# Low Power Wireless ECG Acquisition and Cardiac Stimulation SOCs for Body Sensor Networks

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***Abstract*—In recent years, body sensor networks (BSNs) based applications or devices have become more and more popular, and acceptable to the people for monitoring the real-time health information, such as the electrocardiogram (ECG). In order to enhance the portability and increase the popularization of BSNs, a low-power wireless ECG acquisition system on a chip (SOC) stuck on the body is required. In this tutorial, a bio-signal acquisition system with the features of low power consumption, wireless transmission, and the on-time monitoring will be presented. Moreover, some researches have been reported that it is efficient to electrically generate neural action potential to control dysfunctional organs. Therefore, various implantable microstimulators have been designed for various clinical applications, such as cardiac pacemaker and cochlear implant. The telemetry integrated circuits will be required because they can provide coupling power and are able to transmit or receive data to or from according to implantable body sensor network. In this tutorial, a closed-loop implantable micro-stimulator system on chip (IMSoC), which possesses the sensing of a physiological signal, micro-stimulation, and wireless data/command transmission, will be also presented.**

## I. Introduction

The low-power SOC for out-of/implantable body sensor networks will be introduced in this tutorial, and the required challenged circuits including analog front-end circuits, passive/active RF front-end circuits, power management, digital signal processing circuits will be presented. This tutorial will serve to provide an opportunity for audiences to face and discuss the challenges which are the design techniques of electronics, circuits, and systems in this emerging and exciting research field.

## II. Body Sensor Network SOC

Heart disease has been the number one cause of death for a period of over 10 years [1]. Therefore, several medical devices have been developed to monitor the heart disease for healthcare. In recent years, body sensor network (BSN)-based applications or devices have become increasingly popular and widely accepted [2],. People are now willing to use verified devices for bio-signal acquisition, such as the electrocardiogram (ECG) or the electroencephalogram (EEG), because these devices can help in monitoring patient health in real time [3]. With the development of networks, collected health information can be sent to the cloud server of the nearest clinic or hospital. Doctors can then provide patients with medical advice. In other words, BSN-based devices or applications can help both patients and doctors in daily health monitoring.

### *A. Wireless ECG Acquisition SoC for IEEE 802.15.4 (ZigBee) Applications[4]*

This session presents a wireless bio-signal acquisition system-on-a-chip (WBSA-SoC) specialized for electrocardiogram (ECG) monitoring. The proposed system consists of three subsystems, namely, (1) the ECG acquisition node, (2) the protocol for standard IEEE 802.15.4 ZigBee system, and (3) the radio frequency (RF) transmitter circuits. The ZigBee protocol is adopted for wireless communication to achieve high integration, applicability, and portability. A fully integrated CMOS RF front end containing a quadrature voltage-controlled oscillator and a 2.4 GHz low-IF (i.e., zero-IF) transmitter is employed to transmit ECG signals through wireless communication. The low-power WBSA-SoC is implemented by the TSMC 0.18 μm standard CMOS process. An ARM-based displayer with FPGA demodulation and an RF receiver with analog-to-digital mixed-mode circuits are constructed as verification platform to demonstrate the wireless ECG acquisition system. Measurement results on the human body show that the proposed SoC can effectively acquire ECG signals.

In this session, the ECG acquisition circuits, a transmitter-baseband processor, and an RF front-end transmitter are used to coordinate with the low-power high-integration WBSA-SoC. The WBSA-SoC is responsible for acquiring feeble ECG signals perceived from the electrode leads. The system block diagram is shown in Fig. 1(a). A real-time ECG data receiver is integrated on the board to receive and display the physical signals controlled by the ZigBee firmware. These physical signals include those from RF receiver circuits, the analog-to-digital MM interface, the demodulator implemented by FPGA, and the ARM-based displayer [Fig. 1(b)]. The detailed circuits are described in the subsequent subsections.

### *B. Low-Power Wireless ECG Acquisition and Classification System[5]*

A low-power biosignal acquisition and classification system for body sensor networks is proposed. The proposed system consists of three main parts: 1) a high-pass sigma delta modulator-based biosignal processor (BSP) for signal acquisition and digitization, 2) a low-power, super-regenerative on-off keying transceiver for short-range wireless transmission, and 3) a digital signal processor (DSP) for electrocardiogram (ECG) classification. The BSP and

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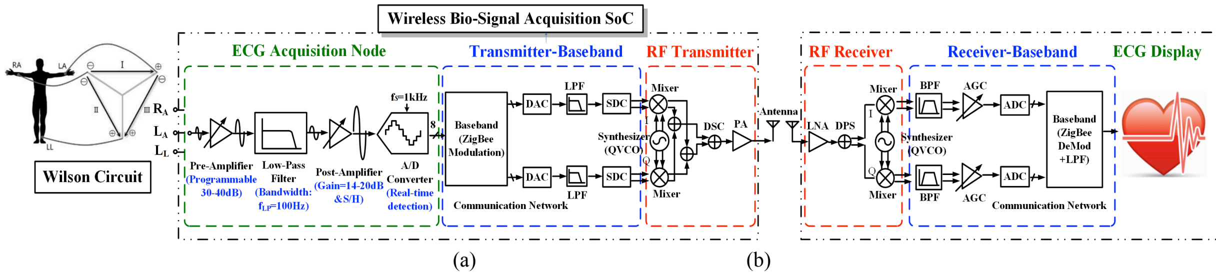


Fig. 1. (a) Block diagram of the proposed WBSA-SoC, and the (b) wireless receiver for ECG monitoring.

transmitter circuits, which are the body-end circuits, can be operated for over 80 days using two 605 mAH zinc–air batteries as the power supply; the power consumption is 586.5 μW. As for the RF receiver and digital signal processor, which are the receiving-end circuits that can be integrated in smartphones or personal computers, power consumption is less than 1 mW. With a wavelet transform-based digital signal processing circuit and a diagnosis control by cardiologists, the accuracy of beat detection and ECG classification are close to 99.44 % and 97.25 %, respectively. All chips are fabricated in TSMC 0.18 μm standard CMOS process.

The proposed system is shown in Fig. 2 which are composed of the BSP and the transmitter, are 1) low power consumption for long-term usage and 2) acquisition resolution that is high enough for ECG signal classification. Given these two objectives, the body-end circuits should have low circuit complexity and require an appropriate architecture for the transceiver to achieve the demand for low power consumption. For the receiving-end circuits, the major objectives are 1) recovering the radio frequency (RF) signal and 2) recovering the biosignal classification. However, the receiving-end circuits can be integrated into a monitoring and control service (MCS), which can come in the form of a smartphone or a personal computer. Unlike body-end circuits, recovering-end circuits do not urgently require low power consumption, as these devices can share the same power source. The following sections describe the major concerns of the proposed system.

### *C. A Programmable Implantable Micro-stimulator SoC with Wireless Telemetry[6]*

A low-power, wireless, and implantable micro-stimulator system on chip with smart powering management, immediate neural signal acquisition, and wireless rechargeable system is proposed. A system controller with parity checking handles the adjustable stimulus parameters for the stimulated objective. In the current paper, the rat's intra-cardiac electrogram is employed as the stimulated model in the animal study, and it is sensed by a low-voltage and low-power monitoring analog front end. The power management unit, which includes a rectifier, battery charging and detection, and a regulator, is used for the power control of the internal circuits. The stimulation data and required clock are extracted by a phase-locked-loop-based phase shift keying demodulator from an inductive AC signal. The full chip, which consumes 48 μW only, is fabricated in a TSMC 0.35 μm 2P4M standard CMOS process to perform the monitoring and pacing functions with inductively powered communication in the *in vivo* study.

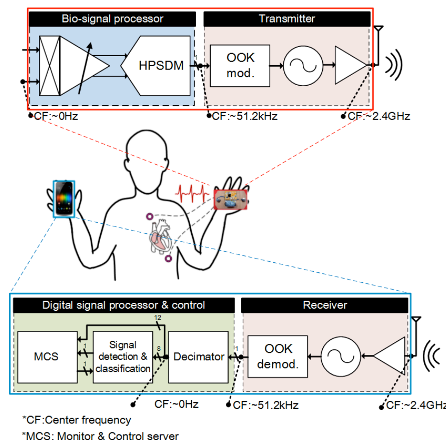


Fig. 2. Block diagrams of the proposed low-power wireless biosignal acquisition and classification system.

## III. Conclusion

This tutorial presents a biosignal acquisition and classification system with wireless telemetry for BSN. Moreover, the WBSA-SoC for BSN application is adopted to acquire actual human-body ECG signals according to ZigBee wireless communication. In the third part, a low-power IMSoC with smart powering management, immediate signal acquisition, and wireless telemetry system, is introduced. The presentation provides the discussion platform on the body sensor network for audiences.

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