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1-Chip ExG Recording System with Electrode Interface Evaluation Functions for Biologically Safe Recording

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Abstract

To record various kinds of biosignals in several applications like medicine and neuroscience, we have developed a 1-chip ExG recording circuit. There are also bio-impedance (IM) and charge injection capacities (CIC) measurement circuits integrated with the 1-chip ExG recording circuit to maintain electrode interfaces biologically safe and to record ExG safely and precisely. With this ExG recording circuit, we have also proposed a wireless ExG recording system for invasive and non-invasive devices. In this paper, we presented the circuit design in detail and the measurement results obtained by the circuit.

1. Introduction

A large number of biosignal (ECG etc.) recording devices for personal health monitoring have been proposed as wearable devices for convenient monitoring during these decades [1]. However, most of these devices can record only one or a few types of biosignals, which means that we have to use additional devices for various biosignal recording. For both invasive and non-invasive devices, ExG signals recorded by electrodes should be amplified and filtered with different gains and filtering bandwidths. Therefore, it is needed to expand the range of amplitude gains and bandwidths for recording the different signals in a single device.

Bio-impedance measurement can be used in body composition estimation and illness detection [2]. On the other hand, the changes of electrode impedance can be applied to contact condition confirmation. Charge injection capacities (CIC) measurement, as the charge injection ability when no degradation occurs on electrodes surface, is an available method to confirm whether the electrode degrades. In this paper, we proposed a wireless 1-chip ExG recording system with electrode interface evaluation function for biologically safe recording.

2. Architecture and circuit design

The block diagram of the system is shown in Fig. 1, where bio-impedance measurement circuit, CIC measurement circuit, and low drop out regulator (LDO) are integrated in the ExG recording circuit. A bluetooth low energy (BLE) module will be used as the interface between the ExG recording and local devices.

There are 13 channels for AC ExG recording (2 electrodes in 1 channel) and 2 channels for recording the DC-EEG signal. In AC ExG recording circuits, 2 electrodes (V_{in} and V_{ref}) sense the potential and input their difference signal into low noise amplifiers (LNA) with 20-40 dB programmable gains. In the LNA, the variable MOS resistances and capacitors change the lower cutoff frequencies with the range of 0.1-200 Hz to remove the low frequency components. Then, MUX selects a signal from 15 channels. After that, low pass filters (LPF) with 200-10 kHz programmable cutoff frequencies will remove higher frequency components, and buffer amplifier (BA) will amplify the signal from LPF and offer enough current for ADC sampling. At the end of the analog front-end, a successive approximation register A/D converter (SAR-ADC) converts the recorded signal. Furthermore, MOS resistors were used instead of poly-Si resistors to decrease the size of circuits.

Bio-impedance measurement with sinusoidal current signal needs a D/A converter (DAC) to generate sinusoidal current signal. The size of this circuit becomes larger because of the high-resolution DAC and higher order filter. Therefore, in our circuit, we used square current waveforms without the DAC and filter, and 20-60 dB programmable gain circuit in order to increase the measurable impedance ranges to 100 Ω -10 MΩ with 0.46 mm^2 area.

In the CIC circuit, current source injects the bipolar square current, then CIC_out will be recorded by LPF and BA. The AMP after the current source is an I/V converter and to verify the current level. With this 0.24 mm^2 circuit, we can perform condition checking of electrode and electrode interface evaluation for biologically safe recording.

3. Evaluation results

The 1-chip ExG recording circuit was fabricated in 1P6M 0.18-μm CMOS technology. We evaluated the functions of ExG biosignals recording, impedance measurement, and CIC of the circuit. The microphotograph of the 1-chip ExG recording circuit is shown in Fig. 2, and the circuit achieved a small size of 4.8 mm^2. To evaluate the ExG recording function, we used the circuit to measure EMG and ECG of a 25 years old male subject. At first, we set two electrodes on bicep, and do motions like dumbbell curls one turn per 2 seconds. With low cutoff frequency of 0.1 Hz in LNA, cutoff frequency of 200 Hz in LPF and 60 dB gain from analog front to end, an EMG signal was recorded as shown in Fig. 3(a). And, we measured the resting ECG of the male subject with 46 dB gain over the analog front to end. We measured the ECG from thumb prominences of left and right hands with 2 electrodes. The recorded ECG signal is shown in Fig. 3(b), which also shows that the heart rate of the subject is about 90 bpm. The enlarged ECG part shows clear PQRST wave components.

A parallel circuit of a 2 kΩ carbon film resistor and an 84 nF ceramic capacitor was measured by the circuit. The square current generated by I_source circuit and the voltage signal recorded by voltage recording circuit are shown in Fig. 4. We measured the impedance of the carbon film resistor and get the square voltage signal in which the resistance can be calculated by the ratio between A and A'. The dotted line is the voltage of the RC parallel. The rise-up period (Δt) can be used in capacity component calculation. The CIC measurement circuit was evaluated with a TiN electrode, and the CIC of the electrode was 0.21 mC/cm^2. Compared to the TiN electrode CIC data in [3], our CIC measurement circuit correctly measured the CIC of TiN electrode.

4. Conclusion

In this paper, we proposed a wireless 1-chip ExG recording system with safety evaluation functions. Both the impedance measurement and the CIC measurement circuit were designed to maintain electrode interfaces biologically safe and to record biosignals safely and precisely. From the measurement results, it is concluded that our circuit can successfully record EMG and ECG. Furthermore, both bio-impedance and CIC measurement circuits which worked for safety evaluation of electrode interface were evaluated successfully.

Acknowledgment

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Reference

[1] A. Sun, *et. al*, *IEEE Trans. Biomed. Circuits Syst.*, Vol. 10, No. 5, pp. 1–10, 2016.
[2] Grimnes, S., *et. al*, *Wiley Encyclopedia of Biomedical Engineering*, 2006.
[3] E. K. Brunton *et al.*, *Front. Neurosci.*, Vol. 09, No. 5, pp. 1–11, 2015.
[4] J. Yoo, *et. al*, *IEEE Journal of Solid-State Circuits*, Vol. 48, No. 1, pp. 214-228, 2013.
[5] C. S. Mestais, *et. al*, *IEEE Trans on Neural Systems and Rehabilitation Engineering*, Vol. 23, No. 1, pp. 10-21, 2015.

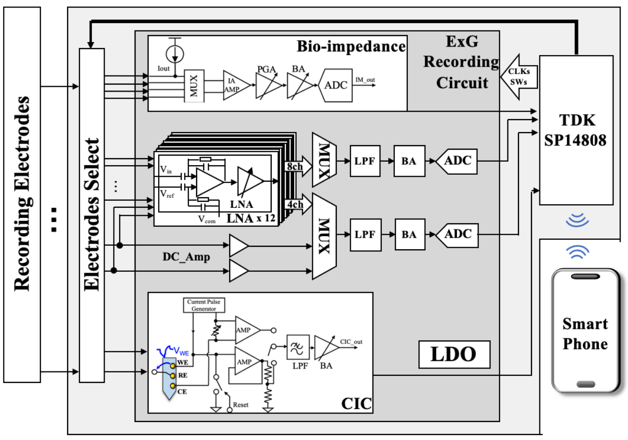

Fig. 1. The block diagram of the ExG recording system with impedance and CIC measurement functions.

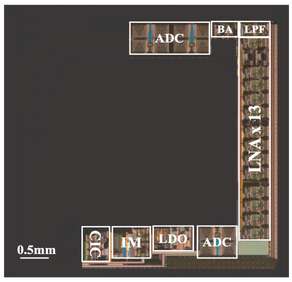

Fig.2 Microphotograph of the 1-Chip ExG recording circuit.

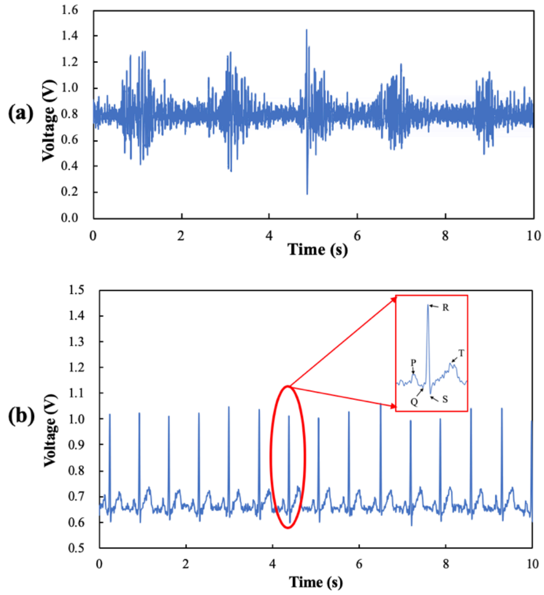

Fig. 3. EMG (a) and ECG (b) signals recorded of male subject.

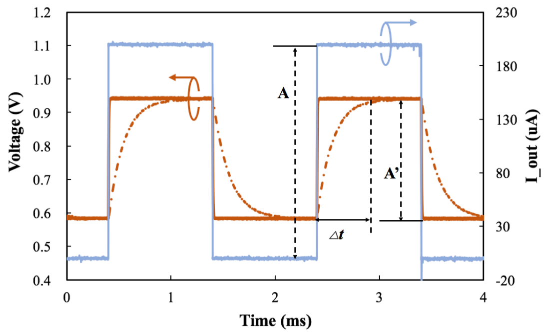

Fig. 4. Result of bio-impedance measurement circuit.

Table 1. Comparison of circuit features.

	This work	*JSSC -2013*[4]	*T-NSRE -2015*[5]
Technology (μm)	0.18	0.18	0.35
Band Width (Hz)	0.1~10k	0.07~100	0.5~300
No. of Channels	13+2(DC)	8	32
Size (mm^2)	4.8	5.67	N/A
Integrated Functions	ExG, DC-EEG, IM, CIC	EEG	ECoG