RF Module Considerations for Low-Power and High-Speed Wireless Capsule Endoscope

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Abstract – For a wireless capsule endoscope with high data rate of 40 Mbps, a new frequency band is proposed to meet worldwide regulations on radiated emission and various RF modulation techniques are considered and compared in terms of ultra low-power consumption and spectral efficiency. The co-simulation technique of RF signals and digital signals is introduced and provided for an OOK system which is a best fit for low-power operation.

Keywords: Wireless capsule endoscope, High data rate, Low power, OOK system.

1 Introduction

In order to diagnose internal organs of a human body, an endoscope that is directly connected with the internal organs is widely used. This method gives very big pain to patients because of pressure and friction of connected area in the internal organs, and it is difficult to insert a long and slender hose in the small intestine or large intestine. Also it is difficult to see images of organs condition surely we want to see, and to diagnose exactly illness because it is not easy to control the endoscope from out-body systems.

Recently the wireless capsule endoscope has been introduced and extensively studied as an alternative. The capsule endoscope products have already been released and utilized even though they are not yet widespread; PillCam [1], NORIKA [2], Endo capsule [3] and so on. These products work for about 8 hours, and have a slow data rate. To see real-time images in the body [4] and to administer a medicine to a right place, a high data rate of 40 Mbps and low-power operation are required.

In this paper, we propose a new frequency band to support the high-speed data rate instead of MICS (Medical Implant Communication Service) band. And we compare various RF modulation techniques for ultra low-power operation. Also we show that RF signals and digital signals of an RF frontend module can be co-simulated in Agilent Ptolemy environment.

2 Wireless Capsule Endoscope

Among various capsule endoscope products, we briefly look into PillCam of GivenImaging Ltd., which came out firstly. There are two types of the capsule endoscopes, one for the small intestine (Φ 11.41 × L 30.85 (mm)) and the other for the large intestine (Φ 11.50 × L 30.85 (mm)) [4-5]. The capsule endoscope consists of eight parts as shown in Fig. 1 [1]. The eight parts are an optical dome, a lens holder, a lens, LEDs, a CMOS image sensor, batteries, a transmitter and an antenna. They are hermetically packaged in a capsule form. The optical dome is used for securing a place for taking images in the front. The lens holder is used to fix the lens. The LEDs illuminate the dark intestine to help the CMOS image sensor to take the images. The batteries occupy the biggest part of the capsule and supply the power to each component. The transmitter and antenna send image data to the out-body systems through a lossy human body. In this paper, we address this capsule endoscope in an RF point of view.

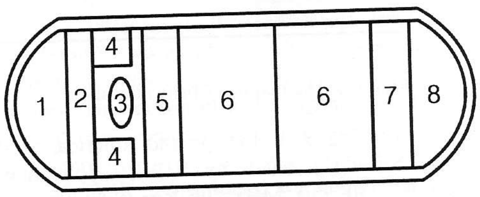

Figure 1. The PillCam structure example.
1-Optical dome, 2-Lens holder, 3-Lens, 4-Illuminatary LEDs, 5-CMOS image sensor, 6-Batteries, 7-Transmitter, 8-Antenna

2.1 Wireless Capsule Endoscope Issues

In the wireless capsule endoscope, we should take following issues into consideration. The first issue is low power consumption [6]. The capsule endoscope for going to inner human body uses small-sized batteries and operates for a long time inside the body, so a low-power operation is a prerequisite. The second issue is a high-speed data rate. Currently the capsule endoscope products have the data rates of 1~2 Mbps, but the data rate more than 20 Mbps is required to send in-body images to an out-body receiver for a future capsule endoscope. Considering overload from the data coding, the data rate should be increased up to 40 Mbps. The third issue is that the capsule endoscope should support bidirectional communications. To move the capsule to the area where much more monitoring is needed and to administer a medicine there, we should control the capsule endoscope. The last issue is a small size. The capsule endoscope should be as small as possible, not to provide inconvenience to the patients, because it is swallowed into the mouth and gets out through the internal organs. All these are very important issues which should be carefully considered in designing the capsule endoscope.

2.2 Frequency Band

Conventional capsule endoscope products use the MICS frequency band of 402~405 MHz. The MICS band is allocated by FCC (Federal Communications Commission) in 1999 for implantable medical device use [7]. In the MICS band, the implantable devices can communicate at a low data rate due to narrow bandwidth, and so cannot support real-time image communications. For the capsule endoscope supporting the data rate of 40 Mbps, a new and wide frequency band needs to be allocated instead of the MICS band.

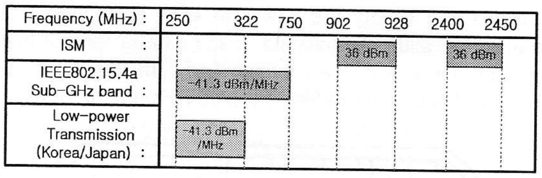

Figure 2. The frequency band allocation.

As shown in Fig. 2, in Europe and America, an IEEE 802.15.4a Sub-GHz band for UWB applications is allocated to 250~750 MHz. In Korea and Japan, an unlicensed low-power transmission band is up to 322 MHz. These two bands have the same regulations on the EIRP (Effective Isotropically Radiated Power). Therefore, the common frequency band of 250~322 MHz can be used for the wireless capsule endoscope. In Korea, 317~328 MHz has been used by a beeper signal band, so the frequency band of 250~310 MHz can be proposed for 40 Mbps in-body communications.

2.3 Modulation

In the capsule endoscopes, low-power consumption is extremely important since they operate at least for several hours with small-sized batteries. Therefore, in selec modulation techniques, lower power consumption h higher priority. When the modulation techniques compared, many tradeoffs should be considered. instance, an increase of transmitted power lead substantial DC power consumption. Coherent modul requires additional 1~2 dB SNR (Signal-to-Noise R compared to non-coherent modulation.

2.3.1 MSK, PSK

MSK (Minimum Shift Keying) modulation is a kin coherent FSK modulation which reduces high-o harmonics by removing phase discontinuity in OQ (Offset Quadrature Phase Shift Keying) modulation.

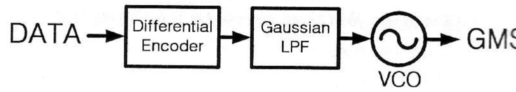

Figure 3. A block diagram of the GMSK transmitter.

Figure 3 shows a simplified block diagram of GMSK (Gaussian MSK) transmitter. A GMSK signa obtained through a VCO (Voltage Controlled Oscilla with a Gaussian-filtered control signal. To obtain linea a PLL (Phased Locked Loop) module is required, bu results in a complex system and slow start-up. The GM modulation is bandwidth-efficient but energy-inefficien

PSK (Phase Shift Keying) modulation is one of linear modulation techniques. The phase of the carrie the QPSK takes one of equally spaced four shifts, such 0, π/2, π, 3π/2 where each phase value corresponds t unique pair of message bits. Figure 4 shows an exampl the QPSK transmitter block diagram. As shown in the F 4, two up-converters are used for I and Q channels of QPSK transmitter, which will increase power consumpt The QPSK modulation technique is spectrally efficient used in CDMA handset applications, but it is not effec in the power consumption.

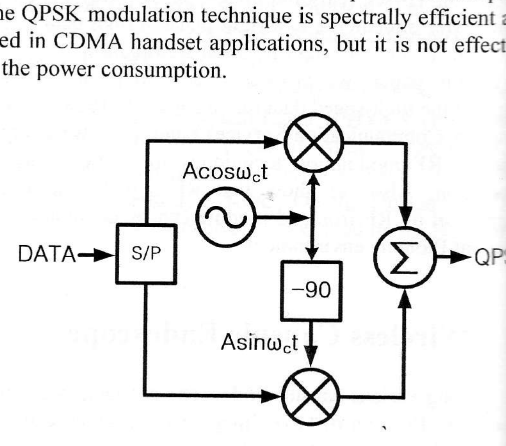

Figure 4. A block diagram of the QPSK transmitter.

Figure 5 shows a block diagram of π/4–DQPSK (Differential QPSK) transmitter. Though it has an advantage of not making a sudden phase change of 180°, the π/4-DQPSK transmitter consists of two QPSK transmitters, and consumes much power.

The BPSK and OQPSK are basically low-power modulation techniques but their applications are limited to low data rate communications. Conventionally they are used in the applications with just a maximum 250 Kbps. Regarding the power consumption and spectral efficiency, the GMSK has better performance than the OQPSK or π/4-DQPSK.

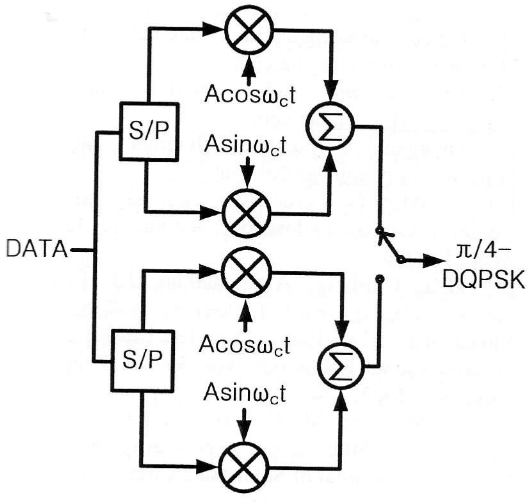

Figure 5. A block diagram of the π/4-DQPSK transmitter.

2.3.2 FSK, OOK, PSK

BFSK (Binary Frequency Shift Keying) is better than the GMSK in terms of power consumption and spectral efficiency. In a coherent system the SNRs of FSK and OOK have 3 dB lower than BPSK (Binary PSK), so FSK and OOK systems should transmit 3 dB more power. The BPSK transmitter requires 6 dB backoff for linearity specification. Eventually we should use FSK or OOK if we consider power consumption in the transmitter.

The FSK and OOK systems can support high-speed data communications. The FSK system requires 1.5 times bandwidth than the OOK system [8], and is more complex. Also the OOK transmitter can reduce battery consumption by a half, comparing with the FSK transmitter, because it operates alternately between on and off modes. The FSK transmitter requires an accurate control on carrier signal frequency and frequency deviation, so a frequency synthesizer should be used for frequency stability. The frequency synthesizer causes the transmitter structure to be more complex and more power-consumed. The OOK transmitter can be made using a SAW (Surface Acoustic Wave) resonator and simple oscillator circuit. Because the SAW resonator has more stable temperature characteristic than an LC resonator, the frequency instability problem can be obviated in the OOK transmitter [9].

The OOK system has a weak point in terms of interference, and the FSK has low spectral efficiency. In the FSK system, switching a wideband signal is ineffective and difficult to implement. A non-coherent OOK receiver has very fast turn-on time and shows improved energy-per-bit performance.

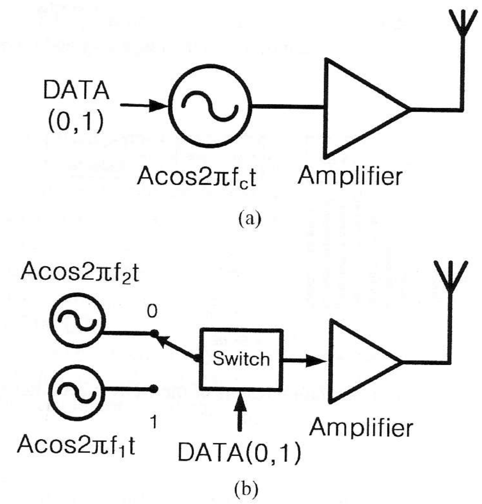

Figure 6. Block diagrams of the OOK and BFSK transmitters.
(a) the OOK transmitter (b) the BFSK transmitter

Figure 6 shows block diagrams of the OOK and BFSK transmitters. In terms of a transmitter structure, the BFSK transmitter uses two oscillators which always turn on, but the OOK transmitter uses an oscillator with alternating on-off modes. This power-efficient signal generation block can also be implemented with an oscillator and high-speed switch, where the oscillator is always on. Comparing the BFSK and OOK transmitters, we know that the OOK transmitter is more power-efficient than the BFSK.

3 Co-simulation

To design modern communication products we need a co-simulation technique which can analyze both RF and digital signals simultaneously. In the low complexity design, it is possible to sum the results which are simulated by each signal processing and analog/RF part simulator. However, today state-of-the-art designs with analog/RF and dedicated on-chip DSP (Digital Signal

Processor) blocks require high level combination at the two-environment boundary. The ADS (Advanced Design System) Ptolomy offers signal processing simulation, while analog/RF simulation is offered by either a circuit envelope or high-frequency SPICE (transient) simulator. In the ADS software, we may utilize Ptolemy co-simulation to find the best design topology.

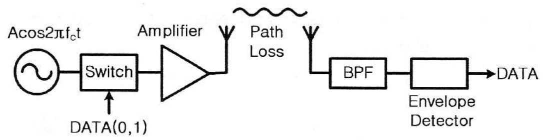

Figure 7. A block diagram of the OOK transmitter and receiver.

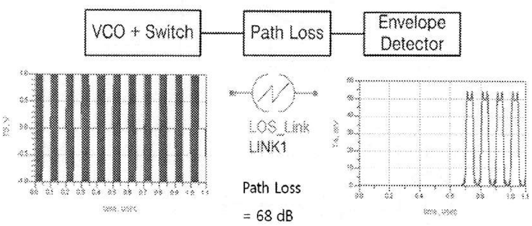

Figure 8. The simulation results of the OOK transmitter and receiver.

Figure 7 shows a block diagram of the OOK transmitter and receiver. The carrier signal is generated from a VCO, and then a high-speed switch, which is controlled by input data, modulates the carrier signal. While propagating through the human body, the transmitted signal from an antenna attenuates due to in-body loss mechanism. In our simulation, the path loss which includes radiation loss, body loss and antenna gain is set to 68 dB [10]. The received signal at an out-body receiver is restored by an envelope detector. Figure 8 shows the simulation results of the OOK transmitter and receiver. From the simulation results, it is known that the OOK system is very suitable for the high-data-rate in-body communication.

4 Conclusions

We propose the new frequency band of 250~310 MHz for the wireless capsule endoscope with high data rate of 40 Mbps, which can meet the worldwide EIRP regulations. And we compare various modulation techniques, and suggest that the OOK is the best modulation for a low-power and high-speed capsule endoscope. Also we introduce the co-simulation technique and verify that the OOK system can be effectively used for 40 Mbps wireless capsule endoscope with the center frequency of 280 MHz.

Acknowledgements

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