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A low-power 2.45 GHz WPAN modulator/demodulator

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A B S T R A C T

This paper presents the architecture as well as the circuit implementation of a wireless personal area networks (WPAN) modulator/demodulator using 2.45 GHz band compliant with the physical layer standard of IEEE 802.15.4. A noncoherent demodulation scheme is employed to resolve the complexity and power dissipation problem, where a phase-shift down sampling method is adopted to detect the maximum phase accumulation which is the location of the correct data. A prototypical system on silicon with core area of 0.39 mm^2 has been realized by using 0.18 μm CMOS process. The packet error rate (PER) is measured to be $<1\%$ given the SNR of 9 dB. The total power consumption is merely 1.37 mW (included Tx and Rx) given a 8.0 MHz system clock.

1. Introduction

Wireless personal area network (WPAN) standard [1] is a wireless standard aiming at a low data rate, low cost, and low power wireless data transmission. The major applications of WPAN are focused on short-range wireless sensor networks, such as industry control, building automation, [2–5], ecology monitoring, and personal healthcare. Particularly, WPAN is an excellent solution for biotelemetry technique [6–9]. Regarding the biotelemetry applications, several important issues should be addressed, including the modulation scheme of the wireless link and the power consumption of the device. WPAN possesses edge of the low cost and low power consumption in addition to a better signal quality due to the adopted modulation scheme compared with the conventional AM (amplitude modulation) based biotelemetry. The WPAN can also be integrated with the existing network infrastructures, such as wireless local area network (WLAN) and general packet radio service (GPRS), to construct a comprehensive network for medical assistance as shown in the scenario in Fig. 1.

The WPAN uses the ISM bands at 868 MHz (European), 915 MHz (USA), or 2.45 GHz (International). It adopts the PSK (phase shift keying)-based modulation scheme. The WPAN standard specifies that 868/915 MHz band employs the BPSK (binary phase shift keying) modulation, while the O-QPSK (offset-quadrature phase shift keying) modulation is used in the 2.45 GHz band. Although the bandwidth efficiency of the QPSK is better than that of O-QPSK, the large phase changes ($\pm 180^\circ$) makes QPSK requires a linear power amplifier (PA) to maintain the signal spectrum within the desired band. Hence, the O-QPSK, which requires a less phase step ($\pm 90^\circ$), is preferable in physical implementations. Besides, the WPAN adopts the direct sequence spread spectrum (DSSS) technique to improve performance and the capability to cope with the multipath problem. At the transmitter end, four bits are packed into one symbol, which is further spread as a 16-chip sequence in the 868/915 MHz band or a 32-chip sequence in the 2.45 GHz band, respectively. Prior modulator/demodulator designs for 868/915 MHz, e.g., [10], obviously cannot be applied to 2.45 GHz WPAN Tx/Rx due to different modulation schemes. Besides, since O-QPSK is a more complicated modulation scheme, low power design consideration is particularly needed to meet the low power dissipation requirement. The detailed specifications of the data rate and the corresponding frequency band are summarized in Table 1.

This paper presents the architecture as well as the hardware implementation of modulator/demodulator for a WPAN using the 2.45 GHz band as an efficient solution of personal medical assistance [11]. Particularly, a phase-shift downsampling method is used for the noncoherent scheme in the demodulator to find the maximum phase accumulation, to detect the location of the correct data [12].

2. WPAN transceiver for 2.45 GHz band

Fig. 2 depicts the structure of the WPAN physical layer protocol data unit (PPDU) packet compliant with IEEE 802.15.4.

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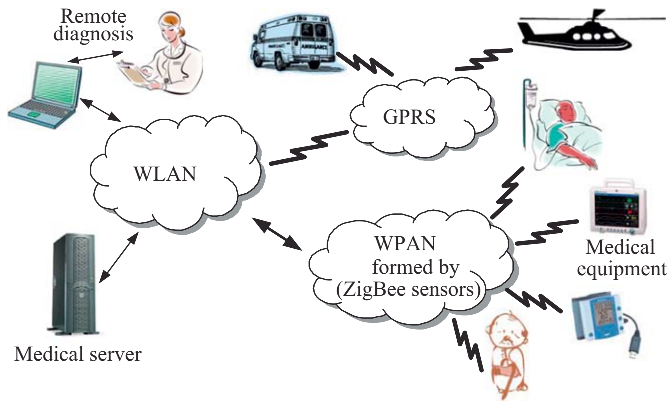

Fig. 1. Applications of WPAN in personal medical assistance.

Table 1
Specifications of data rate and frequency band.

Freq. band	868/915 MHz	2.4 GHz
Bit rate (Kb/s)	20/40	250
Symbol rate (Kchip/s)	20/40	62.5
Chip rate	300/600	2000
Modulation	BPSK	O-QPSK

Octets : 4	1	1		variable
Preamble	Start of frame delimiter	Frame length (7 bits)	Reserved (1 bit)	PSDU
Synchronization header		PHY header		PHY payload

Fig. 2. PPDU packet format.

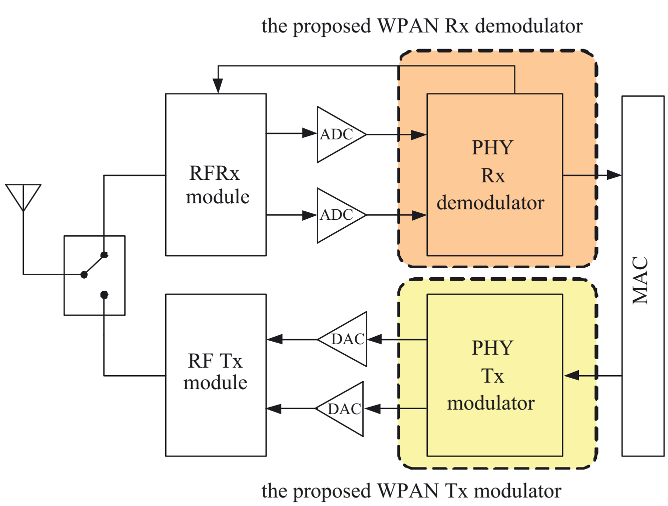

Fig. 3. Block diagram of a WPAN transceiver for 2.45 GHz band.

The preamble field containing 32 bits "0" is for the packet detection and the synchronization in the receiver. The start of frame delimiter (SFD) field denotes the start of the packet data, which is "11100101". The frame length field indicates the number of octets of the physical layer service data unit (PSDU). The PSDU conveys the payload of the packet.

Fig. 3 shows the block diagram of a WPAN transceiver. The RF signal is down-converted to a baseband signal by the RF receiver (Rx) and quantized by the analog-to-digital converters (ADC). These digital signals are sent to the MAC after the digital demodulation performed by the proposed Rx. The PSDU from MAC is modulated by the proposed transmitter (Tx), and the resultant PPDU packet is transmitted by the RF Tx. The details of Rx's demodulator and Tx's modulator are described in the following text.

2.1. Modulator of WPAN Tx

The modulation scheme specified in [1] is shown as in Fig. 4. The binary information from PPDU is mapped into data symbols by the bit-to-symbol block, where the four least significant bits of each octet are packed into one symbol, and the four most significant bits are packed into the next symbol. Then, the spreading function is performed by the symbol-to-chip block. Each symbol is spread as a 32-chip PN (pseudo-random noise) sequence. The chip sequences representing each symbol are modulated by the O-QPSK modulation block with the half-sine pulse shaping. The fundamental O-QPSK method is to sum the in-phase signal with quadrature phase signal delayed by half a cycle in order to avoid the sudden phase shift change that occurs in QPSK. The complex envelope of O-QPSK can be expressed as follows:

$$\tilde{s}(t)=\sum_i(-1)^i\cdot a_{2i-1}\cdot g(t-2iT_c+T_c)+j(-1)^i\cdot a_{2i}\cdot g(t-2iT_c), \quad (1)$$

where a_i is the binary data symbol, $a_i=\pm 1$, T_c is the inverse of the chip rate, and $g(t)$ is the half-sine pulse shape function:

$$g(t)=\begin{cases}\sin\left(\pi\cdot\dfrac{t}{2T_c}\right), & 0\le t\le 2T_c\\ 0 & \text{otherwise}\end{cases} \quad (2)$$

The O-QPSK with half-sine pulse shaping can be interpreted as the minimum shift keying (MSK). Since the MSK is the continuous phase frequency shift keying (CPFSK) with modulation index h=0.5, the complex envelope of the MSK can be expressed as

$$\tilde{s}_MSK(t)=\sum_i\exp\left(2\pi\cdot h\cdot d_i\cdot\int g_r(t)\cdot dt\right) \quad (3)$$

where the d_i is binary symbol, $d_i=\pm 1$, $g_r(t)$ is the rectangular pulse shape function with a amplitude of $1/2T_c$, and a period of T_c.

Notably, when the data symbol of O-QPSK is coded as $d_i=a_i\cdot a_{i-1}$, then MSK and the O-QPSK are identical. The MSK has the constant envelope feature, which allows the use of low-cost, nonlinear PAs in the transmitter design. Moreover, the MSK can be noncoherently demodulated. The noncoherent demodulation is preferred in cost-sensitive low-power applications, since it needs no complicated carrier recovery circuitry in the receiver design. Hence, we employ the MSK with the coding procedure, $d_i=a_i\cdot a_{i-1}$, to carry out the O-QPSK modulation.

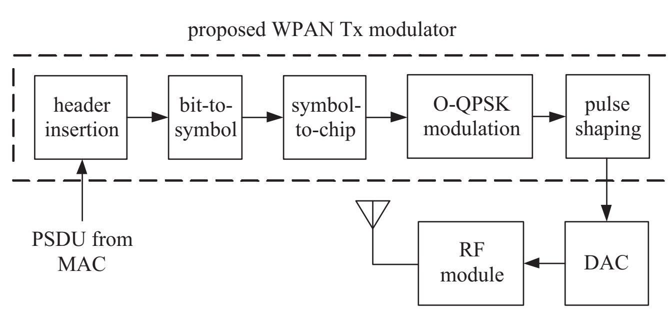

Fig. 4. Detailed block diagram of the proposed WPAN Tx modulator.