68.4 μW 400 MHz intrabody communication receiver front-end for biomedical applications

Horng-Yuan Shih and Yu-Chuan Chang

A 400 MHz sub-hundred microwatt intrabody communication receiver front-end suitable for OOK, ASK and FSK modulation schemes and applied to personal health wearable/implantable devices is presented. 68.4 μW of static power, 24.1 dB of gain, at least 18 dB fundamental above distortions and 167 × 118 μm^2 of core size are achieved in 0.18 μm CMOS technology.

Introduction: Personal health wearable, portable and implantable devices that communicate with a health management system through human bodies are battery/body heat/energy harvesting-powered, which imposes a stringent power budget on the integrated circuits, especially on the transmission interface. The receiver of the transmission interface is required to be continuously active for receiving control signals from the health management system. Therefore, power consumption of the receiver should be as low as possible. To address this requirement, in this Letter a 68.4 μW 400 MHz intrabody communication (IBC) receiver front-end suitable for OOK, ASK and FSK modulation schemes is presented, which meets the requirements for the personal health wearable/implantable devices.

In state-of-the-art ultra-low-power (ULP) wireless receiver front-ends, high *Q* BAW resonators and inductors are used as filters, input matching circuits and loads for reducing power consumption to 1.8 mW [1]. Super-regenerative (SR) architecture adopted for OOK demodulation can reduce power consumption to hundreds of microwatts [2, 3] (400 μW in [2], 390 μW in [3]). A low-noise amplifier (LNA) of the receiver front-end combined with operating in the sub-threshold region and current reuse has good gain, noise and linearity performance while consuming 210 μW [4]. Communication through human bodies is referred to as intrabody communication (IBC) and has much less path loss than through air in the range 200–600 MHz [5], which leads to relaxation of performance requirements of the receiver front-end. Thus, power consumption of the receiver front-end can be greatly reduced. In this Letter, we propose a 400 MHz sub-hundred microwatt IBC receiver front-end for personal health wearable/implantable devices.

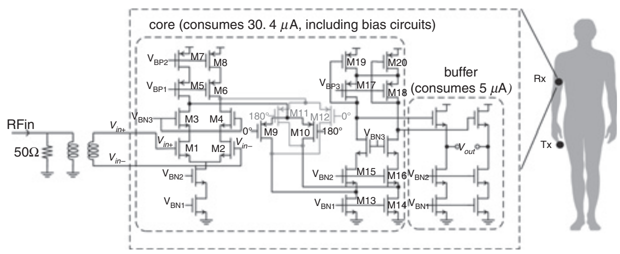

Fig. 1 *Sub-hundred microwatt intrabody communication receiver front-end*

Circuit design: Because it communicates through the human body, the required sensitivity of the receiver front-end is greatly reduced. For example, path losses of 20 and 30 dB in sitting mode and standing mode are measured at 400 MHz. Under a transmitted power of +15 dBm, received signal strengths of −5 and −15 dBm can be obtained, respectively [5]. However, from previous experiments, strong interferers will couple into human bodies, which leads to a high linearity requirement of the receiver front-end. The proposed sub-hundred microwatt high-linearity IBC receiver front-end is shown in Fig. 1. There are no high *Q* devices (including any inductors for loads). All transistors including bias circuits of the receiver front-end are operating in the weak inversion with IC < 0.1 [6]. M1 and M2 biased in the weak inversion region provide transconductance. M3 and M4 are also biased in the weak inversion region as a cascode stage for reducing the Miller effect of the input stage. Moreover, weak inversion operated M5–M8 forms a cascode current source for enlarging the impedance of the current source. M9–M12 are folded to perform the functionality of the mixer. A differential common gate (CG) stage (M15–M16) biased by current source (M13–M14) receives the down-converted baseband current signal. Finally, M17–M20 operate under the weak inversion region to provide a wide-swing load for transforming the down-converted baseband current signal into a voltage signal with a wide dynamic range of voltage.

Experimental results: Without input of the RF signal, the receiver front-end consumes a static current of 35.4 μA under a supply voltage of 1.8 V. 30.4 μA is consumed by the core of the receiver front-end, including bias circuits. An additional 5 μA is consumed by the buffer. The IBC receiver front-end is matched by a 50 Ω shunt resistor for measurement. Thus, there is no voltage gain provided by the input matching network, which meets the application condition of IBC. Moreover, intrinsic performance of devices operated in the weak inversion region can be evaluated in this design. The gain (IF of 100 kHz, RF/LO of 400 MHz/399.9 MHz) and current consumption of the receiver increase with the strength of the input signal before gain saturation. Increasing the strength of the input signal leads the devices to operate from the weak inversion to the moderate inversion because of the raised RMS value of the VGS of M1 and M2. Although all transistors of the receiver front-end are biased under a constant DC current, the output swing raised as the strength of the input signal increase results in the increasing of V_{GS} and V_{DS} of M19 and M20 of the wide-swing load, which adds to the current consumption of the receiver front-end. As shown in Fig. 2, the maximum gain of 24.1 dB is measured under a current consumption of 48 μA at input power of −15 dBm. At input power above −15 dBm, the transconductors (M1 and M2) go to the triode region because V_{GS} is above V_{DS} over a threshold voltage. Owing to operating in the weak inversion region, the measured gain of the receiver front-end reduces to 0 dB at power of the input signal less than −25 dBm. Fig. 2 also shows the two-tone test of the receiver front-end. Because the bias current of the output stage of the receiver front-end increases with the strength of the input signal, the linearity of the receiver front-end also increases with the strength of the input signal. The measured fundamental tone stays at least 18 dB greater than the measured IM3. Therefore, an SNR of at least 18 dB can be sustained by the receiver front-end. According to the measurement results, the sub-hundred microwatt IBC receiver front-end provides enough gain and linearity to be applied to personal health wearable or implantable devices. Fig. 3 shows a die micrograph of the receiver front-end with a core size of 167 × 118 μm^2.

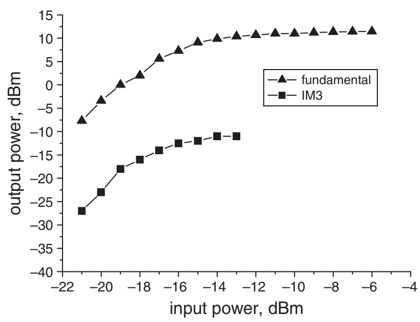

Fig. 2 *Measured gain and linearity performance*

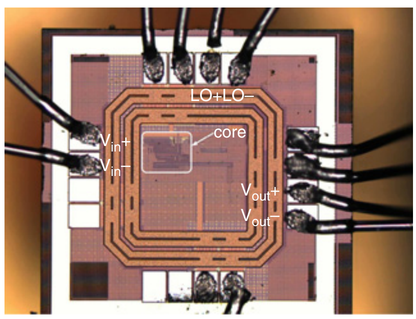

Fig. 3 *Chip micrograph of IBC receiver front-end*

Conclusion: The proposed sub-threshold operated receiver front-end achieves sub-hundred microwatt power consumption, especially operating in the weak inversion region. Measured gains of 24.1 and 18 dB fundamental above distortions make the receiver front-end suitable for intrabody communication applications.

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One or more of the Figures in this Letter are available in colour online.

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