

# Neural-Sensing LSI with Wireless Interface

Takeshi Yoshida, Takayuki Mashimo, Miho Akagi and Atsushi Iwata

Graduate School of Advanced Sciences of Matter, Hiroshima University  
E-mail: {tyoshida,takayuki,miho,iwa}@dsl.hiroshima-u.ac.jp

## 1 Introduction

Various neural sensors fabricated by LSI technologies that have achieved for implantable clinical and physiological applications [1, 2]. The CMOS-LSI technology enables to implement a high-density and a functional system, however a MOSFET has large flicker noise and deviation of threshold voltage, CMOS Operational-Amplifier (OpA) hardly amplifies a weak neural signal. Moreover, the implantable systems needed to transmit system control-commands and to receive sensor data in order to observe the neural signal under freely behaving condition.

In this work, we propose the architecture of a wireless neural-signal-sensing system implemented with a conventional mixed-signal CMOS technology. The proposed circuit performance is evaluated by SPICE simulation and measurement results of a test chip.

## 2 Neural-Sensing LSI Architecture

The block diagram of the proposed wireless neural-signal-sensing system is shown in Fig.1. The system consists of a 10-ch probe, a multiplexer/amplifier (MUX/AMP) block, a 10-bit ADC block and a wireless TX/RX block.

The 10-ch probe has 10-tungsten-needles in a local area of 2-mm- $\phi$ , it enables that the system observes waveforms of various neurons. The MUX/AMP block chooses any 5-channels from the 10-ch probe and signals of selected channels are multiplexed at a pulse width of 19.23- $\mu$ s, therefore the MUX/AMP block achieves an efficient observation of neural signals. The MUX/AMP needs about 80-dB DC-gain and a reduction of a flicker noise and a voltage offset because the neural signals are typically a few ten- $\mu$ V and a few kHz. The ADC block needs 10-bit resolution for 8-bit accuracy achievement and a 10.4-k-sampling-per-second (ksps) operation per channel due to a conversion of the multiplexed signal. The ADC block is discussed in this chapter only. The TX transmits an ADC output data and a system status data and the RX receives an external system control data, such as the probe selection command and DC-gain control command, from the external controller. The voltage-controlled oscillator (LC-VCO), which implemented by an off-chip inductor, supplies a carrier frequency of TX/RX block and system clock at an operation frequency of 100 MHz. Due to the high-carrier frequency, the TX/RX block achieves 520 kbps data transmission rate.

## 3 Design and Test-Chip Implementation

A test-chip of the proposed sensing system was designed and fabricated with a 0.35- $\mu$ m 2-poly 3-metal

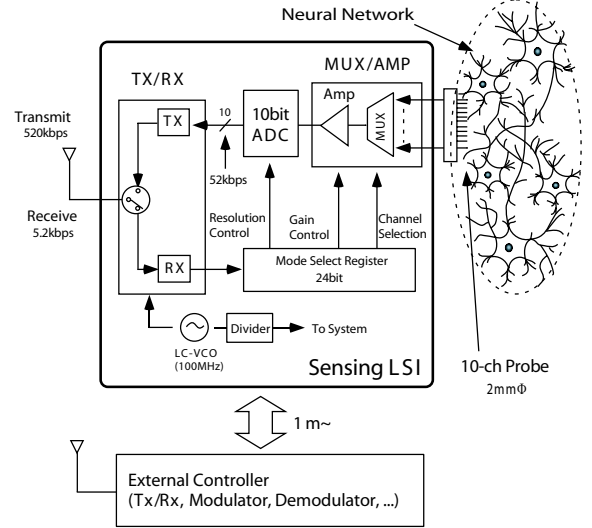


Figure 1: Proposed system architecture.

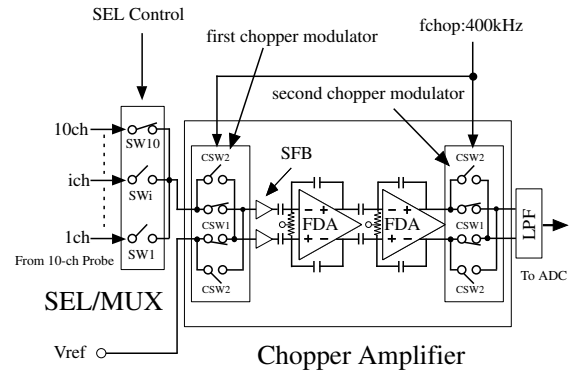


Figure 2: Block diagram of the MUX/AMP block.

CMOS technology. The block diagram of a MUX/AMP block is shown in Fig.2. The MUX/AMP block is implemented using a direct chopper input scheme [3], which enables to detect a signal from a neuron with large-output-resistance. Moreover, the chopper technique reduces a flicker noise of amplifier. The MUX/AMP amplifies a difference between a detected voltage nearby focused neuron and a reference voltage ( $V_{ref}$ ) defines a voltage of cell liquid far from the observation neuron cell. From the SPICE simulation, the chopper amplifier achieved an equivalent input noise of 23 nV/root-Hz at a 400-kHz chopper frequency. A total in-band noise ( $\sim$ 100kHz) was 7.2 $\mu$ V.

The TX/RX block diagram is shown in Fig.3. The TX

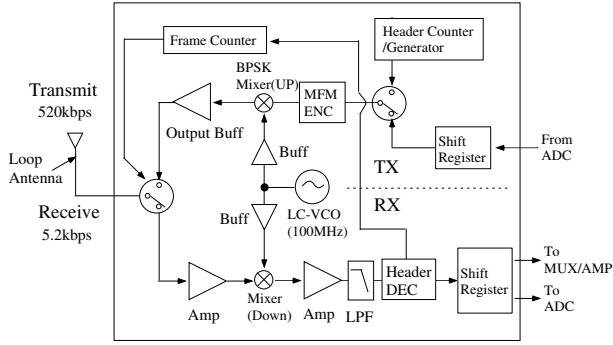


Figure 3: Block diagram of the TX/RX block.

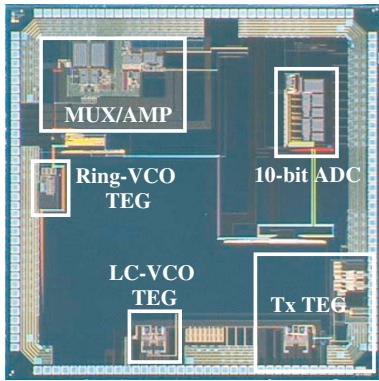


Figure 4: Microphotograph of test chip.

block transmits the ADC data to the external controller using the binary phase-shift-keying (BPSK) modulation. And the modified frequency-modulation (MFM) encoder is implemented in this block, because the MFM achieves about 50-% mark ratio of transmission data. The RX block decodes the BPSK modulated RF data using a direct demodulation method in the case of data receipt. A number of logic gate of the TX/RX block is about 1.2-k, and the power consumption is 0.6-mW at a supply voltage of 3-V, confirmed by SPICE simulation.

Figure 4 shows the microphotograph of the test chip. The test chip includes a MUX/AMP block, an ADC block and a TX block, and the chip area is 25-mm<sup>2</sup>. Measured Output spectra of TX block with BPSK modulation is shown in Fig.5. The LC-VCO has an oscillator frequency of 110.6-MHz, and the BPSK modulation frequency is 500 kHz. The output spectra consist of oscillator frequency and harmonic components of the BPSK modulation frequency. The power dissipation of the LC-VCO is 0.6-mW at a supply voltage of 3 V. We evaluated the proposed MUX/AMP block to measure a nerve fascicle of cricket foot. Figure 6 shows the measured waveforms of (a) a commercially available system and (b) the proposed MUX/AMP. The available system has a 66-dB DC-gain and band-pass-filter with 20-Hz to 5-kHz bandwidth. An envelope curve of pulse signal shows a measured neural signal. The proposed neural-sensing LSI achieved a detection of the neural signal from a large

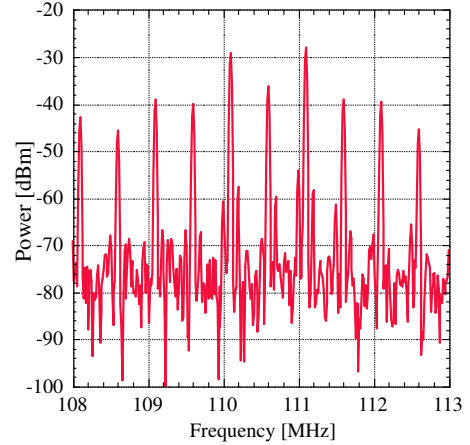


Figure 5: Measured Output spectra of TX block.

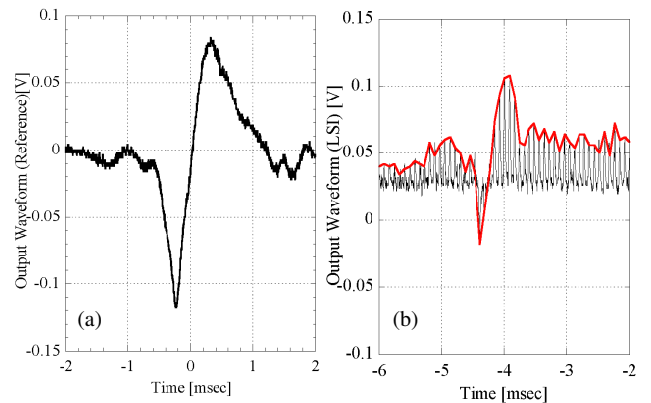


Figure 6: Measured nerve fascicle waveform of (a) the commercially available system and (b) the proposed MUX/AMP.

output-impedance. The chopper amplifier achieved a 66-dB DC-gain, a 3.2- $\mu$ V in-band noise and a 6.0-mW power dissipation at a supply voltage of 3-V.

#### 4 Conclusions

We proposed the architecture of a wireless neural-sensing system with multi-input-channel, which is implemented in a 0.35- $\mu$ m CMOS technology. As measurement results of the test chip, the chopper stabilized amplifier with wireless selectable multiplexer accomplished with a 3.2- $\mu$ V in-band noise and a measurement of nerve fascicle. The TX block achieved 600-kbps wireless data transmission with BPSK modulation at a carrier frequency of 100 MHz.

#### References

- [1] K. D. Wise, Symp. VLSI Circuit, pp.106-109, 2002.
- [2] J. A. V. Arx, et al.,ISSCC, pp.214-215, 1999.
- [3] T. Yoshida, et al.,SASIMI, pp.206-210, 2003.