex diseases. On the other hand, they are providing invaluable tools to increase our scientific understanding of different body parts including the central nervous system. For example, implantable neural interfaces are being used for neural recording and stimulation as in Functional Electrical Stimulation (FES) to assist patients in grasping, standing, or urination. Deep brain stimulation (DBS) has been shown to be an effective treatment for Parkinson's disease. At the same time, these systems are greatly helping researchers to understand the mechanisms of neural communication and control.

For real-time in vivo analysis as well as compression of the recorded biological signals, these systems require increasingly complex signal processing electronics. In addition, they typically require analog signal conditioning electronics and telemetry systems for wireless transfer of data and possibly power. These electronic components need to be implemented under extremely tight area and power constraints for small footprint and increased battery life. The use of nanoscale technology shows tremendous benefits in implementing these circuits due to dramatic improvement in integration density and dynamic power dissipation. However, it also brings new challenges such as reduced reliability and high standby power.

This special issue of JETC presents several articles that highlight the state-of-the-art implantable electronics. Contributions were submitted from researchers across the globe. Each article was selected through a rigorous peer review process. These articles focus on a wide range of design and computing aspects related to implantable microsystems, provide representative case studies covering several domain of applications, and address potential benefits of using emerging technologies in building implantable systems. They illustrate the design issues, design parameters, and optimization of each component for specific applications.

The special issue starts with an article on the history of implantable systems between 1950 and 1970. Contributed by one of the pioneers of implantable systems, Wen H. Ko, it looks back to early examples of such systems, discusses their evolution, and highlights the present challenges associated with designing these systems. It also points out some important emerging trends for developing more powerful implantable systems in future.

The next two articles describe implantable systems that interface with the brain for effective treatment of epileptic seizure, a common chronic neurological disorder. The first of these two articles presents a closed-loop epilepsy prosthesis system consisting of novel automatic seizure detection hardware and a dedicated electrical stimulation unit to suppress a developing seizure. The article by Salam et al. analyzes the effectiveness of the system using prerecorded patient data and in vitro testing. It also identifies suitable stimulation parameters. The next article by Sharad et al. presents a novel discrete wavelet transform (DWT)-based epileptic seizure detection algorithm

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and low-power programmable hardware architecture for its efficient implementation. It exploits the fact that an onset of seizure can be detected by focusing on the very low frequency bands of the recorded neural data to minimize the power budget. The reconfiguration ability allows optimizing the system for individual patient characteristics. The algorithm is validated on prerecorded data from rats and implemented in an advanced process technology with an ultra low power requirement.

The fourth article, authored by Majerus et al., presents the implementation of an automatic online bladder pressure sensing system. Chronic bladder pressure monitoring is important in urodynamics for diagnosis and neuromodulation-based bladder control and rehabilitation. An implantable pressure monitor provides an attractive alternative to the state-of-the-art catheter-based monitoring system. The article presents the architecture and circuit-level implementation details of an ultra low power wireless pressure telemetry system and provides measurement results to demonstrate the effectiveness of such a system.

The next article presents an efficient implementation of an implantable drug-delivery system that provides higher therapeutic efficacy than conventional drug delivery approaches and can enable precise drug dosing of localized treatment, such as cancer therapy or immediate medication needed in case of heart attack. The authors, Huang et al., present a detailed design of a system-on-chip (SoC) that integrates a release-on-demand array of eight individually addressable drug reservoir units and controller/actuation circuitry for precise wireless control of these units. The prototype system has been validated with in-vitro testing.

The last article of the issue presents a study on using emerging nonvolatile memory (NVM) technologies for data storage in an implantable system. It considers Spin transfer torque random access memory (STT-RAM) and spintronic memristor memory for storing data in an implantable electrocardiography (ECG) recording application. Sun et al. present application-specific optimizations of the memory including a change in the read/write schemes and weighs trade-off among several design parameters. It shows that NVM technologies can provide major benefits for implantable systems in terms of storage density and power dissipation when compared to conventional embedded memory.

We hope that this issue will give readers an opportunity to learn more about recent advances in the field of implantable systems, how increasingly powerful computing devices can be incorporated into these systems, and how nanotechnologies play a critical role in advancing their applicability. We also hope the articles included in this issue stimulate critical thinking and create new research pathways.

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