A Miniature RF Communication System for Micro Gastrointestinal Robots

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This paper reports a miniature, low power, wireless communication system that can be used in our gastrointestinal (GI) robots. The system consists of a miniature RF transmitter embedded in the GI robot and a receiver device embedded in a control station outside the body. ISM band radio frequency (433.92MHz) is applied to simplex communication between the GI robot and the control station. Amplitude Shift Keying (ASK) modulation scheme is adopted to ensure reliable and high-speed digital RF link. Clinical tests have been carried out to validate the sound performance of the communication system.

I. Introduction

For over forty years, implantable telemetry systems have been used for animal experiments and human applications, including measurements of heart rate, ECG, EEG, temperature, pH, and pressure and prosthesis purposes [1-5]. Most implantable telemeters use frequency modulation (FM) for analog signal transmission [2-4]. Recent years, digital RF communication systems have been developed for in vivo pressure acquisition [6,7], implantable neural recording [8], functional neurostimulation [9-13], and intraocular visual prostheses [14,15]. The newly developed “M2A” capsule endoscopes also use radio frequency to transmit video frames from the gastrointestinal tract [16]. These RF communication systems were designed for implantable applications.

The development of VLSI and silicon technology recent years makes it possible to produce ultra miniature highly-integrated circuits with powerful functions. Also available are the Chip-on-Board (COB) techniques, which use bare chip dies bounded directly on the PCB substrate to decrease the overall dimension of the circuit board. All these technologies permit us to develop this miniature RF communication system that can meet our extremely strict space restriction demands. The dimension of the RF system developed by the authors is only $12 \times 7 \times 3.5 \text{mm}^3$, which can be easily fit into our GI robots.

II. System Description

The communication system consists of two main parts: the miniature RF transmitter embedded in GI robots, and a RF receiver embedded in a portable data station. The system is showed in Figure 1. With data obtained by sensors integrated in a GI robot, which works in the gastrointestinal tract of human body, the robot transmits coded data to a receiver outside body steadily through this wireless simplex communication system.

![Figure 1 System overview](image)

III. Communication System Design

The communication system design contains three main tasks: system circuit design, determination of optimized transmitting frequency and modulation mode. Firstly, selecting an optical transmitting frequency is crucial for the sound performance of the system. The frequency should enable the communication module to work effectively and reduce radiation power and current consumption. Given the usage permission concerning wireless communication band and requirements of application, 433.92MHz, included in ISM (Industrial Scientific Medical) band, is adapted to work as the carrier frequency. As for modulation mode, it consists of three modes, named amplitude-shift keying (ASK), frequency-shift keying (FSK), and frequency-shift keying (PSK). Because the power consumption of ASK is relatively low, it is applied to our design. The circuit of communication system consists of two blocks, fulfilling function of transmitting and receiving.
The schematic diagram of RF transmitter module is showed in figure 2, followed by schematic diagram of RF receiver module showed in figure 3.

![Diagram of RF transmitter module](image)

**Figure.2 Schematic diagram of RF transmitter module**

![Diagram of receiver module](image)

**Figure.3 Schematic of receiver module**

The fully integrated PLL transmitter chip adopted in transmitting module allows particularly simple, low-cost miniature transmitters to be assembled. If ENABLE=L and the PA_ENABLE=L, the circuit is in standby mode consuming only a small amount of current so that a lithium cell used as power supply can work for a long period of time. With ENABLE=H, the output power of the circuit modulated by means of Pin PA_ENABLE, and the system works under the RF transmission mode. After transmission the circuit is switched back to standby mode with ENABLE=L. With the fully integrated transmitter chip, the external circuit can be minimized. A capacitor is used to block the supply voltage. With two capacitors, the loop antenna is matched to the power amplifier integrated in transmitter chip. Meanwhile, a capacitor is used to ensure that integrated XTO runs on the load resonance frequency of the crystal. At 3V supply voltage, the optimized load impedance is $Z_{load} = (166+j223) \Omega$. Due to cramped space in GI robot, the size of antenna is very small. Small loop antenna is used for it is a kind of magnetic antenna whose energy declines less than electric antenna when passing through tissues of human body. The designed transmitter works at the supply voltage of 2.0V to 4.0V, and the current consumption is 6mA at the maximum data rate of 10kbit/s. Without difficult caused by cramped space in GI robot, the receiver module has adopted a universal design which has become a mature technology and widely used in all kinds of application. So, it is not illustrated in detail here.

**IV. Communication Protocol**

A simple communication protocol was designed to minimize disturbance during communication, since the carrier frequency adopted in this design is a universal one in ISM band. The data are transmitted in the unit of frame. A frame consists of a starting byte, two bits of synchronous symbol, and three bytes of data with check bit. A frame of data is illustrated in figure 4. The receiver receives and checks datum continuously until a datum identical to the starting byte (SB) is received. Then the datum is synchronized through synchronous bits (SYN). Following these operations, the routine of receiving a datum (Data n) and a corresponding check bit (Cb) begins. The check method is parity check.

![Diagram of data frame](image)

**Figure.4 A frame of data**

**V. Test and Result**

A clinical experiment has been performed after the biotelemetry capsule passed a test conducted by Medical Device Monitor and Test Center of Shanghai under State Food and Drug Administration, National Center of Measurement and Test for East China.

To start the clinical experiment, a healthy volunteer swallows the capsule with a glass of water without gastrointestinal preparation, such as cleaning of all fecal material in the intestine and fasting before the examination\[^{[17]}\], which was required by the traditional methods. Then, the capsule passes through the whole gastrointestinal tract, continuously monitoring the digest system and transmitting parameters which are received by a data recorder attached to the volunteer’s belt. After the experiment, the capsule is recovered in the stools at least 24 hours after having been swallowed.

8 volunteers, 6 male and 2 female, with an age range from 34 to 55 have undergone the experiment. Data recorder can receive data transmitted by capsule passing through the whole...
gastrointestinal tract steadily. Data picked up by the data recorder are calibrated according to a calibration table that is validated by Shanghai Medical Instrument Association. A sample of pressure and temperature plot is shown in figure 5.

![Pressure plot](image)

![Temperature plot](image)

Figure 5 A sample of pressure and temperature plot

VI. Conclusion

This paper reported the design and development of a miniature communication system used in our first generation of micro GI robots. Clinical experiment has been performed to validate the function of the communication system. There are great potentials to marry this device with other implantable instruments.

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Reference


