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Low power high data rate wireless endoscopy transceiver

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Abstract

A low power high data rate wireless endoscopy transceiver is presented. Transceiver architecture, circuit topologies and design trade-offs have been considered carefully to satisfy the tight requirements of the medical endoscopy capsule: lower power consumption, high integration degree and high data rate. The prototype, implemented in 0.25 μm CMOS, integrates a super-heterodyne receiver and a super-heterodyne transmitter on a single chip together with an integrated RF local oscillator and LO buffers. The digital modulation and demodulation is also implemented in analog field and no data converters are needed for the whole endoscopy capsule. The measured sensitivity of the receiver is about −70 dBm with a data rate 256 kbps, and the measured output power of the transmitter could achieve −23 dBm with a data rate 1 Mbps. The transceiver operates from a power supply of 2.5 V, while only consuming 15 mW in receiver (RX) mode and 14 mW in transmitter (TX) mode.

Keywords: Wireless transceiver; RF; CMOS; Analog integrated circuit; AGC; ASK; Modulator/demodulator; Endoscopy capsule; Low power

1. Introduction

With the rapid development of microelectronics, wireless electronic devices play an increasingly important role in modern medical applications, such as medical treatments, medical monitoring, medical signal recording, emergency healthcare and so on [1–8]. Significant academic and corporate resources are being directed toward the developments of novel wireless medical applications. Our work is mainly on the development of wireless electronic device for one of such applications: wireless endoscopy capsule.

Medical endoscopy examination methods could be classified into two types: push type and wireless capsule type. The conventional push-type endoscope is mostly commonly used in most hospitals, but it brings great pain and discomfort to the patient. Moreover, it cannot reach the small intestine for diagnosis [9]. On the other hand, the wireless capsule-type endoscope allows the doctors to directly study the entire digestive tract without any anesthesia or insufflation. Capsule-type endoscopes have advantages over noncapsule-type ones in that their small size introduces far less pain to the patients. Due to the noninvasiveness of the procedure, many people start to research the wireless endoscopy capsule and some preliminary developments have been achieved recently [10–14]. Especially, two commercial capsule products have been developed by Given Imaging Inc., Israel [15] and RF System Co., Japan [16], respectively.

A wireless capsule usually includes an image sensor, an IC chip with an off-chip antenna, illuminating LEDs and a battery. The image sensor captures the images of the human digestive tract, then the image information is sent to the IC chip for the digital signal processing (such as image compression, coding, image data storage/reading and so on). A wireless transceiver is also integrated into the same chip to transfer the image information to the transceiver outside the patient's body for diagnosis and receive the control instructions from the outside transceiver.

In the whole wireless endoscopy capsule, the IC chip is the most crucial part. It must be highly integrated since the volume inside the capsule is limited, its power consumption must be low since the small size battery contains limited energy and the capsule should work for at least 8 h, and the

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data rate during the communication should be high to display the images of the digestive tract in real-time mode. The IC chip is usually an analog–digital mixed SOC and consists of a digital controller and a wireless transceiver. The wireless transceiver is our main object and is discussed in details as follows, while the digital controller is presented in other literature [17].

Although there are many novel wireless transceivers in the literatures [18–22], most of them could not be used to develop the medical endoscopy capsule due to the tight requirements on size, power consumption and data rate. So the application-specific wireless transceivers must be developed. There are two techniques which could be used to implement the wireless transceiver in the capsule: passive radio frequency identification technique (RFID) [16,23–25] and active wireless telemetry technique [14,15,26–30]. The RFID-based capsule receives the energy externally through transmitted electromagnetic waves by the transceiver outside the patient's body and does not need the battery module, thus reduce the capsule volume. But it has many disadvantages: harmful high-power RF electromagnetic waves, low data rate and short communication distance. On the other hand, the wireless telemetry-based capsule is powered by the battery and avoids the harmful strong electromagnetic wave radiation toward the patient's body. Most of telemetry-based capsules work in 433/868/915-MHz ISM (industrial, scientific and medical) band to simplify the circuit design [15,26], but the large-size antenna increases the volume of the capsule and makes the swallow procedure discomfortable. Although some literatures present 2.4 GHz circuits for the wireless endoscopy capsules, the circuits are incomplete (only present the RF front-ends or the IF circuits), and the crucial functions are provided off-chip (such as LO signals are provided off-chip) [28–30].

This paper presents the design and implementation of a fully integrated 2.4 GHz low power high data rate wireless endoscopy transceiver. Transceiver architecture, circuit topologies and design trade-offs have been considered carefully to satisfy the tight requirements of the medical endoscopy capsule. The prototype is implemented in 0.25 μm CMOS and the measured results are given out to show the feasibility of achieving the performance required by the wireless endoscopy capsule in 0.25 μm CMOS.

The paper is organized as follows: Section 2 presents the architecture of the wireless transceiver and the detailed circuit description, the measured results are given out in Section 3 and Section 4 draws some conclusions.

2. Transceiver architecture and circuits

Since the analog–digital converter (ADC) or digital–analog converter (DAC) would consume so much power at the present technology [31], our SOC could not contain the ADC or DAC. The receiver in the capsule must directly restore the original digital data, and the transmitter must directly implement the digital modulation, both with the low-power consumption. Also considering the power consumption, RF phase-locked loop (PLL) could not be used since the frequency divider in the RF PLL would consume a lot of power [32–34]. It means RF carrier frequency could not be controlled accurately and ASK becomes the only feasible modulation mode.

There exist various wireless transceiver architectures, such as the super-heterodyne architecture, direct-conversion architecture, low-IF architecture and so on. Each architecture has its own advantages and disadvantages over others. One should select the optimum transceiver architecture based on the application environments. During the design of the transceiver architecture, the following issues help us to make up the decision. (1) Direct-conversion architecture and low-IF architecture need quadrature RF local oscillating (LO) signals. It is very power hungry to generate the quadrature RF LO signals. And two signal paths in these architectures would double the power consumption. (2) Flicker noise in the CMOS circuits will degrade the performance of direct-conversion transceiver. (3) The medical endoscopy examinations are normally done in the hospitals where the interference is not so severe, so the image signal rejection is not a problem for our special application. The super-heterodyne receiver without the image rejection filter could be utilized to develop the wireless capsule. (4) Due to the same reason, the spectral re-growth induced by the transmitter is not a problem for our application. The super-heterodyne transmitter without the image rejection filter could be utilized to develop the wireless capsule. (5) The super-heterodyne receiver/transmitter only has one signal path and the power consumption could be reduced. Based on the above issues, our transceiver (shown in Fig. 1) uses the super-heterodyne architecture both in receiver mode and in transmitter mode. All the blocks within the solid line are integrated into the same chip.

Based on the requirements of the medical endoscopy capsule, the strength of the received signals is designed to be between −80 and −40 dBm, and the RF front-end (LNA and Mixer) provides about +17 dB voltage gain. The voltage level of the signals for '1' sent to the ASK demodulator is about 22 mV so that the demodulator could demodulate the signals correctly, the rest gain is provided by the automatic gain controlled (AGC) loop. The data rate of the receiver is 256 kbps. The transmitter provides 50 Ω output impedance which is matched with the antenna, and −20 dBm output power. The data rate of the transmitter is designed to be higher than 1 Mbps. Both the receiver and the transmitter work in 2.4 GHz ISM band, and the IF frequency is 10 MHz in the receiver and 20 MHz in the transmitter.

2.1. The receiver

The receiver consists of LNA, down-converter and an IF ASK receiver. LNA is a fully integrated LC-tuned cascode amplifier with inductive source degeneration. The source